A SMARTPHONE-BASED CARDIAC MONITORING APP USING COMPUTER VISION FOR HYPERTENSION MANAGEMENT

BY

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A REPORT

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ABSTRACT

Hypertension is a major risk factor for cardiovascular disease and it is often unaware due to it shows no symptoms. This project proposes a smartphone-based cardiac monitoring application to support hypertension self-management and awareness. The application uses smartphone camera-based finger photoplethysmography (PPG) to estimate heart rate (HR), heart rate variability (HRV), and blood pressure (BP). A real-time computer vision technique, the red, green and blue (RGB) light signal extraction method is combined with a robust PPG signal quality assessment module to ensure only reliable signals are processed. The application supports manual BP entry, automatic health classification such as low, normal, elevated or high, trend analysis and personalized recommendations. Other features such as the chatbot-based AI Cardio Assistant, reminders and health record management are also provided. This project shows that the signal quality model using Logistic Regression with physiological check achieved 81% accuracy and 92% precision. The BP estimation model using XGBoost with Ridge Regression calibration meets the ISO, AAMI, and BHS standards, indicating strong potential for cuff-less BP monitoring. Explainable Artificial Intelligence (XAI), including Permutation Importance and Tree SHapley Additive exPlanations (TreeSHAP) further confirms that the BP predictions are driven by meaningful physiological features rather than irrelevant factors. HR estimation using the HeartPy algorithm shows good agreement with the reference measurements, while HRV shows low correlation with ECG and is therefore used only for trend indication. The models are fully integrated into a mobile application developed using Flutter. Firebase is used for authentication and data storage, while Render with FastAPI is used for hosting the machine learning models. In conclusion, the proposed application demonstrates a functional smartphone-based cardiac monitoring application for preventive hypertension management. Future work will focus on improving the BP estimation using a more diverse dataset, enhancing the real-time performance and integrating location-based navigation features in the application.

Area of Study (Minimum 1 and Maximum 2): Mobile Application, Computer Vision

Keywords (Minimum 5 and Maximum 10): Photoplethysmography (PPG), Heart Rate (HR), Heart Rate Variability (HRV), Blood Pressure (BP), Hypertension Management, Explainable Artificial Intelligence (XAI)

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LIST OF SYMBOLS

ms	Milliseconds
mmHg	Millimetre of Mercury
bpm	Beat Per Minutes

LIST OF ABBREVIATIONS

HRV	Heart Rate Variability
CVD	Cardiovascular Disease
WHO	World Health Organization
HR	Heart Rate
BP	Blood Pressure
PPG	Photoplethysmography
PR	Pulse Rate
PRV	Pulse Rate Variability
AI	Artificial Intelligence
XAI	Explainable Artificial Intelligence
ECG	Electrocardiography
API	Application Programming Interface
AUC	Area Under the Curve
MAE	Mean Absolute Error
bpm	Beats Per Minute
ms	Milliseconds
SQI	Signal-Quality Index
RR interval	Pulse Peak(R) to Peak (R)
CNN	Convolutional Neural Network
2D	Two Dimensional
RT	Regression Tree
MLR	Multiple Linear Regression
SVM	Support Vector Machine
ISO	International Organization for Standardization
SD	Standard Deviation
AAMI	Advancement of Medical Instrumentation
BHS	British Hypertension Society
mmHg	Millimetre of Mercury
MAD	Mean Absolute Deviation
XGBoost	Extreme Gradient Boosting
MIMIC	Medical Information Mart for Intensive Care

MAE	Mean Absolute Error
SBP	Systolic Blood Pressure
DBP	Diastolic Blood Pressure
ML	Machine Learning
NLG	Natural Language Generation
SHAP	SHapley Additive exPlanations
LIME	Local Interpretable Model-agnostic Explanations
PI	Permutation Importance
SDNN	Standard Deviation of NN Intervals
RMSSD	Root Mean Square of Successive Differences
UCSF	University of California, San Francisco
PDF	Portable Document Format
BUT	Brno University of Technology
TreeSHAP	Tree SHapley Additive exPlanations
STT	Systolic Upstroke Time
RGB	Red, Green, Blue
JSON	JavaScript Object Notation
HTTPS	HyperText Transfer Protocol Secure
RAM	Random-Access Memory
GB	Gigabyte
SSD	Solid-State Drive
fps	Frames Per Second
NumPy	Numerical Python
SHA-1	Secure Hash Algorithm 1
SHA-256	Secure Hash Algorithm 256-bit
MIT	Massachusetts Institute of Technology
SDK	Software Development Kit
RMSE	Root Mean Square Error
r	Pearson correlation
ME	Mean Error
RMSSD	Root Mean Square of Successive Difference

Chapter 1

Introduction

Hypertension is a critical global health concern. Many existing hypertension monitoring applications remain unreliable, as they often rely on paid subscription, lack heart rate variability (HRV) insights and incorporate weak photoplethysmography (PPG) signal quality control. To address these limitations, this chapter presents the problem statement, motivation and key contributions that drive the development of a smartphone-based cardiac health monitoring application.

1.1 Project Background

Cardiovascular disease (CVD) remains the primary cause of mortality worldwide, with hypertension recognized as one of its major contributing risk factors [1]. According to the World Health Organization (WHO), more than 1.28 billion adults between the ages of 30 and 79 have hypertension and nearly half of them are unaware that they have the condition [2]. Hypertension which is also often called as the “silent killer” usually shows no early symptoms [3]. Therefore, early detection and lifestyle adjustments are important in reducing the risk of developing hypertension.

Studies [4] and [5] indicate that heart rate (HR) and heart rate variability (HRV) have strong links to hypertension. According to [6], HR is how many times the heart beats per minute, whereas HRV is the fluctuations in the time gap between each heartbeat. A higher HR and lower HRV suggest the body is more ‘on alert’ and less balanced and this is linked to the development of hypertension. Additionally, blood pressure (BP), which measures the force exerted by circulating blood against the walls of the arteries during heart pumping, serves as a key physiological parameter and a direct indicator of hypertension. By tracking these markers allows an early detection of potential risks and supports timely intervention.

Nowadays, there are various ways to monitor hypertension but photoplethysmography (PPG) has become one of the most common techniques. PPG detects changes in blood flow at the fingertip using a camera or a smartwatch equipped with a light source. It measures pulse rate (PR), defined as the number of arterial pulse waves per minute, as well as pulse rate variability (PRV), which reflects variations in the time intervals between successive pulse waves [7]. Studies [8] have shown that PRV can serve as a reliable substitute for HRV with reasonable accuracy. Meanwhile, the traditional cuff-based sphygmomanometer remains the most reliable way to measure BP [9].

1.2 Problem Statement

Although hypertension management is becoming more important, many people still lacking affordable and user-friendly tools for monitoring their cardiovascular health outside the clinics. Meanwhile smartwatches can offer continuous health tracking, but most people do not own them due to their high cost and frequent charging requirements. As mentioned in [10], smartphones are widely available, affordable and more suitable for supporting patient engagement beyond clinical environments.

Moreover, [11] reports that many smartphone-based applications primarily focus on heart rate (HR) monitoring but often omit heart rate variability (HRV). This limits the use of valuable indicators like HRV which is a non-invasive and meaningful marker of hypertension risk. On top of that, advanced features such as long-term trend analysis and personalized insights are often locked behind paid subscriptions and making them less accessible to the public.

According to [12], emerging blood pressure (BP) measurement technologies are advancing, but most BP monitoring applications still offer only simple BP logging. This restricts users who do not own cuff-based BP measuring devices and reduces the effectiveness of digital tools for supporting proactive hypertension management. Therefore, there is a need to develop a more advanced and affordable smartphone application that integrates HR, HRV and artificial intelligence (AI) driven BP estimation to assist users in preventive hypertension management.

1.3 Motivation

The motivation of this project is to develop an accessible and affordable smartphone-based application that supports preventive hypertension management. By leveraging computer vision techniques and the smartphone camera with flash, the application monitors users' cardiac health through photoplethysmography (PPG) signals to measure heart rate (HR) and heart rate variability (HRV). The application also incorporates a robust PPG signal quality assessment mechanism that ensures a trustworthy cardiac data acquisition.

Blood pressure (BP) monitoring is equally crucial for early hypertension prevention. To address this, the application integrates with an artificial intelligence (AI) driven BP estimation model that uses PPG-derived features and the user's health data to predict BP values. For users who prefer using a traditional cuff-based BP monitor, the application also supports manual BP logging for continuous tracking of users' health records. Additionally, personalized trend analysis and lifestyle recommendations are provided based on each user's health patterns.

Since this project focuses on hypertension management, the BP estimation model must be reliable in predicting the BP results. Since users may rely on the model's output when making health-related decisions, it is important to confirm that the BP predictions are derived from relevant physiological signals instead of unrelated variables. Therefore, the BP estimation model is evaluated using the explainable artificial intelligence (XAI) techniques to interpret the model and verify that its predictions are primarily driven by meaningful PPG signals. This increases the reliability and trustworthiness of the BP estimation model and supports the overall goal of preventive hypertension management within the application.

The application is intended for self-management and awareness of cardiovascular risks rather than diagnosis. It encourages healthier lifestyle habits and supports preventive management through an affordable and user-friendly solution that does not require reliance on smartwatches and paid subscription platforms.

1.4 Project Objectives

i. To develop a computer vision–based model for cardiac monitoring.

This project will utilize fingertip photoplethysmography (PPG) signals captured using a smartphone camera with flash to measure heart rate (HR) and heart rate variability (HRV). A computer vision–based signal quality assessment mechanism will be developed to ensure reliable PPG signal extraction. These high-quality signals will then serve as the foundation for an artificial intelligence (AI)–driven blood pressure (BP) estimation model, enabling accessible and continuous cardiac monitoring without the need for external medical devices.

ii. To implement a mobile application integrating heart rate (HR), heart rate variability (HRV) and blood pressure (BP) monitoring pipeline for preventive hypertension management.

This project will develop a mobile application that incorporates the full cardiac monitoring pipeline. The application will integrate computer vision algorithms, HR and HRV measurement, AI-based BP estimation, and manual BP recording. All health measurements will be automatically classified into categories such as low, elevated and high. The application will also provide personalized insights, trend analysis, and lifestyle recommendations to support early hypertension management.

iii. **To integrate explainable artificial intelligence (XAI) as a transparency and evaluation component within the hypertension monitoring pipeline.**

Explainable artificial intelligence (XAI) techniques such as Permutation Importance and Tree SHapley Additive exPlanations (TreeSHAP) will be applied to interpret the blood pressure estimation model to identify the PPG-derived physiological features that most strongly influence the BP prediction outcomes. This enables a feature-level validation against the established cardiovascular knowledge and helps verify that the model predictions are primarily driven by meaningful physiological signals rather than unrelated factors. The XAI analysis will be used as a model evaluation and transparency mechanism during the development to enhance the reliability and interpretability of the BP estimation model.

1.5 Project Scope and Direction

By the end of this project, a smartphone-based cardiac health monitoring application focused on hypertension risk awareness and prevention will be delivered. The application utilizes photoplethysmography (PPG) with a built-in signal quality assessment mechanism to ensure reliable PPG signal extraction. These high quality signals are then used to measure heart rate (HR) and heart rate variability (HRV). The signals are also integrated with the user's personal data in an artificial intelligence (AI) driven blood pressure (BP) estimation model. By monitoring these key health indicators, the application supports continuous self-monitoring and early detection of hypertension risk.

In addition, a manual BP recording module is also provided to allow users to track their BP readings obtained from a cuff-based BP measurement device. The application supports automatic classification of HR, HRV and BP readings, together with abnormal BP alerts and lifestyle recommendations. Lastly, this application provides an AI assistant agent that can analyze users' health measurements through a chatbot interface. This allows users to ask questions and receive responses based on their health scores.

Moreover, explainable artificial intelligence (XAI) such as Permutation Importance and Tree SHapley Additive exPlanations is applied to the BP estimation model to validate and evaluate whether the model predictions are primarily driven by meaningful physiological signals rather than unrelated factors. In short, the project focuses on developing an accessible mobile application that supports hypertension risk awareness through non-invasive monitoring and intelligent health insights.

The major characteristics will be:

- Real-time HR and HRV measurement using contact-based PPG.
- BP estimation using a machine learning model that combines PPG-derived features with personal health data.
- A PPG signal quality assessment mechanism to improve measurement accuracy.
- Manual BP recording
- Automatic classification in all health measurements into low, normal, elevated and high categories.
- Personalized lifestyle recommendations and trend analysis to support hypertension prevention.
- Utilisation of XAI techniques to verify that the BP estimation model predictions are primarily driven by meaningful PPG-derived physiological features.
- An AI assistant in a chatbot interface to respond to users' questions based on their health measurement records.
- A user-friendly mobile application interface with core features accessible without subscriptions.
- Secure storage of user data.

This project does not address the following aspects:

- Integration with external devices such as smartwatches or electrocardiogram (ECG) monitors.
- AI-driven medical diagnosis as analytics will serve for awareness and prevention only.
- Paid Application Programming Interface (API)s or premium third-party features, as the application will rely on free or custom modules.
- Medical-grade certification, as the application is intended for personal health awareness rather than clinical use.

1.6 Impact, Significance and Contributions

The contribution of this project is to develop an accessible and affordable smartphone-based application for monitoring cardiac health and supporting hypertension prevention. Instead of relying on expensive wearables or paid premium features, the application allows users to capture key cardiovascular indicators using only the smartphone camera and flash. This approach makes preventive health monitoring more inclusive and widely available outside clinical environments.

Another contribution is the integration of heart rate (HR), heart rate variability (HRV) and blood pressure (BP) measurement using fingertip photoplethysmography (PPG). It is supported by a robust signal quality assessment mechanism. Fingertip PPG is considered in this project because it does not require additional monitoring devices and can capture reliable cardiovascular data in non-clinical settings.

Moreover, the project introduces a machine learning (ML)-based blood pressure (BP) estimation model that combines users' PPG-derived features with personal health data to enable cuffless BP monitoring and early detection of hypertension risk. The BP estimation model is further validated using the explainable artificial intelligence (XAI) techniques such as Permutation Importance and Tree SHapley Additive exPlanations (TreeSHAP) to ensure that the BP predictions are reliably based on the physiological signals rather than unrelated features.

Lastly, an AI assistant chatbot is incorporated to analyze users' health scores and respond to their health-related questions. The application focuses on awareness and self-management rather than medical diagnosis. By delivering early detection cues and actionable insights, it offers a comprehensive and innovative solution for cardiac health tracking.

1.7 Report Organization

The report is organized into the following chapters to outline the development, implementation and evaluation of the proposed cardiac monitoring mobile application for hypertension management. Chapter 1 presents the project begins with the background, problem statement, motivation, scope, objectives and contributions.

Chapter 2 discusses a comprehensive literature review covering photoplethysmography (PPG) signal quality assessment, heart rate (HR) measurement algorithms, cuffless blood pressure (BP) estimation, explainable artificial intelligence (XAI) techniques and the existing cardiac monitoring applications. It highlights the strengths and drawbacks of current solutions and establishes the foundation for the proposed framework.

Chapter 3 details the system methodology by presenting the system use case diagram and system architecture. Each component and its functionalities are explained and the project timeline is also included to illustrate the development schedule.

Chapter 4 focuses on system design, including model selection such as the PPG signal quality assessment model, heart rate (HR) and heart rate variability (HRV) measurement algorithms and BP estimation models. It also discusses the application of explainable artificial intelligence (XAI) for evaluating the BP estimation model. In addition, the system flowchart, component specifications, database design and wireframes are presented in this chapter.

Chapter 5 focuses on system implementation, where hardware and software specifications, system setup and configuration are defined. It also describes the operation of the proposed application with the implementation challenges during the system development.

Chapter 6 presents the evaluation of the system's performance, including testing results and a discussion of the challenges encountered during the evaluation process. Chapter 7 concludes the report by summarizing the project and offering recommendations for future improvements.

Chapter 2

Literature Review

In this chapter, significant algorithms for cardiac monitoring are reviewed with a focus on the use of photoplethysmography (PPG) based methods in mobile applications. The existing PPG-based cardiac monitoring applications are also surveyed. Besides, the strengths and limitations of each algorithm are discussed to highlight the current constraints and to justify the methodology adopted in this project.

2.1 Photoplethysmography (PPG) for Cardiac Monitoring

Reference [13] states that photoplethysmography (PPG) is an optical method used to measure blood volume changes in tissues and it has been widely adopted in mobile and wearable health monitoring applications. Because of its simplicity and non-invasive nature, extracting physiological parameters from PPG enables the estimation of variables such as heart rate (HR) and heart rate variability (HRV).

According to [14], a comprehensive review highlights the importance of robust PPG system design, including signal preprocessing, noise artifact handling, peak detection and signal-quality indexing to ensure reliable HR and HRV measurements. However, the review also notes that there is currently no standardized preprocessing pipeline for PPG and noise handling remains a critical factor for achieving accuracy.

In addition, [15] conducted an information-theoretic analysis showing that HR estimation from PPG is well-conditioned, with a high mutual information (87.7%), indicating that the PPG signal contains rich information about HR. Also, it achieved a low multi-valued mapping factor (0.75), showing that the mapping from PPG to HR is stable and unambiguous.

Similarly, [16] reported that a clinical validation of a PPG-based mobile app achieved high accuracy for HR measurement with the area under the curve (AUC=0.976) and a mean absolute error (MAE) with 2.96 beats per minutes (bpm). A greater AUC number means the model performs better while a lower MAE usually means the prediction is accurate. These findings suggest that PPG is a reliable method for HR and HRV measurement.

2.1.1 HeartPy Algorithm

[17] introduced HeartPy, an open-source Python toolkit for analyzing noisy photoplethysmography (PPG) and electrocardiography (ECG) signals. HeartPy employs a rolling mean–based adaptive thresholding algorithm. It is combined with inter-beat interval consistency checks to achieve robust peak detection. The validation studies demonstrated a strong agreement with ECG ground truth and reporting a mean absolute error (MAE) of approximately 3 to 4 beats per minute (bpm) for PPG and less than 1 bpm for ECG. This highlights its suitability for wellness and research applications. However, HeartPy performs poorly when processing noisy or motion-affected PPG data. Besides, HeartPy is not a machine learning–based method as it relies on fixed rules for peak detection rather than adaptive learning which may limit its validity in more challenging conditions.

2.1.2 pyPPG Algorithm

According to [18], pyPPG is an open-source Python toolbox for the comprehensive analysis of photoplethysmography (PPG) signals. It emphasizes fiducial point detection across the PPG waveform. It includes detecting the systolic peaks, onsets and dicrotic notches and supports the extraction of over 70 physiological biomarkers. pyPPG integrates multiple preprocessing steps such as filtering, smoothing and detrending. These preprocessing steps provide a structured output for both beat-to-beat heart rate and higher-level cardiovascular indices. The validation studies report a high accuracy with an F1-score (0.88) and mean absolute fiducial timing errors below 10 milliseconds (ms) which indicates its reliability. However, pyPPG is primarily designed for offline signal analysis and requires relatively clean and continuous data. It is not suited for real-time smartphone applications as it lacks support for real-time processing of a user's fingertip PPG signals.

2.1.3 RapidHRV Algorithm

[19] proposed RapidHRV for the robust extraction of heart rate (HR) and heart rate variability (HRV) metrics from noisy PPG and electrocardiography (ECG) data. Its streamlined pipeline offers one-line modules for preprocessing, analysis and interactive visualization, along with automated artifact rejection. The validation on fingertip PPG demonstrated a reliable HR and HRV estimation under low noise and stable contact conditions. This highlights its potential for integration into consumer devices. However, RapidHRV was primarily developed as a

research toolkit. Thus, it is not optimized for direct real-time smartphone deployment and its performance degrades in high-motion environments.

2.1.4 Comparison of Various PPG-Based Cardiac Monitoring Algorithms

In summary, PPG-based methods is reliable in estimating heart rate (HR) for cardiac monitoring on smartphones. Several representative algorithms and their reported validations were reviewed. Table 2.1.4.1 summarizes the PPG-based algorithms, performance, highlighting their strengths and limitations that inform the methodology adopted in this project.

Table 2.1.4.1 Comparison of Various PPG-based Cardiac Monitoring Algorithms

Technique Used	Accuracy	Advantages	Disadvantages	Remarks
HeartPy [17]				
Peak detection using a rolling mean–based adaptive threshold with inter-beat interval checks	Correct detection with 95.1% (PPG)	Easy to integrate into Python and is a widely used open-source toolkit	Rule-based, not machine learning–based, performance decreases with noisy or motion-affected data	Suitable for real-time smartphone use due to its lightweight design.
pyPPG [18]				
Fiducial point detection (systolic peaks, onsets, dicrotic notches) and more than 70 biomarkers	Peak detection with F1-score 88.19%	Provides comprehensive cardiovascular analysis and rich feature extraction beyond HR/HRV	Requires relatively clean, continuous signals, designed for offline analysis and computationally heavier	Less suitable for smartphone apps, useful for extended offline biomarker analysis
RapidHRV [19]				
Outlier detection and rejection, automated preprocessing of raw PPG and ultra-short window HR/HRV estimation	Effective even at lower sampling rates (≥20 Hz)	Includes automated artifact rejection, streamlined analysis pipeline	Accuracy declines under high-motion or unstable fingertip contact; primarily designed for research use, not optimized for real-time mobile deployment	Potential as a research foundation, but requires optimization for mobile, less robust in uncontrolled conditions

2.2 Reviews on PPG-Based Signal Quality Assessment Techniques

Photoplethysmogram (PPG) signals collected from mobile devices often contain noise and motion artifacts, which can lead to inaccurate measurements and misleading diagnostic outcomes. Therefore, it is important to verify the PPG signal quality before performing any analysis to ensure reliable cardiac monitoring results.

According to [20], several PPG signal quality assessment methods have been proposed. [21] introduced a PPG waveform feature–based approach that evaluates eight Signal Quality Indices (SQIs) such as perfusion index, skewness, kurtosis, entropy, zero-crossing rate, non-stationarity and systolic wave detector matching. These features were used to classify the PPG data into excellent, acceptable and poor categories. The study showed that the skewness achieved the best classification performance with a F1-scores of 86% (excellent), 87.2% (acceptable) and 79.1% (poor). It demonstrates the effectiveness of skewness in identifying clear and stable waveforms, making it suitable for mobile PPG applications.

In [22], a rule-based SQI framework was introduced to evaluate the PPG signal morphology and consistency then categorize each segment as good or poor quality. Figure 2.2.1 illustrates the flowchart of the SQI algorithm, as the process begins with pulse peak detection to extract beat-to-beat (RR) intervals. If peaks are undetectable, the signal is labeled poor quality. Additional criteria, such as maintaining HR between 40–180 bpm, ensuring RR intervals less than 3 seconds and a ratio of maximum to minimum RR interval less than 2.2, are applied to verify rhythm stability. A template-matching correlation step follows, where a coefficient of at least 0.86 denotes good quality. This threshold achieved 91% sensitivity and 95% specificity, accurately identifying high-quality signals in 97% of the cases.

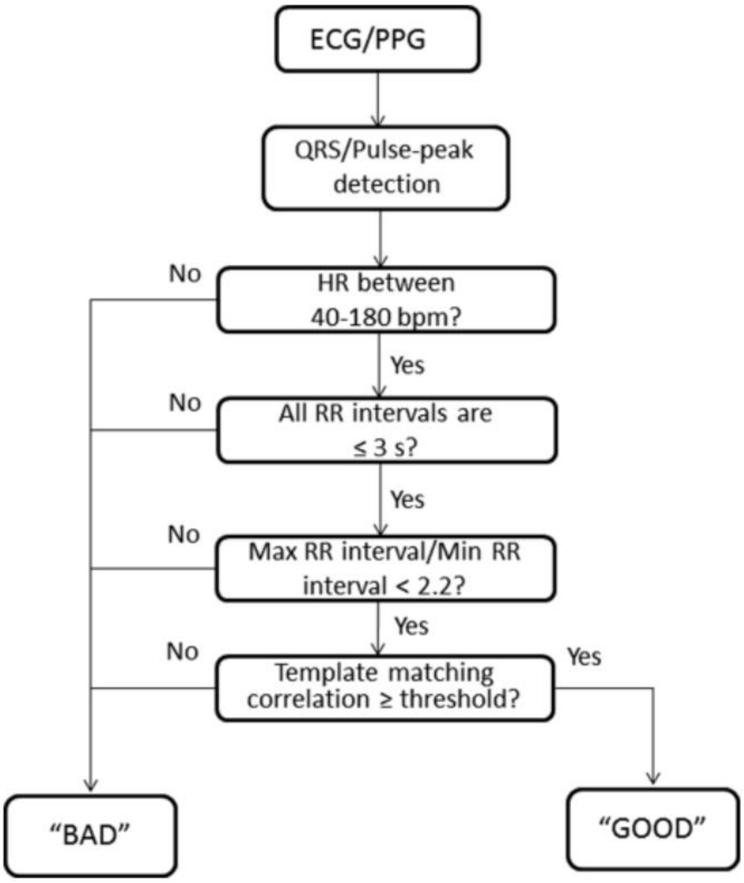


Figure 2.2.1 Flowchart of the SQI algorithm [22]

Another approach utilizes machine learning–based SQI models which [23] proposed a five-layer fuzzy neural network that classified signal quality into three categories using PPG data from stroke and non-stroke individuals, achieving 81% sensitivity and 90% specificity. Similarly, [24] developed a two-layer convolutional neural network (CNN) that transformed smartphone-based PPG signals into phase-space trajectory images. The model achieved 97.5% accuracy, 96.4% sensitivity and 98.7% specificity, demonstrating that high accuracy quality classification can be achieved without complex preprocessing or manual feature extraction.

2.2.1 Comparison of Various PPG-Based Signal Quality Assessment Techniques

In summary, the reliability of PPG-based measurements is highly dependent on the accuracy of signal quality assessment. Several PPG signal quality assessment techniques and their reported validations were reviewed. Table 2.2.1.1 summarizes the key techniques, datasets and performances, highlighting their respective strengths and limitations that inform the methodology adopted in this study.

Table 2.2.1.1 Comparison of Various PPG-Based Signal Quality Assessment Techniques

Study	Technique Used	Dataset	Accuracy	Advantages	Disadvantages	Remarks
PPG Waveform Feature Method						
[21]	Statistical features (Perfusion Index, Skewness, Kurtosis, Entropy, Zero-Crossing Rate, Non-stationarity, Systolic Wave Detector Matching)	Various public PPG datasets	Best F1-scores with skewness: 86% (excellent), 87.2% (acceptable), 79.1% (poor)	Simple implementation and low computational cost.	Sensitive to parameter tuning.	Effective for quick SQI in smartphone apps.
Rule-Based Signal Quality Index (SQI) / Template Matching Method						
[22]	Rule-based morphological analysis (peak detection, HR & RR interval constraints, template matching)	Volunteers' data (Wearable dataset)	Sensitivity: 91% Specificity: 95% Manual agreement: 97%	High interpretability and clear decision logic.	Requires careful rule design.	Suitable for real-time SQI.
Machine Learning / Deep Learning Method						
[23]	5-layer fuzzy neural network for multi-class SQI classification	Volunteers' data (Stroke and non-stroke users)	High-SQI PPG: sensitivity (81%), specificity (90%) Low-SQI PPG: sensitivity (84%), specificity (93%)	Adaptive learning and suitable for biomedical signals.	Requires feature extraction.	Less suitable for smartphone apps.
[24]	2-layer Convolutional Neural Network using recurrence plots (2D phase-space images)	Volunteers' data(Smartphone recordings)	Accuracy: 97.5% Sensitivity: 96.4%; Specificity: 98.7% PPV: 84.8%	High accuracy with automatic feature learning.	Requires a large labeled dataset.	Heavy for smartphone apps.

2.3 Reviews on PPG-Based Blood Pressure Estimation Techniques

With the increasing emphasis on early detection and management of hypertension, blood pressure (BP) measurement has become a critical health parameter. Several studies have explored methods that estimate BP using only a single photoplethysmography (PPG) signal [19].

[25] introduced a cuffless PPG-based BP estimation approach, where pulse-related features such as pulse area, rising time and 25% pulse width were extracted from the public PPG datasets. Figure 2.3.1 shows the flowchart of the proposed BP estimation pipeline. The performance of regression tree (RT), multiple linear regression (MLR) and support vector machine (SVM) models was compared using 10-fold cross-validation. The results were validated based on three BP categories (normotension, hypertension and hypotension) and against the International Organization for Standardization (ISO) standard for noninvasive BP devices, which requires a mean difference of less than or equal to 5mmHg and standard deviation (SD) of less than or equal to 8mmHg. RT demonstrated the best accuracy due to its robustness to noise and ability to model nonlinear relationships.

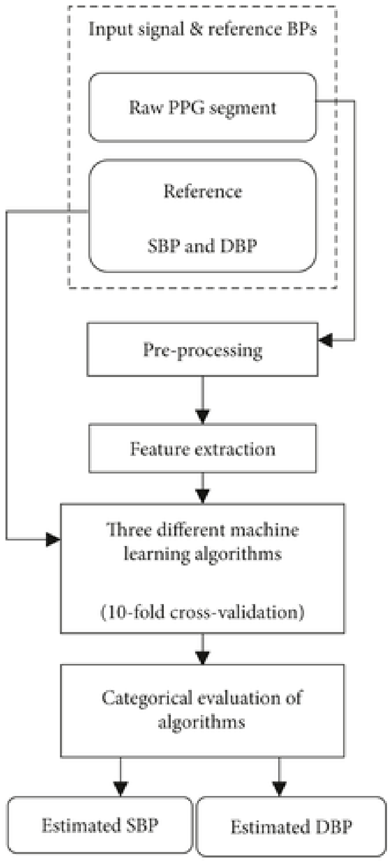


Figure 2.3.1 Flowchart of the Blood Pressure Estimation Pipeline [25]

Additionally, [26] proposed a three-Gaussian decomposition method to extract physiologically meaningful PPG features. The PPG waveform was decomposed into the primary systolic wave, reflected wave and dicrotic notch to capture detailed morphological characteristics relevant to BP estimation. Using these features, the XGBoost regression model achieved the best performance. The model satisfied the Association for the Advancement of Medical Instrumentation (AAMI) requirement, which specifies a mean difference of less than or equal to 5mmHg and a SD of less than or equal to 8mmHg. It also met the British Hypertension Society (BHS) Grade A standard, which requires at least 60% of readings within ±5mmHg, 85% within ±10mmHg and 95% within ±15mmHg, demonstrating strong clinical reliability.

Meanwhile, [27] developed a BP prediction model using Lasso regression by integrating PPG features with demographic information. The dataset was categorized based on median demographic values and separate models were trained for each subgroup to improve prediction accuracy. Figure 2.3.2 illustrates the system workflow. The method was also implemented on a smartphone application capable of acquiring fingertip PPG data and estimating BP with a 95% confidence interval.

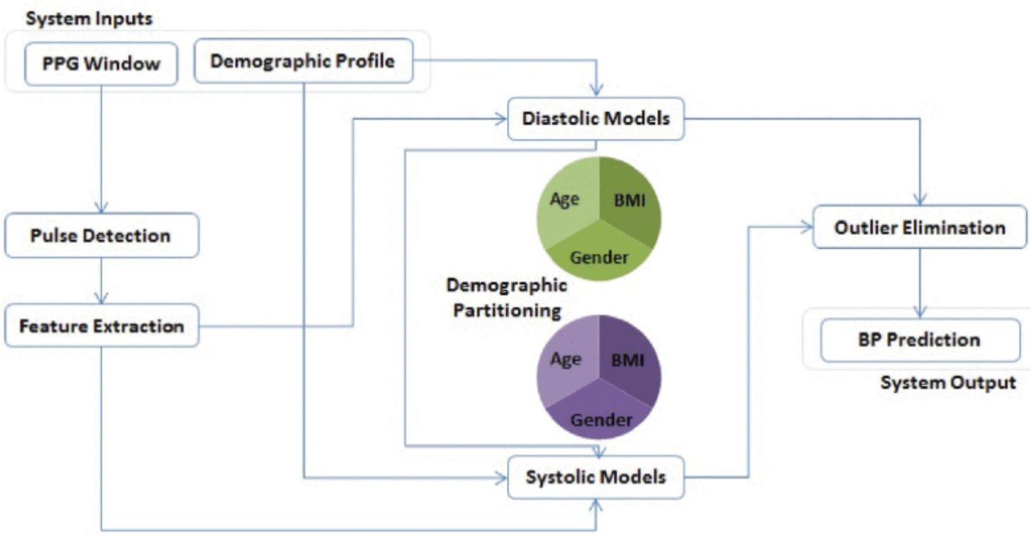


Figure 2.3.2 Flowchart of the Blood Pressure Estimation System [27]

2.3.1 Comparison of Various PPG-Based Blood Pressure Estimation Techniques

Table 2.3.1.1 summarizes the key techniques of PPG-based blood pressure (BP) estimation, datasets and performances, highlighting their respective strengths and limitations, which provide insights into the methodology adopted in this project.

Table 2.3.1.1 Comparison of Various PPG-Based BP Estimation Methods

Study	Technique Used	Dataset	Accuracy	Advantages	Disadvantages	Remarks
[25]	Regression Tree (RT) Multiple Linear Regression (MLR) Support Vector Machine (SVM)	Public PPG datasets (Queensland, 32 subjects)	RT: Mean difference = −0.1mmHg(SBP), −0.6 mmHg(DBP) SD = 6.5 mmHg (SBP), 5.2 mmHg (DBP)	Simple model, robust to noisy data, meets ISO validation standard [mean difference ≤ 5mmHg with SD ≤ 8mmHg for SBP and DBP]	Requires a high-quality PPG signal.	RT is suitable for lightweight real-time estimation.
[26]	Three-Gaussian Model + XGBoost	MIMIC (44 subjects) Queensland (31 subjects) Guilin People's Hospital (219 subjects)	Mean difference ± SD = −0.21 ± 5.21 mmHg (SBP), −0.19 ± 3.37 mmHg (DBP)	High estimation accuracy, handles large datasets well, meets • AAMI [mean difference ≤ 5mmHg with SD ≤ 8mmHg for SBP and DBP] • BHS Grade A standards [60% within ±5 mmHg, 85% within ±10 mmHg and 95% within ±15 mmHg]	Computationally heavier than RT.	Feasible for smartphone apps if computation is optimized.
[27]	Lasso Regression (demographic info + PPG features)	Volunteer data (205 subjects)	MAE: 6.9 mmHg (SBP), 5.0 mmHg (DBP)	Incorporates demographic variability, can improve personalization.	Requires user demographic input.	Implemented on a smartphone app, 95% confidence interval on BP estimation.

2.4 Reviews on Explainable Artificial Intelligence (XAI)

With the merging of machine learning (ML) and artificial intelligence (AI) nowadays, it is important to understand how ML models perform and generate predictions from input features. Therefore, explainable AI (XAI) is introduced to provide interpretable reasoning for model predictions to ensure safety and user trust in the ML-based systems.

[28] reviewed the existing XAI approaches and categorized them into the pre-modeling explainability, interpretable models, and post-modeling explainability. Pre-modeling explainability focuses on understanding and preprocessing datasets before model training. Interpretable models are inherently transparent by design while post-modeling explainability applies additional techniques to explain the complex black-box models after training. Figure 2.4.1 shows the conceptual diagram of the three degrees of explainability.

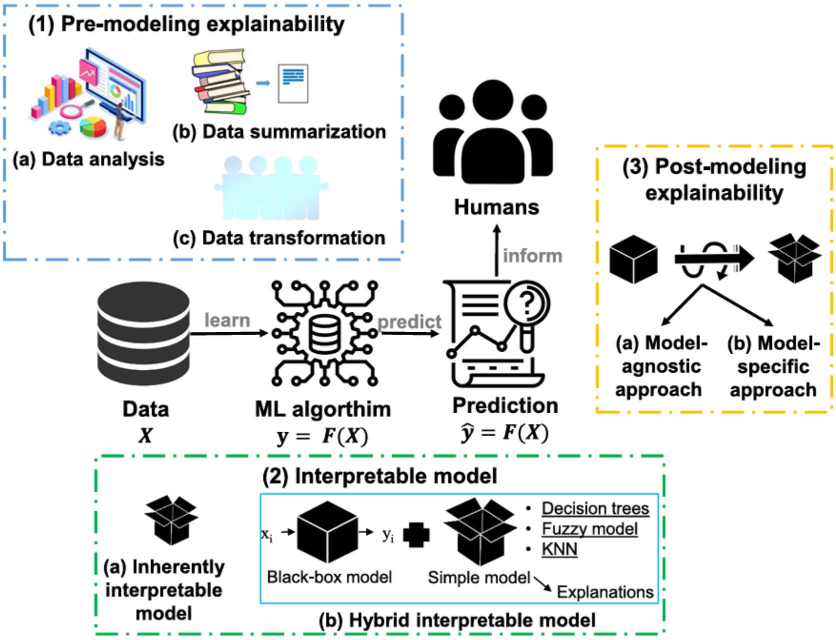


Figure 2.4.1 Conceptual Diagram of Three Degrees of Explainability [28]

Among these categories, post-modeling explainability is widely adopted for modern ML models due to its flexibility in analyzing trained models without modifying its internal structures. Post-modeling explainability can be further divided into model-agnostic and model-specific approaches. Model-agnostic approaches can be applied to a wide range of ML models whereas model-specific approaches are designed for deep learning models. Common techniques used in model-agnosic approach includes textual justification, visualization, simplification, and feature relevance analysis which are shown in Figure 2.4.2.

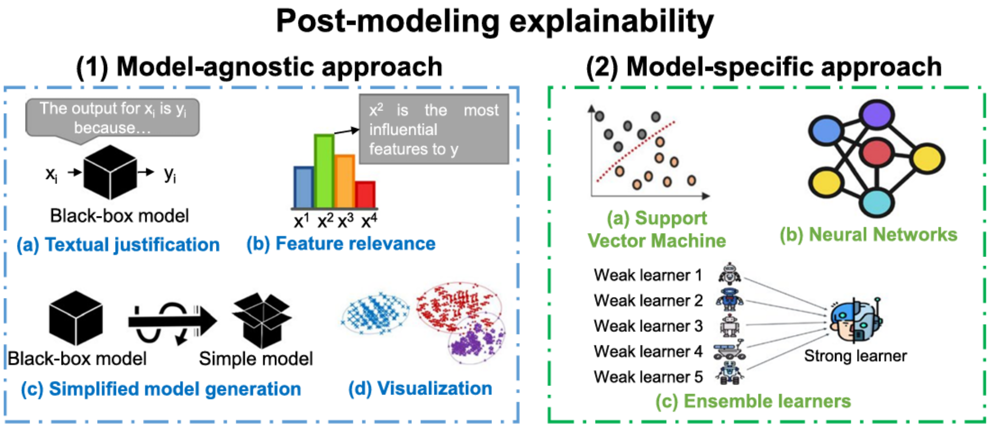


Figure 2.4.2 Conceptual Diagram of Two Categories of Post-Modeling Explainability [28]

Textual justification techniques employ natural language generation (NLG) methods to generate a text explanation of the model predictions. Feature relevance methods are the most widely used as they quantify the contribution of each input variable to the final predictions. Such quantitative explanations are important to verify whether the model relies on meaningful features rather than spurious correlations.

Representative feature-relevance techniques include SHAP (SHapley Additive exPlanations), which assigns feature importance values based on cooperative game theory to explain both individual predictions and overall model behaviour. Additionally, LIME (Local Interpretable Model-agnostic Explanations) which provides locally interpretable surrogate explanations that support model debugging and interactive analysis. Next, permutation importance (PI) evaluates the importance of each feature by randomly shuffling the feature values and observing how much the model performance decreases. As a result, a larger performance decrease indicates a more influential feature [29].

The simplification model generation approach involves interpreting the complex models by approximating them with simpler surrogate models while preserving similar predictive performance. Lastly, the visualization technique illustrates the model structures and hidden patterns through graphical representations. Tools such as FairSight and explAIner enable visualization of interactions within ML models to enhance interpretability.

2.4.1 Comparison of Various Model-agnostic Approaches

Table 2.4.1.1 summarizes the model-agnostic approaches by highlighting the common techniques used, their respective strengths and limitations, which provide insights into the selection of the explainable artificial intelligence (XAI) methodology adopted in this project.

Table 2.4.1.1 Comparison of Various Model-agnostic Approaches in Post-modelling explainability

Technique Used	Description	Advantages	Disadvantages	Remarks
Model-agnostic Approaches [28], [29]				
Textual Justification (NLG-based explanation)	Natural language generation (NLG) produces human-readable sentences to explain model predictions.	Easy for non-technical users to understand.	May depends on predefined templates rather than real causal insight.	Suitable for mobile health applications to present healthcare insights in a user-friendly language
Feature Relevance Analysis (SHAP, LIME, permutation importance)	Estimates the influence of each input feature on model predictions through mathematical attribution methods.	Provides quantitative interpretability; enables identification of influential features.	Explanations may require technical expertise to interpret.	Suitable for validating the models and ensuring predictions are physiologically meaningful.
Model Simplification (Surrogate models)	Approximates complex black-box models with simpler interpretable models while maintaining similar performance.	Improves interpretability; easier deployment and debugging.	Possible loss of prediction accuracy; surrogate may not perfectly represent original model behavior.	Less practical for real-time mobile BP estimation, where prediction accuracy is critical.
Visualization Techniques (FairSight, explAIner, SHAP plots)	Uses graphical representations to illustrate feature interactions, importance, and prediction behavior.	Enhances understanding of hidden model patterns.	Requires technical interpretation.	Suitable for the model development and evaluation stage.

2.5 Reviews on Existing PPG-Based Cardiac Monitoring Mobile Applications

Four existing photoplethysmography (PPG)-based cardiac monitoring mobile applications such as Instant Heart Rate, InPulse – Heart Rate Monitor, Instant Pulse-Blood Pressure, Heart Rate Monitor – Pulse App and Blood Pressure App – BP Tracker were reviewed. This review focuses on the core physiological measurement functions such as heart rate (HR) and blood pressure (BP) estimation as well as the usability and interaction design of the applications.

2.5.1 Instant Heart Rate

According to [30], Instant Heart Rate is a wellness-focused mobile application that uses smartphone camera–based photoplethysmography (PPG) to monitor heart rate (HR), log daily blood pressure (BP) and provide data-driven insights. Figure 2.5.1.1 shows the main interface of Instant Heart Rate after a user has successfully logged in. The three key features offered are quick HR scanning, detailed HR scanning and manual BP entry.

For HR measurement, a fingertip is placed over the camera and flash, allowing the application to detect the fingertip blood volume changes and measure beats per minute (BPM). During the measurement, Instant Heart Rate displays a real-time waveform to indicate that the measurement is in progress. Once the measurement is complete, Instant Heart Rate provides insights into HR trends and waveform visualizations, as shown in Figure 2.5.1.2.

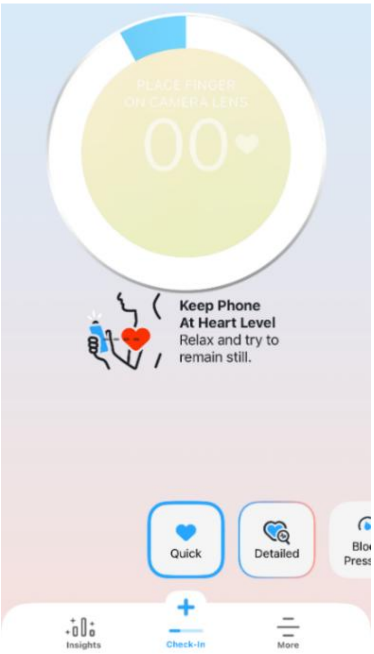


Figure 2.5.1.1 Main Interface in Instant Heart Rate

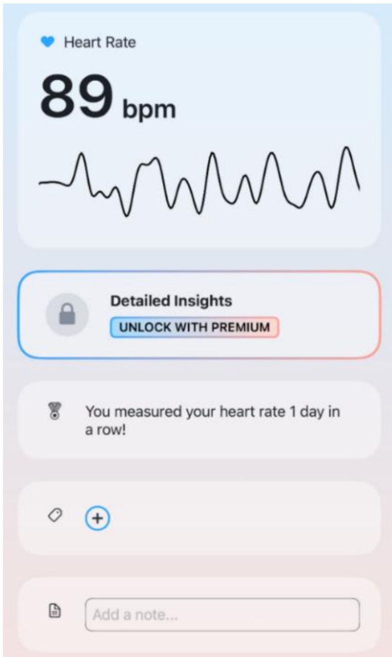


Figure 2.5.1.2 Heart Rate Insights of Instant Heart Rate

For premium users, detailed results, including heart rate variability (HRV) metrics such as the standard deviation of NN intervals (SDNN), the root mean square of successive differences (RMSSD) and exportable reports for clinician review are available. These features have been validated by research that was conducted at the University of California, San Francisco (UCSF) and Stanford University School of Medicine.

For BP tracking, Instant Heart Rate requires manual blood pressure logging, which is shown in Figure 2.5.1.3. Users can enter their systolic and diastolic BP values, heart rate and the time of measurement. After input, the app displays BP data in a histogram view as shown in Figure 2.5.1.4.

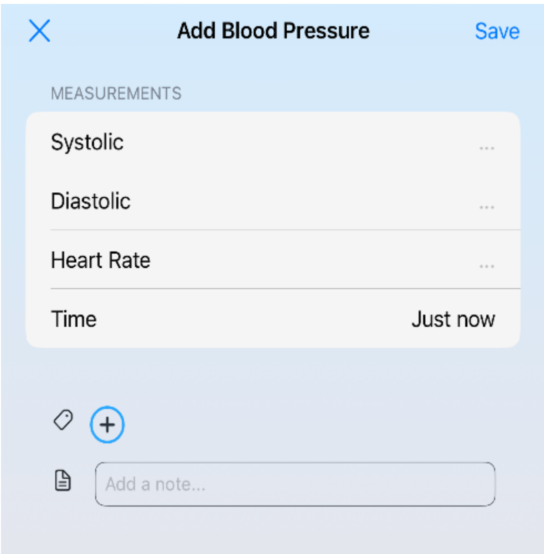


Figure 2.5.1.3 Blood Pressure Logging in Instant Heart Rate

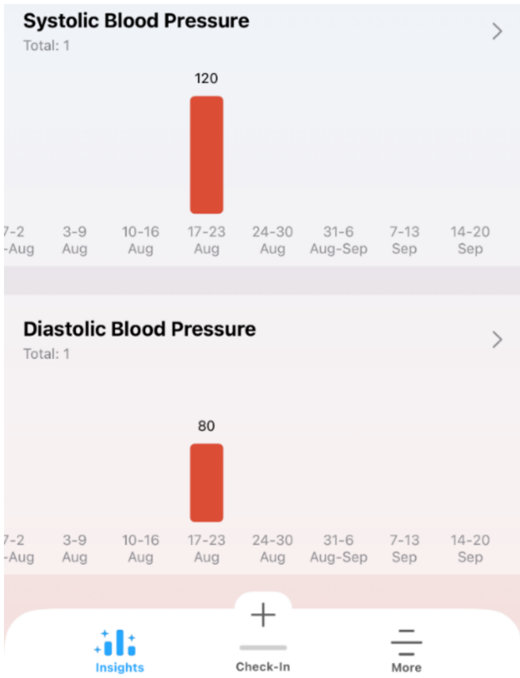


Figure 2.5.1.4 Histogram Chart for Blood Pressure Tracking in Instant Heart Rate

2.5.2 InPulse – Heart Rate Monitor

[31] InPulse, developed by AIBY, is a health and fitness application that uses fingertip photoplethysmography (PPG) via the smartphone camera and flash to measure heart rate (HR). InPulse provides access to health records, HR scans, blood pressure (BP) logging, oxygen level tracking and various assessments such as heart health tests, mental and physical health tests and a heart risk test. However, most of these features are available only to InPulse Premium users. Figure 2.5.2.1 shows the InPulse user interface in the free version, where most features remain locked.

(a) (b) (c)

Figure 2.5.2.1 Main Interface of InPulse: (a) to (c) Displaying the Home Page

For HR scanning, InPulse includes user-friendly guidance and offers on-screen tips with smartphone vibration to ensure proper fingertip placement and improve measurement accuracy, which is shown in Figure 2.5.2.2. Once the measurement is complete, Figure 2.5.2.3 shows an example from the free version of the InPulse app, where the pulse rate is displayed along with the heart rate age.

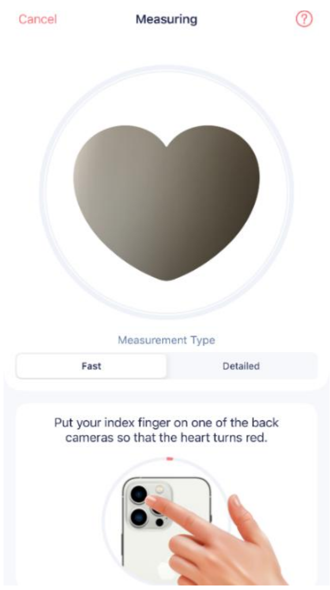


Figure 2.5.2.2 Heart Rate Measuring Interface of InPulse

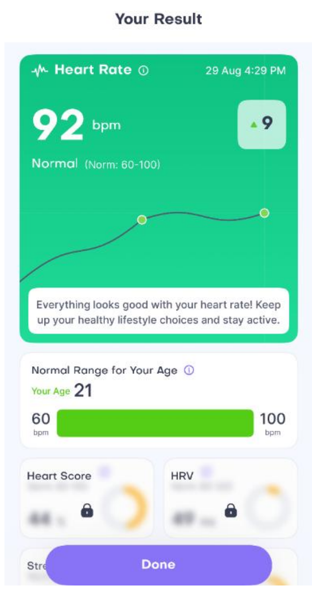


Figure 2.5.2.3 Heart Rate Results in InPulse

For BP tracking, Figure 2.5.2.4 shows how InPulse prompts users to log their blood pressure for daily recordkeeping. The BP logging results, accompanied by text-based tips for managing blood pressure are shown in Figure 2.5.2.5. Detailed test results and personalized health recommendations require a paid subscription in InPulse.

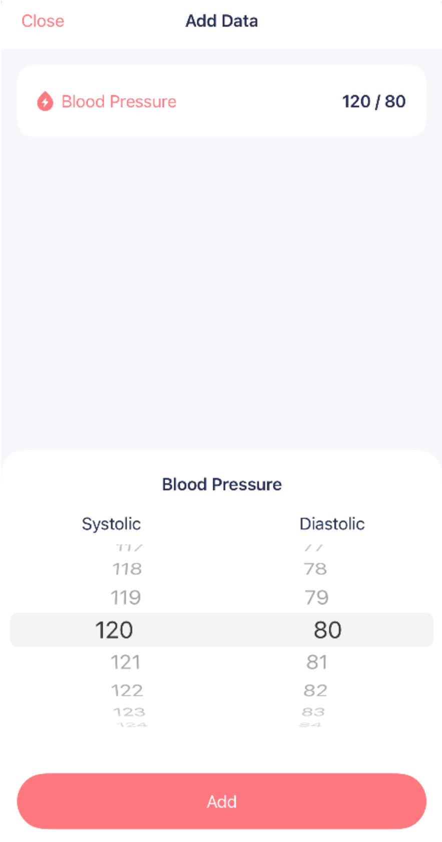


Figure 2.5.2.4 Blood Pressure Logging in InPulse

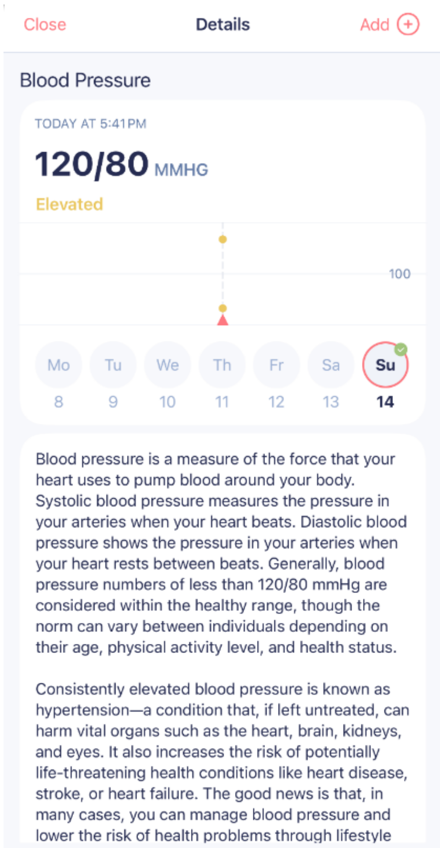


Figure 2.5.2.5 Blood Pressure Logging Details in InPulse

2.5.3 Instant Pulse-Blood Pressure

[32] Instant Pulse–Blood Pressure by Plus1Health provides fast and accessible heart rate (HR) measurement. It uses fingertip photoplethysmography (PPG) through the smartphone camera and flash to detect blood circulation and calculate HR. Figure 2.5.3.1 shows the user interface of Instant Pulse, which is designed to be simple and minimalistic, offering HR measurement, blood pressure (BP) logging and oxygen logging for daily tracking.

For HR measurement, Figure 2.5.3.2 displays the HR measurement interface with a real-time waveform. However, no camera preview or placement guidance is provided and vibration feedback is absent, which reduces usability. The analysis of a user's HR, accompanied by basic stress level logging, is shown in Figure 2.5.3.3.

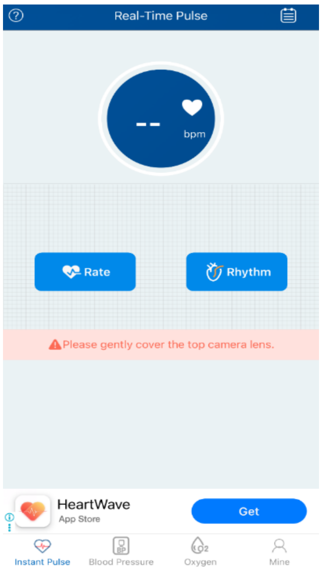


Figure 2.5.3.1 Main Interface of Instant Pulse-Blood Pressure

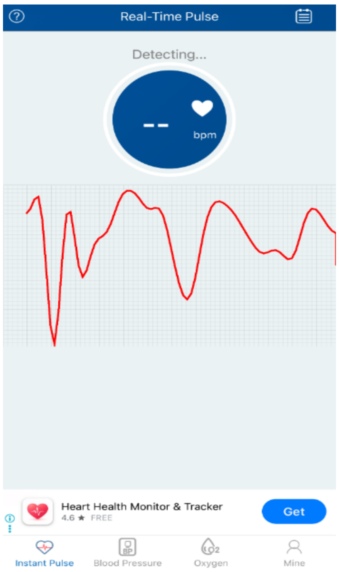


Figure 2.5.3.2 Heart Rate Measurement in Instant Pulse-Blood Pressure

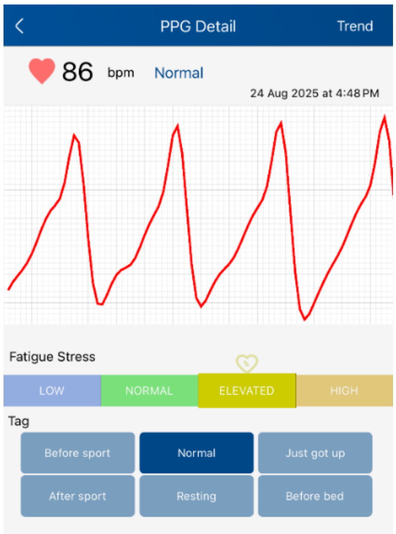


Figure 2.5.3.3 Heart Rate Measurement Results in Instant Pulse-Blood Pressure

For BP tracking, Figure 2.5.3.4 shows the manual BP logging feature, where users are prompted to enter BP values. The recorded results are displayed as shown in Figure 2.5.3.5. Since the app follows a subscription-based model, advanced features such as graphical trend analysis are available only through paid plans. In the free version, the user interface is limited, offering only basic daily logging without detailed analysis or insights. Furthermore, the free plan contains frequent advertisements, which negatively affect the usability and overall user experience [33].

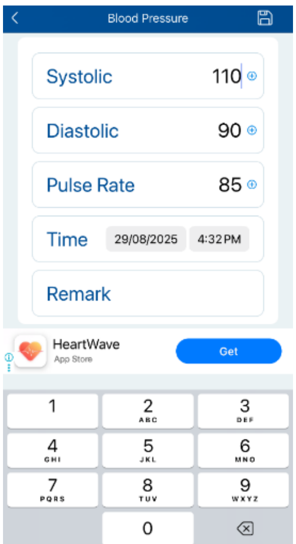


Figure 2.5.3.4 Blood Pressure Logging in Instant Pulse-Blood Pressure

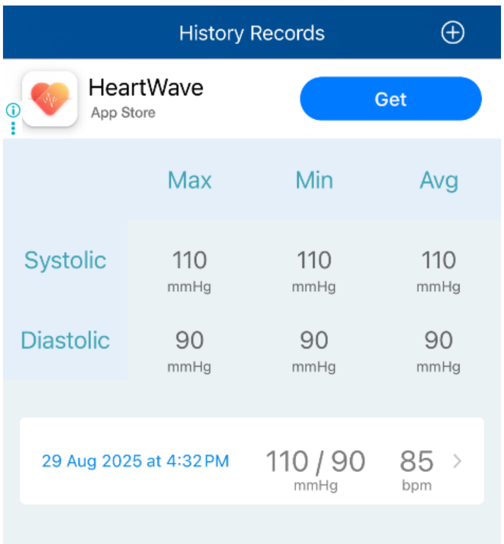
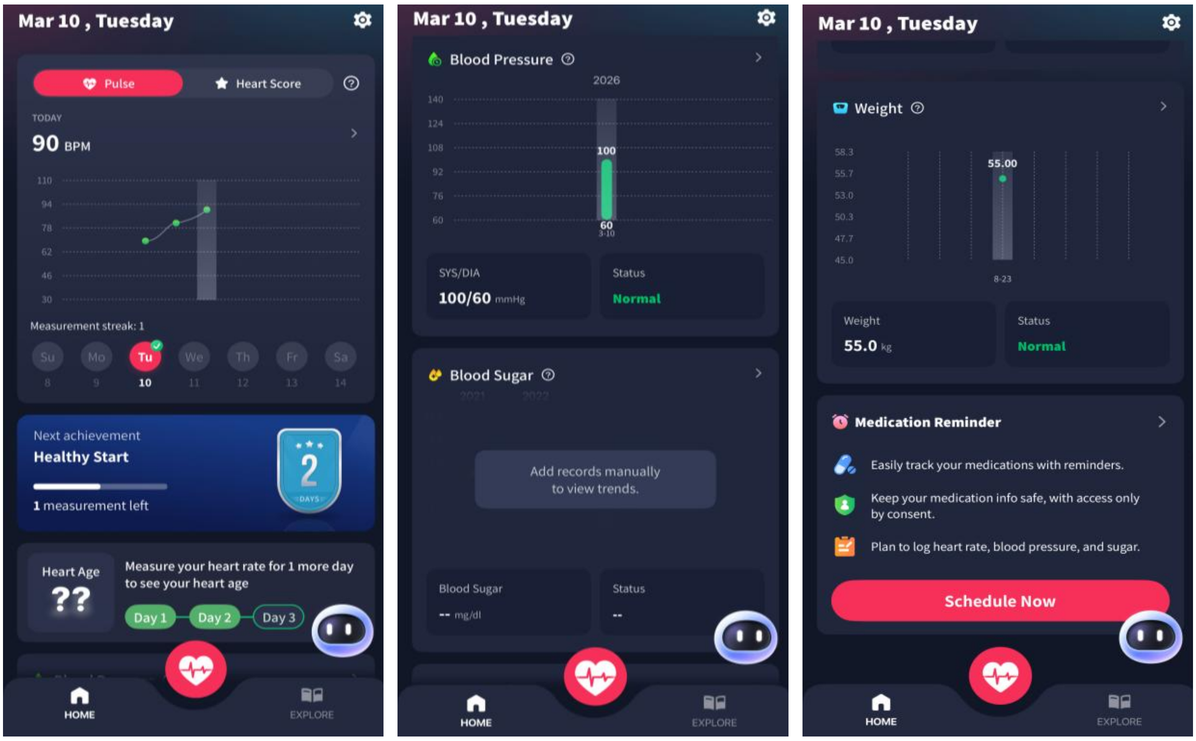


Figure 2.5.3.5 Blood Pressure Overview Instant Pulse-Blood Pressure

2.5.4 Heart Rate Monitor – Pulse App

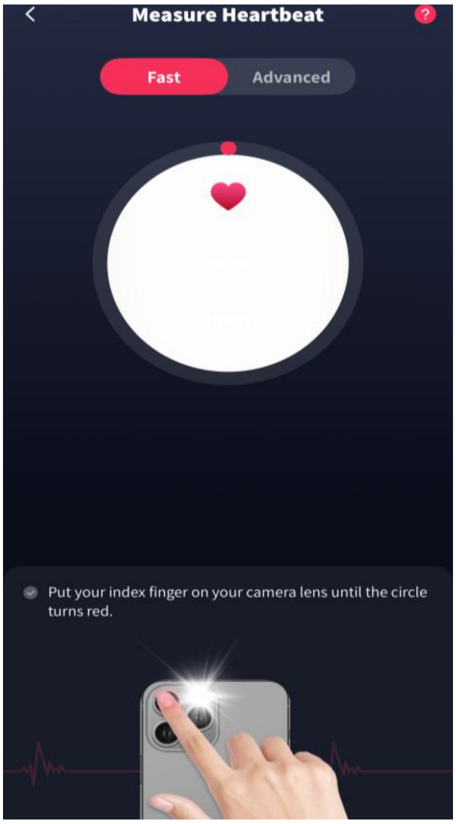
[34] Heart Rate Monitor – Pulse App by AKRURA PTE LTD is a cardiac monitoring application. It measures heart rate (HR) and pulse using the fingertip photoplethysmographic (PPG) method and without requiring a medical heart rate monitor. Figure 2.5.4.1 displays the home page of the application. The application provides several features which including HR measurements, manual blood pressure (BP) recording, manual blood sugar recording and a medication reminder.



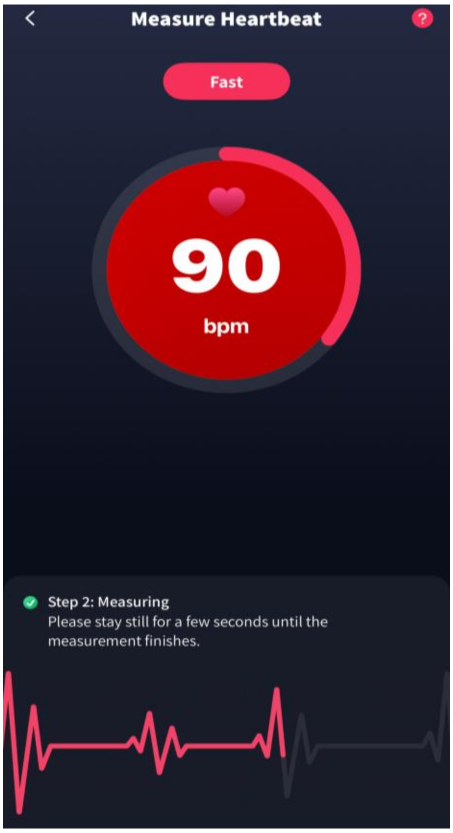
(a) (b) (c)

Figure 2.5.4.1 Main Interface of Heart Rate Monitor – Pulse App: (a) to (c) Displaying the Home Page

For HR measurements, the application first displays the fingertip positioning guidance along with a real-time camera lens on the screen, as shown in Figure 2.5.4.2 (a). When the user places their fingertip over the lens, the application begins measuring the HR and displaying the HR wavelength, which is shown in Figure 2.5.4.2 (b).



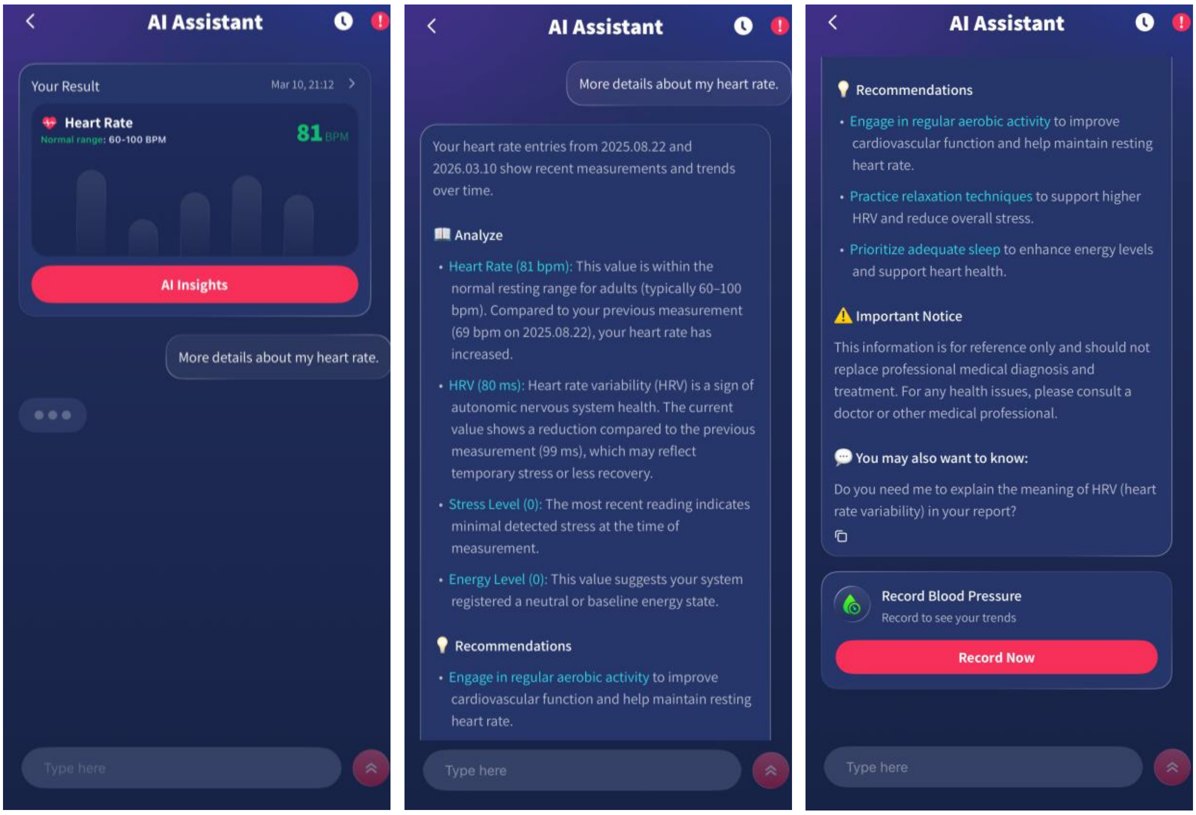
(a)



(b)

Figure 2.5.4.2 Heart Rate Measurement in Heart Rate Monitor – Pulse App: (a) and (b) Displaying the Heart Rate Measurement Process

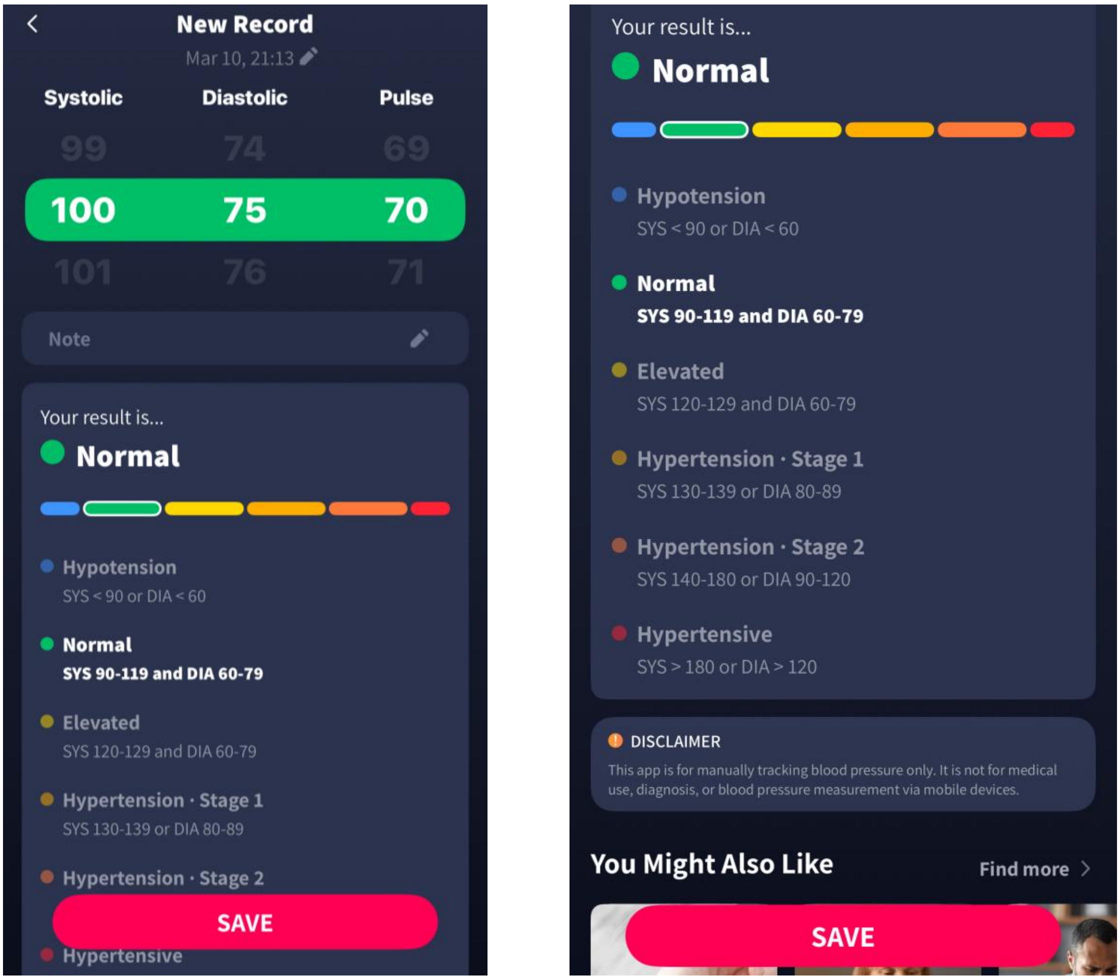
After successfully taking the HR measurements, the application directs the user to the AI assistant interface and displays a message indicating that the previous measurement record is 81 BPM. Below the message is a button of "All insights" which is shown in Figure 2.5.4.3 (a). Figure 2.5.4.3 (b) and (c) show that when the user clicks the button, the AI assistant analyzes the user's HR and HRV measurements and provides a simple explanation of each measurement. In addition, it displays a disclaimer stating that the information provided is for reference purposes only and should not be considered a medical diagnosis. After explaining the user's health measurement, the application then prompts the user to record their BP.



(a) (b) (c)

Figure 2.5.4.3 Heart Rate Results Page of Heart Rate Monitor – Pulse App: (a) to (c) Displaying the Heart Rate Results with AI Assistant

For BP recording, Figure 2.5.4.4 (a) and (b) show that the users can manually record their systolic and diastolic BP as well as the pulse by scrolling through the values. During the process, the system categorizes the recorded values based on the BP range. The application also displays the standard BP ranges so that the users can understand whether their recorded values fall within the normal range.



(a) (b)

Figure 2.5.4.4 Manual Blood Pressure and Pulse Recording in Heart Rate Monitor – Pulse App: (a) and (b) Displaying the Manual Recording Process

2.5.5 Blood Pressure App – BP Tracker

[35] Blood Pressure App – BP Tracker by AKRURA PTE LTD offers basic health-tracking functions such as blood pressure (BP) and pulse recording. Figure 2.5.5.1 shows the application's home page, which supports manual record entry and a quick-scan function for health measurements. Figure 2.5.5.2 presents the user interface for manual health record entry, where users can input systolic and diastolic BP values, which are automatically categorized into BP ranges such as low, normal, or high. Users can also record pulse values and the date of measurement.

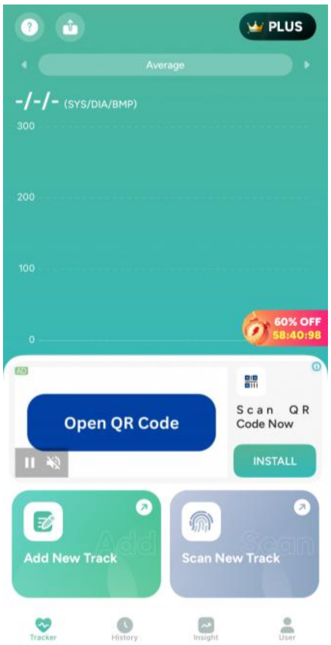


Figure 2.5.5.1 Main Interface of Blood Pressure App – BP Tracker

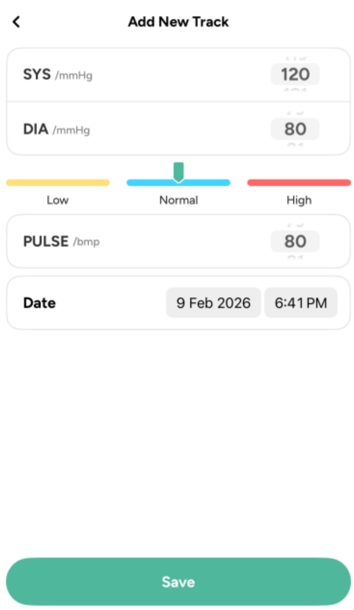


Figure 2.5.5.2 Manual Record Entry in Blood Pressure App – BP Tracker

For the quick scan function, users are required to place a fingertip on the smartphone camera with flash to capture photoplethysmography (PPG) signals for estimating BP and pulse, as shown in Figure 2.5.5.3. The measurement results are displayed in Figure 2.5.5.4, including the automatically categorized BP range. However, the results page presents only numerical measurement values without further interpretation or health insights, which may limit user understanding.

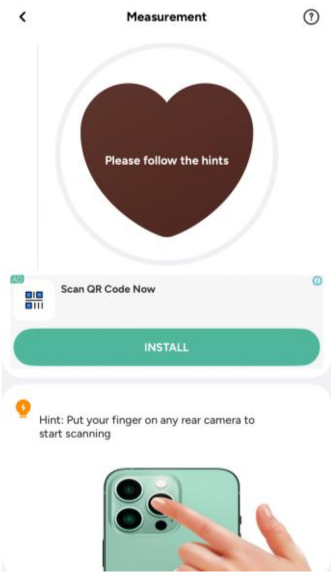


Figure 2.5.5.3 Quick Scan in Blood Pressure App – BP Tracker

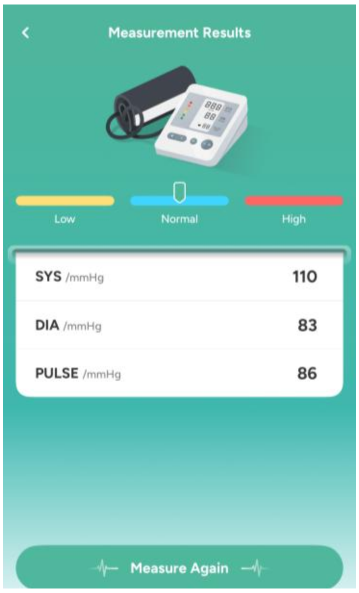


Figure 2.5.5.4 Measurement Results in Blood Pressure App – BP Tracker

2.5.6 Limitation on Existing PPG-Based Cardiac Monitoring Mobile Applications

The reviewed cardiac monitoring applications exhibit several limitations. The most notable is the underutilization of heart rate variability (HRV). Although HRV is a well-established biomarker for assessing cardiovascular health and hypertension. But most existing applications do not analyze HRV trends or provide meaningful insights. For instance, Instant Heart Rate and InPulse restrict HRV analysis to premium versions, while Instant Pulse–Blood Pressure and Blood Pressure App – BP Tracker lack the HRV functionality altogether. This gap represents a missed opportunity for the early identification of elevated risk.

Another limitation is the lack of consistent photoplethysmography (PPG) signal quality assessment and user guidance. Reliable PPG readings depend heavily on correct fingertip placement and clean signal clarity. For instance, Instant Heart Rate provides users with basic fingertip positioning instructions and shows a real-time waveform to assist users. In contrast, Instant Pulse–Blood Pressure offers no such guidance which can lead to producing unreliable readings and reduced user confidence.

Besides, blood pressure (BP) is also a key indicator for managing hypertension, but most of the existing applications only support manual BP logging. This becomes a barrier for users who do not own a cuff-based BP device and resulting in another missed chance to help users track hypertension risk.

Lastly, the reviewed applications also provide underdeveloped personalized lifestyle recommendations. For example, Instant Heart Rate and InPulse display only simple trend graphs without classifying readings such as normal, elevated, hypertensive, or offering personalized recommendations. Similarly, Instant Pulse–Blood Pressure and Blood Pressure App – BP Tracker only presents raw data without meaningful context which reduces its effectiveness for proactive hypertension management.

2.5.7 Summary of Existing PPG-Based Cardiac Monitoring Mobile Applications

Table 2.5.7.1 summarizes the reviewed photoplethysmography (PPG)-based cardiac monitoring mobile applications, highlighting their key functionalities and limitations. The comparison provides functional and design insights that serve as the foundation of the proposed system in this project.

Table 2.5.7.1 Comparison of Previous Works with Proposed Application

Functions / Exiting Mobile Application	**Instant Heart Rate [31]**	**InPulse – Heart Rate Monitor [32]**	**Instant Pulse-Blood Pressure [33]**	**Heart Rate Monitor – Pulse App [34]**	**Blood Pressure App – BP Tracker [35]**
User registration / User authentication	√	√	√	√	X
HR Measurement using PPG	√	√	√	√	√
Signal Quality Assessment	√	√	√	√	√
Fingertip Positioning Guidance	√	√ + Vibration	X	√	√
HRV Analysis	√ (Premium only)	√ (Premium only)	X	√	X
BP Estimation	X	X	X	X	√ + Classification
Manual BP Logging	√	√	√	√ + Classification	√ + Classification
Health Insights (BP, HR, HRV)	√ (Premium only)	√ (Premium only)	X	√ + AI Assistant	X
Data Insights	√ (Premium only)	√ (Premium only)	√ (Premium only)	√	X

Chapter 3

System Methodology/Approach

This section provides an overview of the proposed application through a use case diagram and a system architecture diagram. Use case descriptions and activity diagrams are also provided to give a more detailed visualization of how each function operates within the application. In addition, the development methodology adopted in this project and the project timeline are discussed so that the application can be completed within the allocated time frame.

3.1 Overview of Proposed Application

A smartphone-based cardiac health monitoring application is proposed to address the limitations of the existing cardiac monitoring applications discussed in Chapter 2.4.6. The proposed application utilizes the fingertip photoplethysmography (PPG) through the smartphone camera and flash to capture cardiovascular signals. A signal quality assessment mechanism is incorporated in the application to ensure that only reliable PPG signals are used for further analysis. These validated PPG signals are then used to derive the key cardiovascular indicators such as heart rate (HR), heart rate variability (HRV) and blood pressure (BP) estimation.

The proposed application integrates the physiological signals with user demographics to support BP estimation and HR and HRV measurement. In addition, the application also allows users to record BP readings manually for continuous hypertension tracking. All measurements are automatically categorized as low, normal, elevated or high ranges. The application further analyzes the measurement trends over time to provide alerts, lifestyle recommendations and suggestions for medical consultation when abnormal patterns related to hypertension are detected.

In summary, the purpose of the application is to provide an affordable, accessible and a user-friendly tool for cardiovascular monitoring and early awareness of hypertension risk, rather than serving as a clinical diagnostic application. Table 3.1.1 presents a comparison between the existing cardiac monitoring applications and the proposed solution in terms of the key functional features.

Table 3.1.1 Comparison of Previous Works with Proposed Application

Functions / Mobile Application	**Instant Heart Rate [31]**	**InPulse – Heart Rate Monitor [32]**	**Instant Pulse- Blood Pressure [33]**	**Heart Rate Monitor – Pulse App [34]**	**Blood Pressure App – BP Tracker [35]**	**Proposed Application**
User registration / User authentication	√	√	√	√	X	√
HR Measurement using PPG	√	√	√	√	√	√
Signal Quality Assessment	√	√	√	√	√	√
Fingertip Positioning Guidance	√	√ + Vibration	X	√	√	√
HRV Analysis	√ (Premium only)	√ (Premium only)	X	√	X	√ + Classification
BP Estimation	X	X	X	X	√ + Classification	√ + Classification
Manual BP Logging	√	√	√	√ + Classification	√ + Classification	√ + Classification
Health Insights (BP, HR, HRV)	√ (Premium only)	√ (Premium only)	X	√ + AI Assistant	X	√ + Alerts + AI Assistant + Recommendations
Data Insights	√ (Premium only)	√ (Premium only)	√ (Premium only)	√	X	√ + Personalized trend analysis

3.2 System Architecture Diagram

Figure 3.2.1 displays the system architecture diagram of the proposed cardiac health monitoring application. The blue region represents the mobile application components while the green region represents the backend services that support the application. Most core functions require communication over the Internet to interact with the backend services.

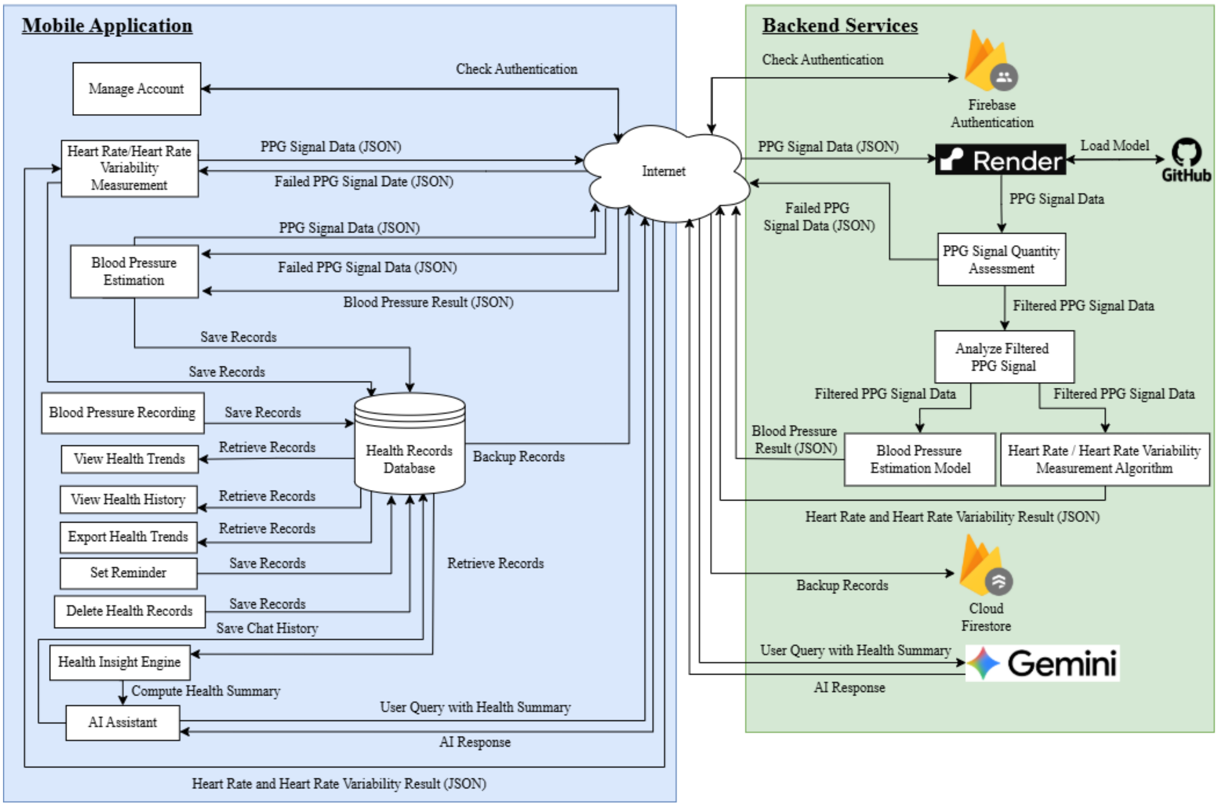


Figure 3.2.1 System Architecture Diagram

In the backend services, Google Cloud Firebase is used to store user information and backup the users' records. GitHub is used to host the health measurement model files while the Render serves as the cloud platform that deploys and runs the models. Gemini is used as the artificial intelligence (AI) model to respond to user queries through the chatbot-based AI assistant.

First, when users manage their accounts, authentication requests are sent from the mobile application to Firebase Authentication through the Internet. Once authenticated, users can access the application. The core functionalities include heart rate (HR), heart rate variability (HRV) measurement and blood pressure (BP) estimation. The process begins by capturing the user's fingertip photoplethysmography (PPG) signal and formatting it in JavaScript Object Notation (JSON) format. This signal is then transmitted over the Internet to the Render where the backend service is deployed. Render loads the required health measurement model files from GitHub during the deployment and strat process the PPG signals to estimate the results.

The backend first performs a PPG signal quality assessment. If the signal contains excessive noise or motion artifacts, the service returns a "failed PPG signal" response to the application. If the PPG signal passes the quality assessment, the filtered signal is then analyzed and passed to the HR and HRV measurement algorithm and the BP estimation model. Once the HR, HRV and BP values are computed, the results are sent to the mobile application in JSON format via the Internet. Apart from the core features, users can record their actual BP, view health trends, view health records, set a medicine reminder, export their health records and delete their past measurements.

Moreover, the application supports a chatbot-based AI assistant that analyzes users' health records and answers their questions. First, the application retrieves the users' health records and computes a personalized health summary. When a user enters a question, the application sends the query along with the computed health summary to Gemini via the Internet. The AI assistant also provides Gemini with system instructions to respond as a cardiac health monitoring assistant and to avoid providing medical diagnoses or advice. Gemini then returns a response, which is displayed on the AI assistant interface and contains the health information relevant to the user's record. All user health records are stored locally within the application and are also backed up to Google Cloud Firestore via the Internet to ensure data safety and availability.

3.3 User Requirements

This section defines the functional and non-functional requirements of the proposed cardiac monitoring application. The functional requirements describe the main features and system operations of the proposed application while the non-functional requirements specify the performance, usability and reliability that the application must satisfy.

3.3.1 Functional Requirements

Table 3.3.1.1 presents the functional requirements that must be satisfied by the proposed cardiac monitoring application.

Table 3.3.1.1 Functional Requirements for Cardiac Monitoring Application

ID	Functional Requirements
FR01	The application shall allow users to register an account by providing the required personal information.
FR02	The application shall allow users to log in to the application.
FR03	The application shall allow users to log in to the application using a Google account.
FR04	The application shall allow users to reset their passwords on the login page.
FR05	The application shall allow users to capture fingertip video using the smartphone camera with flash for photoplethysmography (PPG) signal acquisition.
FR06	The application shall implement computer vision techniques to check real-time fingertip positioning during the PPG signal acquisition process to ensure reliable PPG signal capture.
FR07	The application shall analyze heart rate (HR) and heart rate variability (HRV) from the user’s PPG signal.
FR08	The application shall estimate blood pressure (BP) from the user’s PPG signal.
FR09	The application shall allow users to manually record their BP readings.
FR10	The application shall automatically classify HR, HRV, and BP values into predefined categories such as low, normal, elevated or high.
FR11	The application shall display trend graphs for HR, HRV, estimated BP and recorded BP.
FR12	The application shall allow users to select a specific date range for viewing trend graphs.
FR13	The application shall analyse user health records to generate personalized health insights and provide lifestyle recommendations.
FR14	The application shall summarize the users’ historical cardiac measurements including HR, HRV and BP to generate a health scores.
FR15	The application shall allow the user to ask any health-related questions and generate contextual responses based on the user’s measurement insights.
FR16	The application shall provide non-diagnostic explanations and health guidance based on the user’s cardiac measurements and detected trends.
FR17	The application shall allow users to update their profile information and their password.
FR18	The application shall allow users to set reminders for daily health measurements and medication intake.

FR19	The application shall allow users to edit reminder settings and delete the reminder.
FR20	The application shall allow users to export health records in Excel or portable document format (PDF) format.
FR21	The application shall allow users to select a specific date range when exporting the health records.
FR22	The application shall allow users to delete the selected or all health records.
FR23	The application shall allow users to log out of the application.

3.3.2 Non-Functional Requirements

Table 3.3.2.1 presents the non-functional requirements that must be satisfied by the proposed cardiac monitoring application.

Table 3.3.2.1 Non-Functional Requirements for Cardiac Monitoring Application

ID	Non-Functional Requirements
NFR01	The application shall store users' health data in real time upon successful measurement or data entry.
NFR02	The application shall ensure secure data transmission and storage by implementing encryption and authentication mechanisms to protect user credentials and health data.
NFR03	The application shall be able to access the smartphone camera and flash.
NFR04	The application shall operate effectively under normal indoor lighting conditions for fingertip photoplethysmography (PPG) signal acquisition.
NFR05	The application shall generate the measurement results within 30 seconds after PPG signal acquisition.
NFR06	The application shall deliver reminder notifications at the scheduled time.
NFR07	The application shall validate user inputs and display appropriate error messages for invalid entries.
NFR08	The application shall remain accessible to users with an active internet connection.
NFR09	The application shall be designed with a modular architecture to support maintainability and future enhancements.

3.4 System Use Case Diagram and Use Case Description

This section outlines the interactions between the users and the proposed cardiac monitoring application through a use case diagram and detailed use case descriptions. It illustrates how users interact with the system's main functions and features.

3.4.1 System Use Case Diagram

Figure 3.4.1.1 illustrates the system use case diagram which outlines the overall functionality of the proposed cardiac health monitoring mobile application.

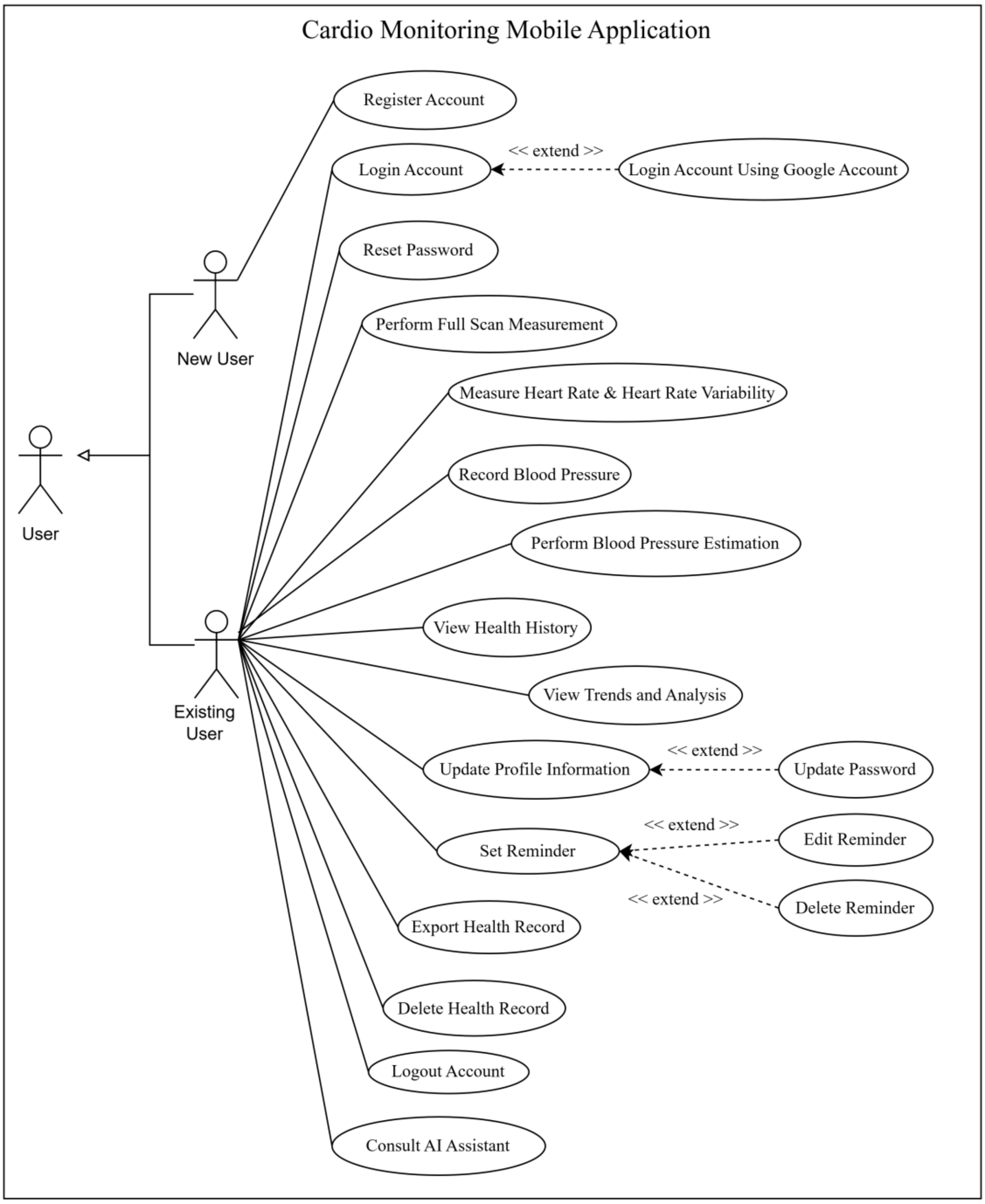


Figure 3.4.1.1 System Use Case Diagram

First, users must register an account before signing in to the application. After successful registration, users can log in using their registered accounts. If users have a Google account, they can choose to log in using Google authentication. After logging in with a Google account, if the user has not registered before, the application will prompt the user to complete their profile before performing health measurements.

The application provides several core functionalities for monitoring cardiac health. Users can perform full scan measurements, measure heart rate (HR) and heart rate variability (HRV), estimate blood pressure (BP) and record actual BP readings. The system allows users to view their health history and analyze trends based on past records.

In addition, users can manage their personal information by updating their profile and changing their password. The application also supports reminders for health monitoring or medication. Users can edit and delete reminders. Besides, the system provides an export health records function and can also delete unwanted health records. Furthermore, the application includes an AI assistant that enables users to obtain insights and ask questions related to their cardiac health. Users can also log out of the application.

3.4.2 System Use Case Description

This section provides a detailed description of the functionalities in the proposed Cardiac Monitoring Application. Table 3.4.2.1 and Appendix A, Table A.1.1 to A.1.18 explain each function in terms of how it operates within the system.

UC01 - Register Account

Table 3.4.2.1 Use Case Description of Register Account

<table>
<tr><td>Use Case Name: Register Account</td><td>ID: UC01</td><td>Importance Level: High</td></tr>
<tr><td>Primary Actor: New User</td><td colspan="2">Use Case Type: Detail, Essential</td></tr>
<tr><td colspan="3">Stakeholders and Interests:
New User - wants to create a personal account to access the application’s features.</td></tr>
<tr><td colspan="3">Brief Description:
This use case describes how the new user registers an account by providing the required personal information.</td></tr>
<tr><td colspan="3">Trigger: The new user selects the “Sign Up” option on the application login page.
Type: External</td></tr>
</table>

Relationships: Association: New User Include: None Extend: None Generalization: None
Normal Flow of Events: 1. The user selects the “Sign Up” option. 2. The system displays the registration form and prompts the user to enter personal information (name, age, gender, weight, height, email and password). 3. The user submits the form. 4. The system checks whether all required fields are completed. If any field is empty, The S-1: Empty Field Alert is performed. 5. The system validates the format of the entered information. If any input format is invalid, The S-2: Invalid Format Alert is performed. 6. The system checks whether the email already exists in the database. If a duplicate account is found, The S-3: Duplicate Account Alert is performed. 7. The system creates a new user account and stores the user information in the database. 8. The system displays a successful registration message and redirects the user to the login page.
SubFlows: S-1: Empty Field Alert 1. The system displays an error message requesting the user to complete all required fields. 2. The user re-enters the missing information and resubmits the form. S-2: Invalid Format Alert 1. The system displays an error message for the invalid input format in the respective fields. 2. The user re-enters the correct input and resubmits the form.

S-3: Duplicate Account Alert 1. The system displays an error message for email address is already registered. 2. The user re-enters a different email address and resubmits the form.
Alternate/Exceptional Flows: 7a. If a network failure occurs during account creation, the system displays an error message “Network error. Please check your internet connection and try again.” User reconnects to the internet and resubmits the form.

3.5 Activity Diagram

This section presents the activity diagrams of the proposed cardiac health monitoring application. Figure 3.5.1 and Appendix A, Table A.2.1 to A.2.18 provide a visual representation of each workflow of the application functions and are structured using swimlanes which clearly distinguish the responsibilities of each participant involved in the workflow.

UC01 - Register Account

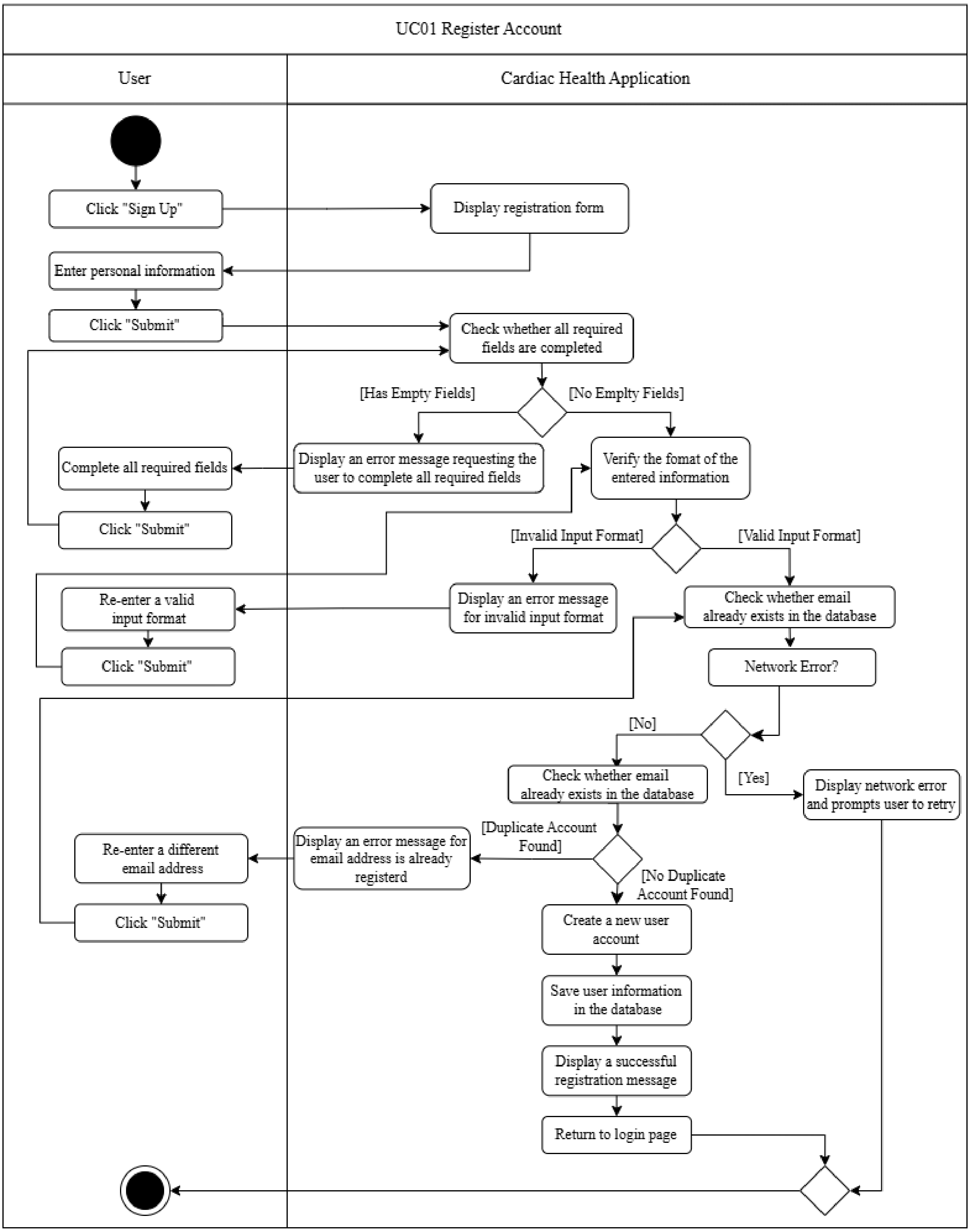


Figure 3.5.1 UC01 Register Account Activity Diagram

3.6 System Development Methodologies

The development of the cardiac monitoring mobile application will be carried out using the Agile methodology. Agile methodology manages project development by breaking tasks into smaller, manageable units. Instead of producing a single prototype and final product over an extended period, it enables the team to work iteratively and deliver incremental components more rapidly [36]. Figure 3.6.1 shows the six phases of Agile methodology including planning, design, development, testing, deployment and review.

Figure 3.6.1 Agile Methodology Phases [36]

- **Planning**

During the planning phase, essential features of the cardiac monitoring application are defined. These include user registration and authentication, heart rate (HR) and heart rate variability (HRV) measurement, blood pressure (BP) estimation using photoplethysmography (PPG) and manual BP recording. Supporting functions such as categorizing users' readings, providing lifestyle recommendations, data visualization, a chatbot-based AI assistant, reminder and exporting health records are also outlined to ensure the application addresses the health monitoring objectives.

- **Design**

This phase focuses on system architecture and user interface layout. The front end involves designing the layout for the mobile application and the main functions. The back end manages user authentication, core processing models and health data storage. The database schema organizes the records such as user accounts, AI assistant chatbot history, and the measurement readings of HR, HRV and BP.

- **Development**

During development, the identified modules are implemented incrementally. Core tasks include coding the registration and authentication system, building the HR and HRV monitoring component with PPG signal quality assessment, integrating the BP estimation module with PPG signal quality assessment and implementing manual BP recording. All health measurements are processed with a predefined automated classification mechanism. Additional features such as trend analysis, lifestyle recommendations, an AI assistant, profile management, reminder settings and data export are implemented in later iterations.

- **Testing**

Testing verifies the accuracy, stability and usability of each module. User workflows such as registration, full scan measurement, HR and HRV measurement, BP estimation and BP recording are tested to ensure correct input prompts and produce reliable results. Several tests are conducted on the PPG signal quality assessment, AI assistant response accuracy and reminder notification delivery. The responsiveness of the user interface is also evaluated to confirm that the application provides a dependable and smooth experience.

- **Deployment**

In the deployment phase, the application is first managed and version-controlled using GitHub. The Android application is then packaged and deployed to Android devices for deployment. The deployed application allows users to monitor heart rate (HR) and heart rate variability (HRV), estimate blood pressure (BP), perform full-scan measurements, record actual BP readings, review historical data, consult the AI assistant regarding their health measurements and receive recommendations through the insights dashboard.

- **Review**

The review phase evaluates whether the application meets the functional requirements, non-functional requirements and the project objectives. Each feature is evaluated incrementally during development to enable the early detection and correction of issues. Also, the application is further reviewed for usability, accuracy and overall performance.

3.7 Timeline and Gantt Chart

Figure 3.7.1 presents the timeline of Project I over seven weeks using a Gantt chart while Figure 3.7.2 displays the timeline of Project II over fourteen weeks. Both charts provide a detailed overview of the project execution. By utilizing these visual schedules, project progress can be monitored and task priorities or non-critical tasks can be identified. This enables effective time management and supports successful project delivery.

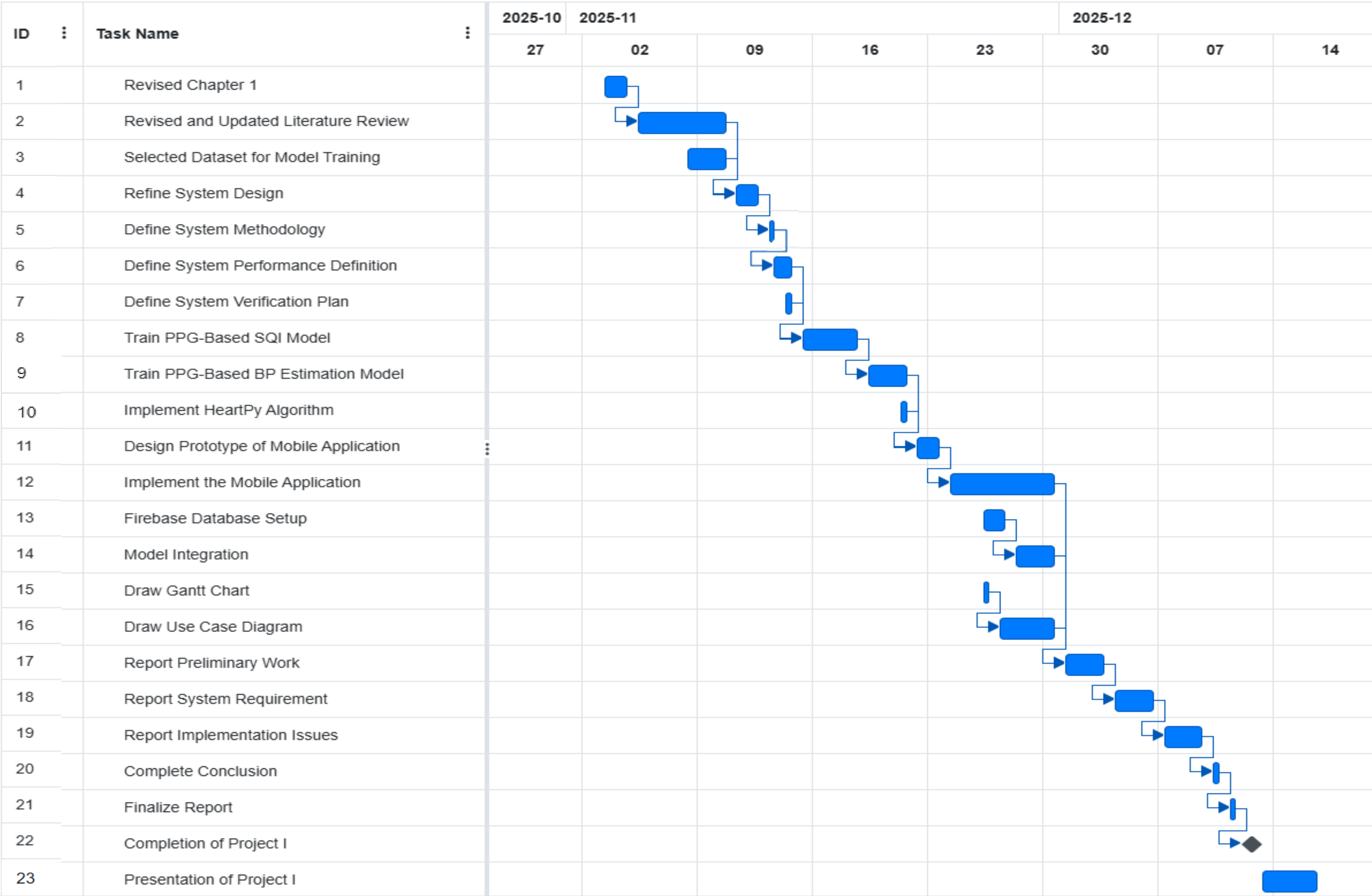


Figure 3.7.1 Gantt Chart of Project I

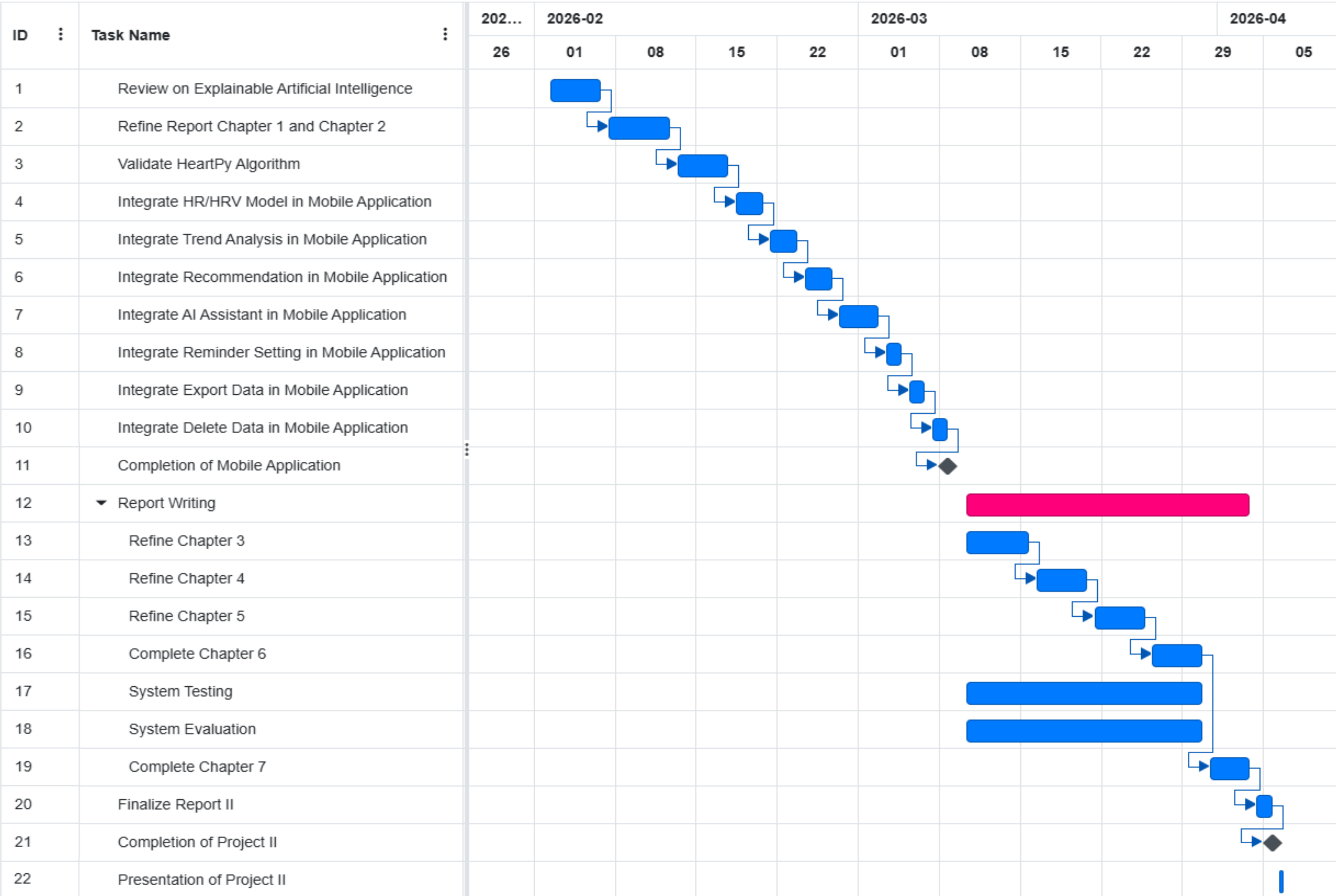


Figure 3.7.2 Gantt Chart of Project

Chapter 4
System Design

This chapter outlines the design and implementation of the proposed cardiac monitoring mobile application. A system block diagram outlines the interaction of each service involved in this project. The trained model is included and followed by the system and model flowchart. In addition, the system component specifications are presented including the tools and platforms used during the development process. The application interface wireframes design is also presented to illustrate the layout and structure of the application screens.

4.1 System Block Diagram

Figure 4.1.1 illustrates the system block diagram of the proposed cardiac monitoring application. The application is made up of several main components including the user, mobile application, backend server, machine learning models, a cloud database and an external Gemini artificial intelligence (AI) service.

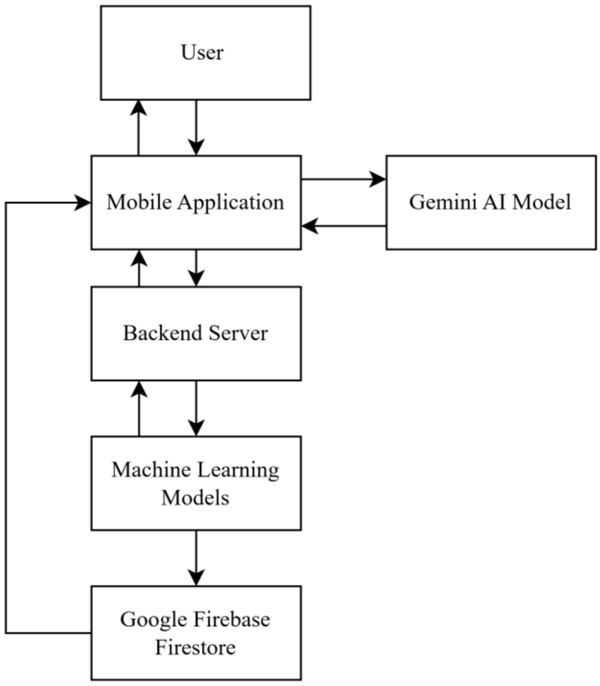


Figure 4.1.1 System Block Diagram

First, the user interacts with the mobile application and the application connects to the backend server. The backend server is primarily used to host the trained machine learning models and to handle the health measurement requests. When the user inputs their physiological data, the mobile application sends it to the backend server through the FastAPI service. Then the backend server processes the physiological data using the machine learning models and returns the measurement results to the application.

The machine learning component consists of three models including the photoplethysmography (PPG) signal quality assessment model, heart rate (HR) and heart rate variability (HRV) measurement model and the blood pressure (BP) estimation model. The PPG signal quality assessment model checks whether the input PPG signal is usable for further health measurement while the HR, HRV and BP estimation model uses the processed data to compute the user's HR, HRV and BP results.

After the measurement is completed, the results are stored in the Google Firestore database. This database acts as cloud storage which keeps the user records and the measurement history. In addition, the system also integrates the Gemini AI Model as an external service to support the chatbot-based AI assistance features. The mobile application communicates with the Gemini AI Model via the Gemini API and the AI model responds with the health insights based on the user measurement history to the application.

4.2 Dataset Chosen

Two datasets were used in this section. First, the dataset is provided by the Brno University of Technology Smartphone Photoplethysmography (PPG) Database (BUT PPG) and it is used to evaluate the PPG quality and estimate heart rate (HR) [37]. The dataset includes a total of 3888 PPG signal recordings. Each recordings around 10 seconds and is associated with the electrocardiography (ECG) signals. The PPG data were collected using smartphones which aligns with the objective of this project to develop a smartphone-based finger PPG cardiac monitoring application. In addition, the dataset includes reference blood pressure (BP) values. Therefore, the annotated HR and BP values can serve as reference measurements for estimating these parameters from PPG signals in this project.

The second dataset includes 4 columns of data including the file name, age, gender and heart rate. It also contains 51 fingertip videos and was captured using a smartphone camera with flashes in a range of 5 to 77 years of age [38]. Those videos were recorded for 20 seconds and the ground truth HR is provided using a pulse oximeter. In this project, this dataset was used to validate the performance of the PPG signal quality assessment model using the smartphone-recorded fingertip videos.

4.3 Model Selection

This section discusses the photoplethysmography (PPG) signal quality assessment model and the blood pressure (BP) estimation model selected for this project. In addition, explainable artificial intelligence (XAI) is applied in the BP model selection process to validate and analyze whether the selected model is suitable for this project.

4.3.1 Photoplethysmography (PPG) Signal Quality Assessment Model

Three photoplethysmography (PPG) signal quality assessment models including a Rule-Based classifier, a Random Forest classifier, and a Logistic Regression model with Physiological Guardrails were developed and evaluated. Table 4.3.1.1 shows a comparison of the three models. The **Logistic Regression with Physiological Guardrails model was selected** as the final model because it achieves the best overall balance across all metrics.

Table 4.3.1.1 Comparison of Three PPG Signal Quality Assessment Models

Metrics/Models	Rule-Based	Random Forest	Logistic Regression + Physiological Guardrails
Accuracy	0.79	0.83	0.81
Sensitivity (Recall)	0.01	0.42	0.13
Specificity	0.99	0.66	0.92
F1-Score	0.01	0.51	0.23
False Positive	3.00	34.00	2.00

Based on Table 4.3.1.1, the Rule-Based model achieved the highest specificity (0.99) but it almost completely failed to detect the valid signals as it achieved a sensitivity of only 0.01. Meanwhile, the Random Forest model improved the sensitivity to 0.13 but produced 34 false positives. This indicates that both models are unreliable for real-world applications.

The selected Logistic Regression with physiological guardrails model achieved an accuracy of 81%, a sensitivity of 0.13 and only 2 false positives. It strikes the best balance between correctly accepting good quality signals and rejecting the noisy ones. The model measured seven PPG signal features including basic statistical features, a spectral feature and morphological derivative features. The features are waveform skewness, peak sharpness (kurtosis), power spectrum ratio (PPR), pulse slope, waveform smoothness and acceleration consistency. Besides, median value imputation is used to handle signals that are too short or contain missing data. The dataset was split into 80% for model training and 20% for validation.

The model also applies a conservative filtering strategy in which heart rate (HR) values greater than 180 bpm or lower than 40 bpm are rejected as noise or artifacts. This is to ensure that only physiologically valid PPG segments are passed and forwarded for heart rate (HR), Heart rate variability (HRV) and blood pressure (BP) estimation. This indicates that the model prioritises signal reliability over recall which is more suitable in a real-world health monitoring application.

4.3.2 Blood Pressure Estimation Model

Two blood pressure (BP) estimation models including a Random Forest and XGBoost model were initially developed. The BP estimation model utilized the beat-specific morphological features such as pulse slope, rise time and amplitude and integrated with demographic variables such as age, gender, height and weight. These demographics serve as critical proxies for arterial compliance, enabling the model to calibrate the non-linear relationship between photoplethysmography (PPG) morphology and absolute BP. By doing so may reduce prediction errors caused by inter-subject variability in vascular stiffness. Table 4.3.2.1 shows the comparison of the developed models.

Table 4.3.2.1 Comparison of Two Blood Pressure Estimation Models

Metrics/Models	Random Forest	XGBoost
MAE (SBP/DBP)	4.00/3.29 mmHg	4.10/2.96 mmHg
SD (SBP/DBP)	5.33/4.23 mmHg	5.47/4.08 mmHg
SBP ≤ 5 mmHg	67.3%	67.5%
DBP ≤ 5 mmHg	78.4%	82.2%
SBP ≤ 10 mmHg	91.4%	91.2%
DBP ≤ 10 mmHg	96.9%	96.7%
Meet AAMI/ ISO/ BHS Standards?	Pass	Pass

Both models met the Advancement of Medical Instrumentation (AAMI), International Organization for Standardization (ISO), and British Hypertension Society (BHS) requirements which are used as a standard for a cuffless blood pressure measurement in mobile applications.

Both models achieved a very similar accuracy on the BP estimation. However, **XGBoost was selected** as the primary BP estimation model because it has a compact model size and faster inference speed than a Random Forest model [39]. Therefore, the XGBoost model is selected for the backend model and applied to the real-time cardiac monitoring applications.

4.3.2.1 Evaluation on Blood Pressure Estimation Model Using XAI

To evaluate the reliability of the XGBoost blood pressure estimation model, a global and local Explainable Artificial Intelligence (XAI) analysis was conducted using Permutation Feature Importance and Tree SHapley Additive exPlanations (TreeSHAP). For the Permutation Feature Importance, it operates on a fitted predictive model m and a tabular dataset D. It begins by computing reference scores of the model on the original data. For each feature j, the corresponding column in D is randomly shuffled across K repetitions to generate a corrupted dataset. It deliberately breaks the relationship between that feature and the target variable. The importance score for feature j is defined as:

$$i_j = s - \frac{1}{K}\sum_{k=1}^{K} s_{k,j}$$

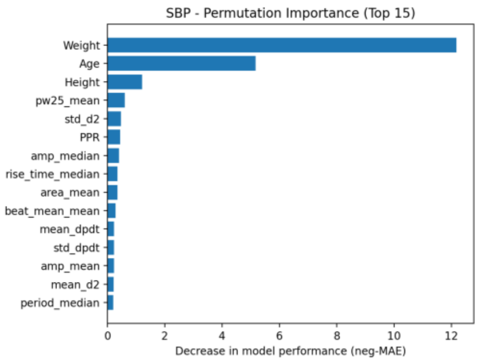
The $s_{k,j}$ is the model score evaluated on the corrupted data at repetition K. A positive i_j indicates that removing the feature's information degrades the model performance and with a larger i_j values reflecting a stronger reliance on that feature [40].

In this project, **Permutation Importance** was computed using the permutation_importance function from the scikit-learn library with $K = 10$ repetitions of the feature importance computation and negative mean absolute error (MAE) as the scoring metric. First, MAE was chosen as it is widely used in BP estimation studies because it directly quantifies absolute error in clinically interpretable units (mmHg). The MAE reflects the average absolute difference between predicted and actual BP values. The MAE is defined as:

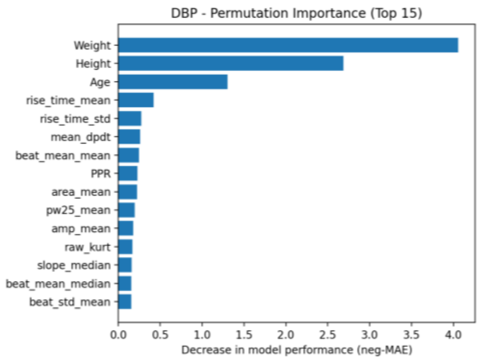
$$\mathrm{MAE}_{(y,\check{y})} = \frac{1}{n_{\mathrm{samples}}} \sum_{i=0}^{n_{\mathrm{samples}}-1} |y_i - \check{y}_i|$$

The $\check{y}_i$ represents the predicted value of the i-th sample and y_i denotes the corresponding true value [41]. Second, the negative MAE is selected as the final scoring metric as it aligns with scikit-learn's higher-is-better scoring convention. A larger negative MAE value indicates a greater drop in the model performance when the feature is removed and therefore indicates a higher feature importance.

The Permutation Feature Importance technique was applied to the XGBoost BP estimation model to determine whether the model predicts blood pressure based on photoplethysmography (PPG) waveform features or demographic variables. The results revealed that the demographic features such as weight, age and height ranked among the highest importance scores for both systolic BP (SBP) and diastolic BP (DBP) predictions as shown in Figure 4.3.2.1.1. This finding indicates that the model is not suitable for a cuffless blood pressure monitoring application as it relies predominantly on static personal attributes that carry no real-time physiological information.



(a)



(b)

Figure 4.2.3.1.1 XGBoost Permutation Feature Importance Top 15 Results (a) SBP Permutation Feature Importance; (b) DBP Permutation Feature Importance

After the global Permutation Feature Importance identified which features the model relied on, a local XAI analysis was applied to explain the individual predictions. This was implemented using the TreeSHAP technique which is a rapid and precise form of SHapley Additive ExPlanations (SHAP) that is specifically developed for tree-based models like XGBoost [42]. The SHAP breaks down how the XGBoost BP estimation model predicted a specific value for each BP reading.

According to [42], **SHAP** is grounded in cooperative game theory where each feature is treated as a "player" contributing to the final prediction. SHAP assigns a value to each feature representing its fair share of the difference between the model's prediction for a specific instance and the average prediction across all instances which is also known as the baseline. The general SHAP decomposition is defined as:

$$f(x) = \emptyset_0(f) + \sum_{i=1}^{M} \emptyset_1(f, x)$$

where the $f(x)$ denotes the model prediction for that instance, $\emptyset_0(f)$ is the baseline representing the average model output over the background dataset and $\emptyset_1(f, x)$ is the SHAP value of the feature i. A positive $\emptyset_1$ shifts the prediction higher while a negative $\emptyset_1$ pulls it lower.

In this project, the **TreeSHAP local XAI** was applied to corroborate further and strengthen the global permutation importance findings. TreeSHAP was implemented using the SHAP Python library's TreeExplainer which takes a trained XGBoost booster and a background dataset where a small subset of training data is used as a reference baseline to calculate the average model prediction as inputs. Then it computes the exact feature contributions for each sample-level explanation by traversing the model's internal decision tree paths directly and without requiring any random sampling or approximation.

```
=== Local Explanation (User-safe, technical) ===
SBP Pred: 135.0 mmHg
  Pushed up by: Weight (↑ 9.536), Gender (↑ 1.134), Height (↑ 1.015), mean_d2 (↑ 0.678), amp_median (↑ 0.483)
  Pushed down by: Age (↓ 0.682), rise_time_median (↓ 0.348), pw25_std (↓ 0.218), beat_std_std (↓ 0.207), pw25_mean (↓ 0.150)

DBP Pred: 93.2 mmHg
  Pushed up by: Age (↑ 8.948), Weight (↑ 4.648), Height (↑ 1.714), Gender (↑ 0.539), rise_time_mean (↑ 0.448)
  Pushed down by: std_d2 (↓ 0.138), period_median (↓ 0.115), amp_median (↓ 0.100), mean_dpdt (↓ 0.071), beat_std_std (↓ 0.046)
```

Figure 4.2.3.1.2 TreeSHAP local XAI Results

Figure 4.2.3.1.2 shows one sample of the local XAI explanation where both the SBP and DBP predictions where it were dominated by the demographic features. The weight alone contributed +9.536 mmHg toward SBP and +4.648 mmHg toward DBP. In contrast, the largest PPG-derived contributor for SBP was mean_d2 at +0.678 mmHg and for DBP was rise_time_mean at +0.448 mmHg. The PPG-derived contributor is having a smaller contribution than the demographic features.

This confirms that the XGBoost model is not performing genuine physiological inference from the PPG waveform but is instead functioning as a demographic-based lookup table with only marginal waveform adjustments. The convergence of global and local XAI evidence at both population and individual levels conclusively demonstrates the model's unsuitability for real-time cuffless blood pressure monitoring. Therefore, an improved XGBoost model is then proposed to address this limitation.

To address the over-reliance on demographic features identified through global and local XAI analysis, **an improved XGBoost model with Personal Calibration (K=1) was**

developed. First, a base XGBoost model was trained exclusively on the PPG-derived morphological features and removed all demographic variables from the input. This ensures that the base model learns the physiological waveform patterns rather than static personal attributes for BP estimation.

Next, a **lightweight Ridge Regression Calibrator** was fitted per user using a single reference blood pressure measurement (K=1) alongside the base model's initial prediction. Ridge Regression was selected because it has been shown to achieve smaller mean squared errors of coefficients and predictions than ordinary least squares for finite samples. It is also effective in preventing overfitting issues [43]. Therefore, with only a single calibration point available per user, regularization via the ridge penalty is essential to prevent the model from overfitting to the single reference measurement. According to [44], the ridge regression solution is defined as:

$$\beta_\lambda = (X^T X + \lambda I)^{-1} X^T y$$

The X represents the input feature matrix containing the base model's BP predictions and demographic variables while y denotes the reference blood pressure values obtained from cuff measurements. The regularization hyperparameter, λ, determines the degree of shrinkage, while I represents the identity matrix. The estimator simplifies to ordinary least squares when $\lambda = 0$. As λ rises, the coefficients gradually shrink toward zero, sacrificing an insignificant amount of bias for a considerable reduction in variance. This characteristic is useful in the $K = 1$ calibration setting because it prevents the model from overfitting to a single reference measurement.

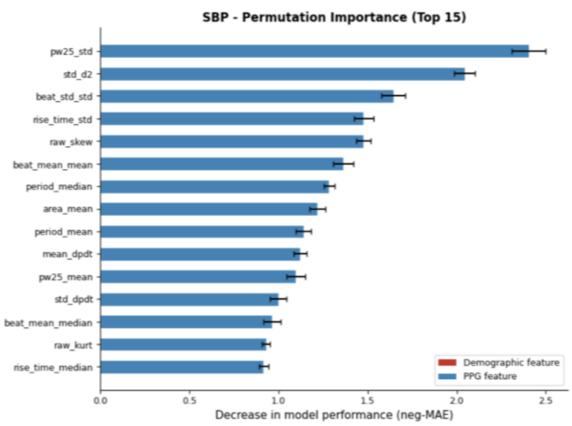
This one-shot calibration process personalizes the prediction to the individual user, thus adjusting for inter-subject variability caused by variances in vascular stiffness, arterial compliance, and cardiovascular baseline. By anchoring the prediction to the user's own measured reference point rather than the population-level demographic proxies, the calibrated model produces estimates that more genuinely reflect the individual's cardiovascular state.

The improved model was evaluated across K=0, 1, 2, and 3 calibration shots to determine the minimum number of reference readings that needed to achieve the clinically acceptable accuracy based on the AAMI and BHS standards. Table 4.3.2.1.1 displayed the comparison of the three BP estimation models with different calibration values. The results showed that $K = 0$ indicates lower error values as it does not provide any personalization. As K increases, the model becomes more personalized but may introduce higher variance due to limited calibration samples. When K = 1, it achieves a good balance between accuracy, practicality and also satisfies the cuffless BP estimation standards. Therefore, K = 1 is selected as the optimal configuration for the BP estimation model.

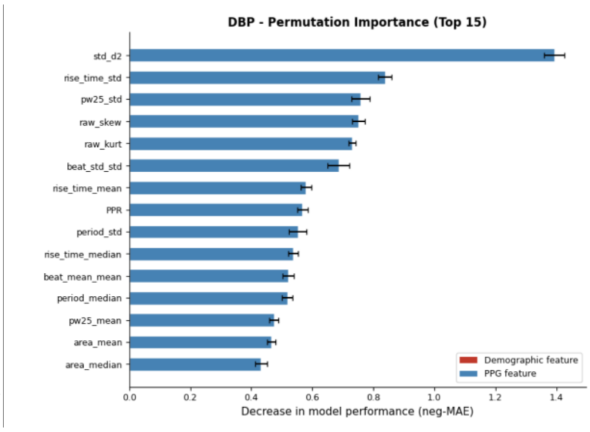
Table 4.3.2.1.1 Comparison of Three BP Estimation Models with Different Calibration Values

Metrics/Calibrations	K =0	K =1	K =2	K =3
SBP MAE	1.69 mmHg	4.30 mmHg	4.42 mmHg	4.64 mmHg
DBP MAE	1.06 mmHg	3.12 mmHg	3.25 mmHg	3.40 mmHg
SBP ≤ 5 mmHg	94.9%	68.4%	67.3%	65.7%
DBP ≤ 5 mmHg	99.8%	75.4%	74.7%	73.4%

Lastly, a **global permutation importance analysis** was conducted to verify that the improved model no longer exhibits demographic dependency in its BP estimation. As shown in Figure 4.2.3.1.3, the results show a clear contrast with the original XGBoost model. For both SBP and DBP, all top 15 features are exclusively PPG-derived morphological features with no demographic features appearing anywhere in the rankings. This confirms that the calibrated model has successfully shifted its reliance away from static personal attributes and toward the physiologically meaningful waveform characteristics.



(a)



(b)

Figure 4.2.3.1.3 XGBoost with Personal Calibration Permutation Feature Importance Top 15 Results (a) SBP Permutation Feature Importance; (b) DBP Permutation Feature Importance

Then, a **TreeSHAP local XAI analysis** was performed to further confirm how the improved XGBoost BP estimation model predicts BP values. Figure 4.2.3.1.4 shows the results. The predicted systolic BP (SBP) is 118.3 mmHg while the predicted diastolic BP (DBP) is 75.1 mmHg.

```
=== Local Explanation (User-safe, technical) ===
SBP Pred: 118.3 mmHg
  Pushed up by: mean_d2 (↑ 0.468), area_mean (↑ 0.449), amp_std (↑ 0.360), period_mean (↑ 0.337), beat_std_std (↑ 0.318)
  Pushed down by: amp_median (↓ 1.469), rise_time_median (↓ 1.148), std_d2 (↓ 1.068), period_median (↓ 0.713), pw25_mean (↓ 0.387)

DBP Pred: 75.1 mmHg
  Pushed up by: beat_std_median (↑ 0.303), rise_time_mean (↑ 0.259), slope_median (↑ 0.249), raw_skew (↑ 0.249), amp_mean (↑ 0.238)
  Pushed down by: beat_std_mean (↓ 0.423), period_mean (↓ 0.204), pw25_mean (↓ 0.175), beat_mean_mean (↓ 0.153), std_dpdt (↓ 0.144)
```

Figure 4.2.3.1.4 TreeSHAP local XAI Results on Improved XGBoost BP Estimation Model

The local XAI analysis revealed that the top contributor **pushing up the SBP** is mean_d2 which represents the mean of the second derivative of the PPG signal. According to [45], the second derivative of the PPG signal is highly related to arterial stiffness and aortic compliance which directly influences SBP. Therefore, higher vascular stiffness is associated with a higher SBP. The second contributor pushing up SBP is area_mean which represents the mean area under the PPG beat. As stated in [46], a larger pulse area indicates greater blood volume per beat and leading to a higher pressure value.

Besides, the contributors **pushing down the SBP** are amp_median and rise_time_median. The amp_median represents the median peak-to-trough amplitude of the PPG waveform across all beats. A higher amp_median reflects more elastic and compliant vessels. According to [47], stiffer vessels produce a smaller PPG amplitude but higher SBP. This indicates the inverse also holds where greater vessel elasticity produces a larger PPG amplitude and lower SBP. Therefore, a higher amp_median is associated with lower SBP. The rise_time_median represents the median time from the PPG trough to the systolic peak. A longer rise time implies a slower ventricular ejection and leads to a lower SBP [48].

For DBP, the main contributors **pushing up the DBP** are beat_std_median and rise_time_mean. The beat_std_median captures the median of the standard deviation of amplitude values computed within each individual PPG beat, reflecting the overall pulsatility and morphological variability of the waveform. According to [49], the amplitude of the systolic peak in the PPG waveform is linked to stroke volume, while the diastolic decay is influenced by vascular resistance and compliance. Therefore, a waveform with higher amplitude variability that is captured by a higher beat_std_median corresponds to a more active cardiovascular state, which is associated with higher diastolic pressure.

The rise_time_mean represents the average time from the PPG trough to the systolic peak across all beats. According to [50], PPG upstroke time intervals such as the systolic upstroke time (STT) have been shown to improve diastolic BP prediction accuracy. This confirms that rise time is a physiologically meaningful feature for DBP estimation.

For the contributors **pushing down the DBP**, the main contributors are beat_std_mean and period_mean. The period_mean represents the average duration of one complete PPG beat cycle which is inversely related to heart rate. A longer period means a slower heart rate. According to [51], the arterioles control the pace of diastolic runoff in the arterial tree, whereas energy conserved during systole is used to perfuse the capillary beds during diastole. Therefore, a longer period_mean results in greater diastolic runoff and a lower DBP. The beat_std_mean represents the mean of the standard deviation of amplitude values within each beat across all beats. A lower beat_std_mean indicates more uniform and less pulsatile beats. This reflects a lower peripheral vascular resistance and resulting in a lower DBP [52].

Table 4.3.2.1.2 Comparison of Three BP Estimation Models

Metrics/Models	Random Forest	XGBoost	XGBoost + Personal Calibration (K=1)
MAE (SBP/DBP)	4.00/3.29 mmHg	4.10/2.96 mmHg	4.30/3.12 mmHg
SD (SBP/DBP)	5.33/4.23 mmHg	5.47/4.08 mmHg	7.39/5.39 mmHg
SBP ≤ 5 mmHg	67.3%	67.5%	68.4%
DBP ≤ 5 mmHg	78.4%	82.2%	75.4%
SBP ≤ 10 mmHg	91.4%	91.2%	81.1%
DBP ≤ 10 mmHg	96.9%	96.7%	90.4%
Meet AAMI/ ISO/ BHS Standards?	Pass	Pass	Pass
Calibration needed?	No	No	Yes (1 reading)

4.4 System Flowchart

Figure 4.4.1 illustrates the system operation flowchart which mainly focuses on the full scan process that includes measuring the heart rate (HR), heart rate variability (HRV) and blood pressure (BP). The system begins with the mobile application which combines the computer vision techniques by initializing the camera sensor and LED flash to capture the user's fingertip photoplethysmography (PPG) signal.

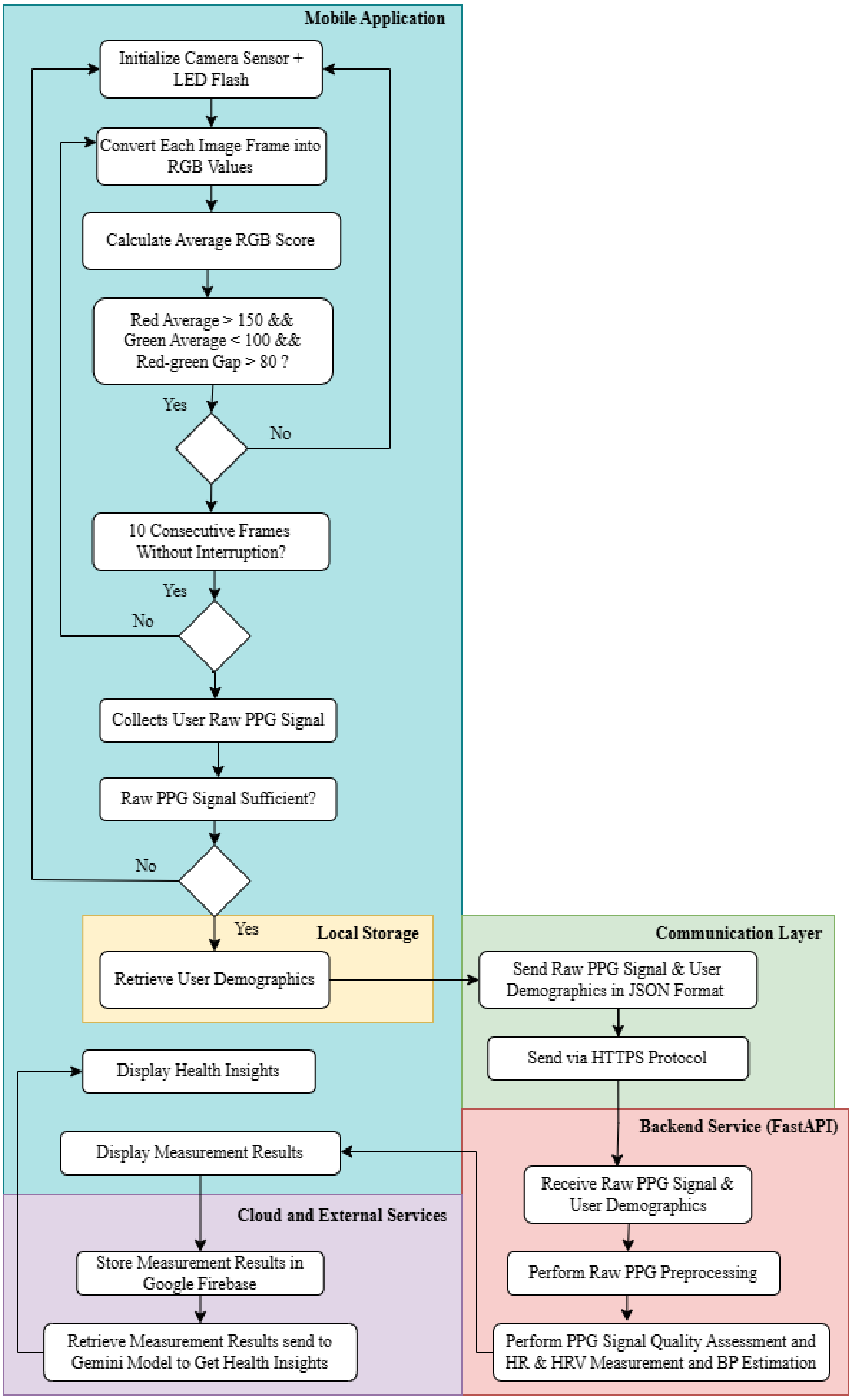


Figure 4.4.1 System Flowchart Diagram

The captured frames are then processed into Red, Green, and Blue (RGB) values and the average red and green brightness across the entire frame is calculated. When the fingertip is placed over the flash, the backlit blood tissue produces a distinctively high red average, as blood reflects red light strongly, while producing a low green average, as haemoglobin absorbs green light [53]. Therefore, a validation check is performed and requires the red average to exceed 150, the green average to remain below 100 and the red-green gap to exceed 80. If all three conditions are satisfied across 10 consecutive frames without any interruption, the fingertip is confirmed as properly positioned and the system proceeds to PPG signal collection. If any single frame fails the checking, the user is prompted to reposition.

The system then evaluates whether the raw PPG signal is sufficient for further processing. If the signal quality is poor, the user is prompted to reposition their finger and repeat the measurement. If the signal is acceptable, the application retrieves the user's demographic information from the local storage and sends it with the PPG signal to the backend server in JavaScript Object Notation (JSON) format via a secure HyperText Transfer Protocol Secure (HTTPS) protocol.

At the backend, the received data undergoes preprocessing to clean the PPG data before being passed to the machine learning models. These models perform PPG signal quality assessment, HR, HRV measurement and BP estimation. The generated results are then returned to the mobile application.

The application displays the measurement results to the user and stores the results in Google Firebase for future reference. Additionally, the stored data can be sent to the Gemini model to generate personalized health insights or to answer any health-related questions based on the user's health measurement records. The Gemini model generated answers are then returned and displayed in the application.

4.4.1 Photoplethysmography (PPG) Signal Quality Assessment Model Flowchart

Figure 4.4.1.1 illustrates the photoplethysmography (PPG) signal quality assessment pipeline. The process begins with reading the raw PPG data that is sent from the mobile application and extracts the signal quality features such as shape statistics and the power ratio in the physiological band. The extracted signal features are then passed to the Logistic Regression model which is discussed in Chapter 4.3.1 and produces a confidence score. If the score falls below the threshold of 0.80, the PPG signal is immediately rejected as poor quality.

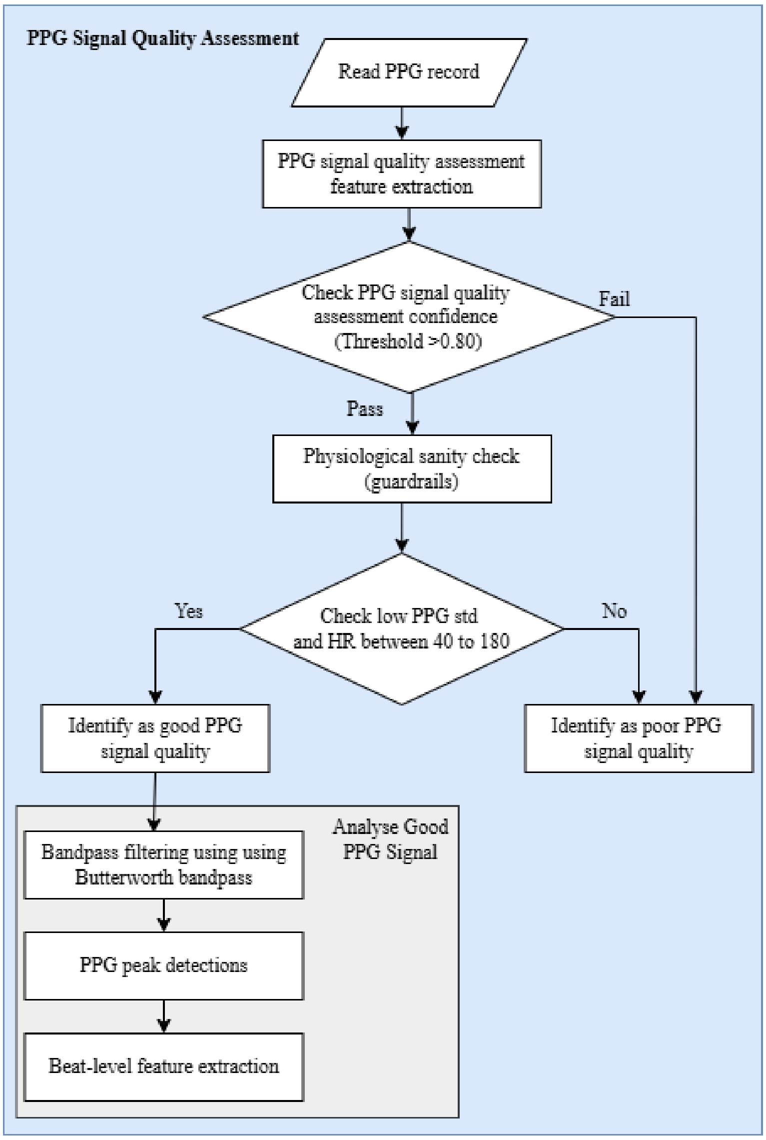


Figure 4.4.1.1 PPG Signal Quality Assessment Flowchart

If the PPG signal passes the confidence check, it proceeds to the physiological guardrails check where two additional sanity checks are applied. The conditions are that the PPG standard deviation must be sufficiently low and the estimated heart rate must fall within the physiologically valid range of 40 to 180bpm. The signals that satisfy both conditions are classified as good quality.

The good quality signal is then forwarded for further analysis including the bandpass filtering using a Butterworth filter, PPG peak detection and beat-level feature extraction. The signals that fail either guardrail condition are rejected as poor quality and discarded. These validations ensure that only aclean physiologically plausible PPG segments are used for heart rate (HR), heart rate variability (HRV) and blood pressure (BP) measurement. It also minimises the risk of inaccurate predictions caused by motion artefacts or sensor noise.

4.4.2 Blood Pressure Estimation Model Flowchart

Figure 4.4.2.1 illustrates the blood pressure (BP) estimation pipeline for the mobile application. The process begins with reading the user's photoplethysmography (PPG) signal data which is already passed through the PPG signal quality assessment model. If the signal is classified as poor quality, the application displays an error message of “Weak PPG Signal insufficient for BP estimation” and prompts the user to repeat the measurement.

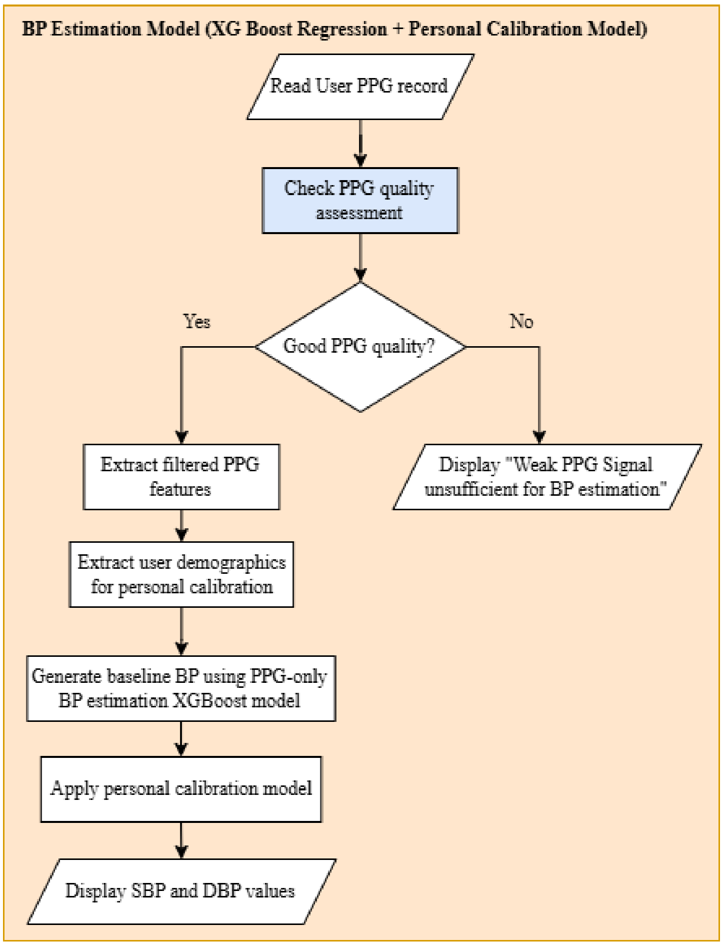


Figure 4.4.2.1 Blood Pressure Estimation Model Flowchart

If the signal passes the quality check, the filtered PPG morphological features are extracted with the user's demographic data. This serves as the personal calibration input. The filtered PPG data inputs are first passed to the XGBoost model to generate a baseline BP estimate. The personal calibration model then adjusts the baseline prediction according to the individual user's physiological characteristics and produces the final systolic BP (SBP) and diastolic BP (DBP) values. In this project, combining a global PPG-based model with a personal calibration layer ensures that the final BP estimation output is tailored to the individual rather than relying solely on population-level patterns.

4.5 System Components Specifications

This section describes the tools and platforms used to develop the proposed cardiac monitoring application. It discusses the mobile application platforms and the backend services used in this project.

4.5.1 Mobile Application Platforms

The mobile application is developed using **Flutter** which is an open-source framework that supports cross-platform application development. Flutter enables the system to be built using a single codebase while providing a responsive and user-friendly interface. It is used to implement the main functionalities of the system, including data input and result visualization. Furthermore, **Android Studio** serves as the development environment for building and evaluating mobile applications. It includes tools for coding, debugging, and launching the application on Android devices.

4.5.2 Backend Services

The mobile application communicates with the backend server using **FastAPI.** When the user records their photoplethysmography (PPG) signals, the data is formatted in **JSON** (JavaScript Object Notation) and sent to the backend server through hypertext transfer protocol **(HTTP) requests**. The backend server then processes the data and returns the prediction results which are also in JSON format and displayed in the application. The backend system is implemented using **Python** and deployed using the **FastAPI service** on **Render** which the cloud hosting platform. Figure 4.5.2.1 shows the screenshot of the model that was deployed in the Render.

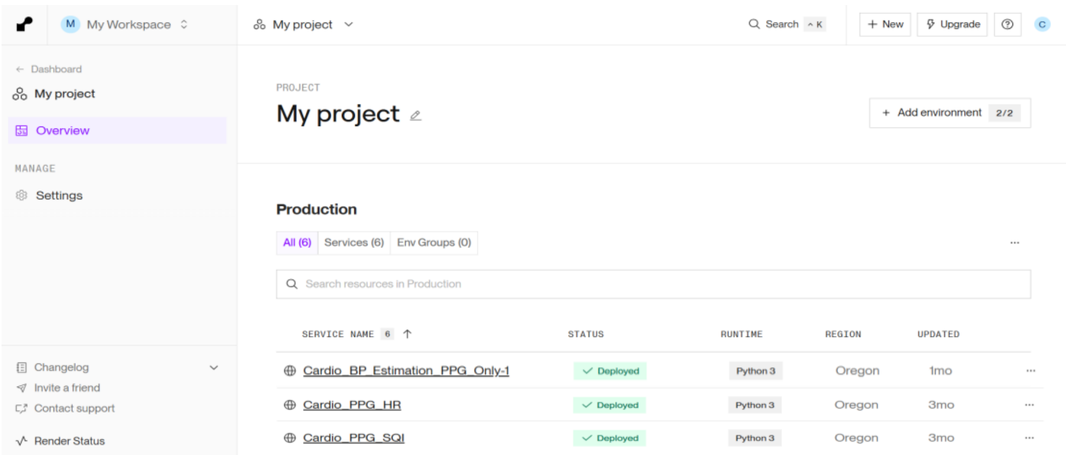


Figure 4.5.2.1 Render Dashboard

The machine learning models are trained and tested using **Google Colab**. **GitHub** is used to manage the project code and support the project deployment. In addition, **Google AI Studio** is integrated in this project to enable the artificial intelligence chatbot-based AI features that analyse users' health insights. Figure 4.5.2.2 shows the API key generated in the Google AI Studio.

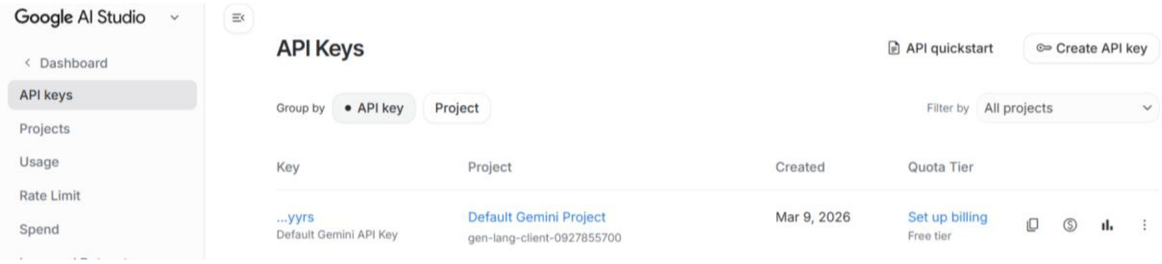


Figure 4.5.2.2 Google AI Studio Dashboard

Next, **Google Firebase** was used for user authentication and the **Firestore Database** is to store the user's information. Figure 4.5.2.3 shows the Firebase authentication dashboard that manages the user account.

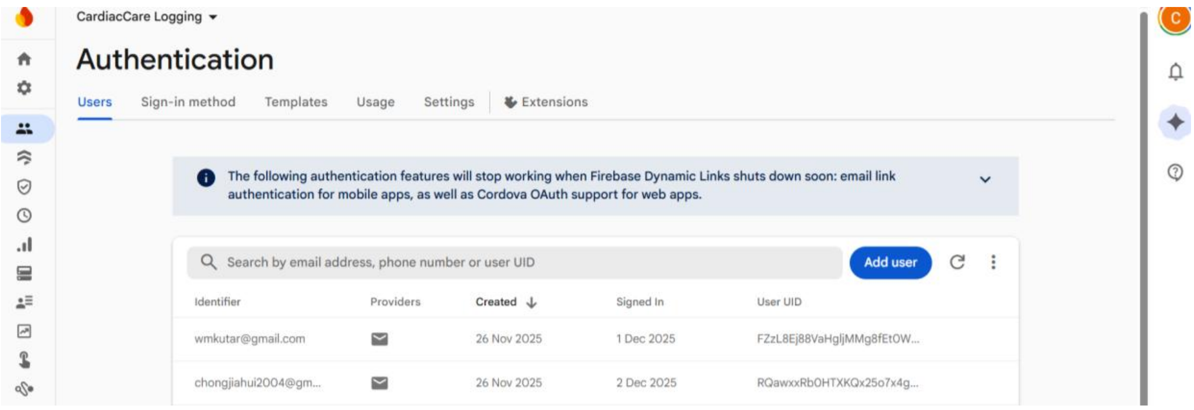


Figure 4.5.2.3 Google Firebase Dashboard on User's Authentication

Figure 4.5.2.4 shows the NoSQL database implementation using Google Firestore. It stores the user's personal information, measurement results and the AI assistant chat history.

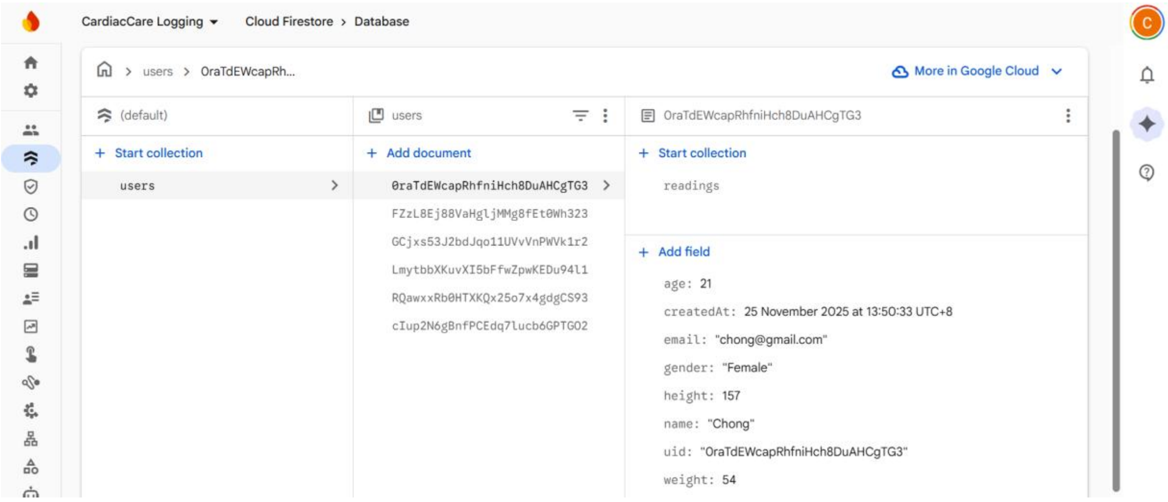


Figure 4.5.2.4 Google Firebase Dashboard on User's Information

4.6 Database Specification and Data Dictionary

The data is managed using Google Firebase Firestore collections. The tables below describe all collections and followed by a detailed data dictionary that explains each collection.

Table 4.6.1 Collection Description Table

Collection	Description
users	Stores all users' details, including login information.
readings	Stores all users' health measurements including heart rate (HR), heart rate variability (HRV), blood pressure (BP) estimation and recorded BP.
cardiac_chats	Stores the AI assistant chat data organized by user. The user's uid identifies each document.
messages	Stores individual chat messages

4.6.1 Data Dictionary for users collection

Table 4.6.1.1 describes the data dictionary for the users collection which is mainly used to store the user's personal information.

Table 4.6.1.1 Data Dictionary for users collection

Attribute	Description	Data Type	Nullable	Example Values
uid	Unique identifier assigned to each user	string	No	GCjxs53J2bdJqo11UVvVnPWVk1r5
name	User's full name	string	No	Alex
createdAt	Date and time when the user account was created	timestamp	No	26 November 2025 at 15:20:33 UTC+8
email	User's email address	string	No	alex@email.com
age	User's age in years	int64	No	20
gender	User's gender	string	No	Male
height	User's height in centimeters (cm)	double	No	180
weight	User's weight in kilograms (kg)	double	No	70

4.6.2 Data Dictionary for readings collection

Table 4.6.2.1 describes the data dictionary for the readings collection which is mainly used to store the user's health measurement readings.

Table 4.6.2.1 Data Dictionary for readings collection

Attribute	Description	Data Type	Nullable	Example Values
uid	Unique identifier assigned to each user	string	No	GCjxs53J2bdJqo11UVvVnPWVk1r5
timestamp	Date and time when the user measurement was recorded	timestamp	No	26 November 2025 at 15:20:33 UTC+8
type	Types of measurements recorded include heart rate (HR), heart rate variability (HRV), blood pressure estimation (BP), blood pressure recording (BP_LOG) and full scan (FULL_SCAN)	string	No	FULL_SCAN
hr	User's heart rate measurement	int64	Yes	80
hrv	User's heart rate variability measurement	double	Yes	160.03
diastolic	User's diastolic blood pressure estimation	int64	Yes	120
systolic	User's systolic blood pressure estimation	int64	Yes	70
notes	User's notes for recording the actual blood pressure readings	string	Yes	Testing

4.6.3 Data Dictionary for caridac_chats collection

Table 4.6.3.1 describes the data dictionary for the cardiac chats collection which is mainly used to store the assigned user's ID for each chat session.

Table 4.6.3.1 Data Dictionary for caridac_chat collection

Attribute	Description	Data Type	Nullable	Example Values
uid	Unique identifier of the user associated with the chat	string	No	GCjxs53J2bdJqo11UVvVnPWVk1r5

4.6.4 Data Dictionary for messages collection

Table 4.6.4.1 describes the data dictionary for the messages collection which is mainly used to store the chatbot-based AI assistant messages.

Table 4.6.4.1 Data Dictionary for messages collection

Attribute	Description	Data Type	Nullable	Example Values
role	Role of the sender (user or model)	string	No	user
time	Date and time when the message was sent	timestamp	No	26 November 2025 at 15:20:33 UTC+8
text	Message content in the chatbot	string	No	Heart health overview

4.7 Application Interface Design

This section presents the wireframes of the mobile application interfaces. Figure 4.7.1 to 4.7.4 and Appendix A, Figure A.3.1 to A.3.20 present the wireframes illustrating the layout and structure of each application screen.

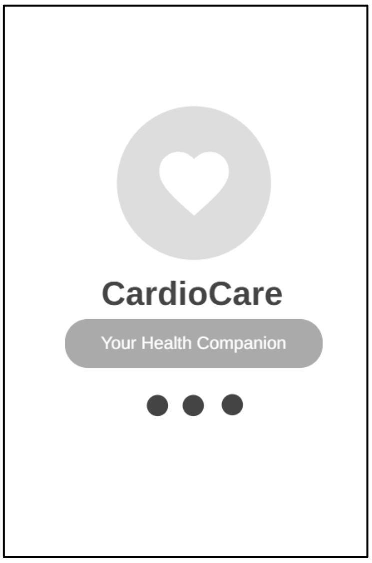


Figure 4.7.1 Boarding Page Prototype

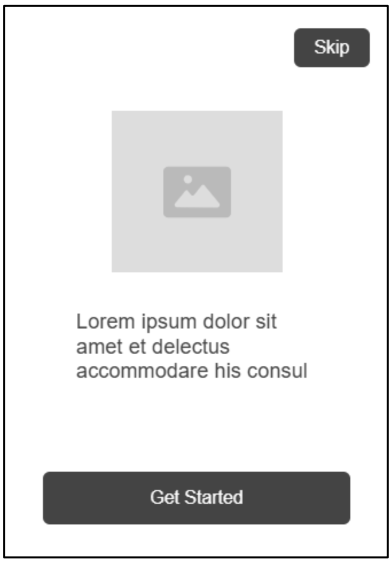


Figure 4.7.2 Welcome Page Prototype

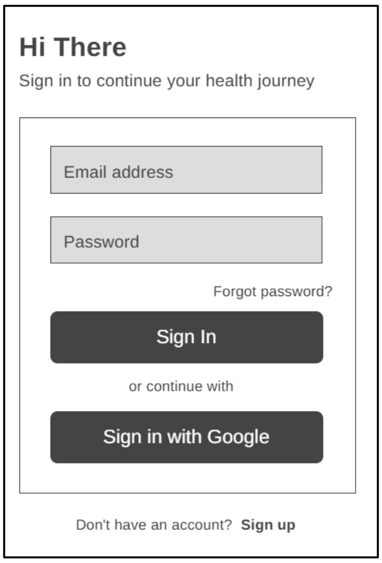


Figure 4.7.3 Login Page Prototype

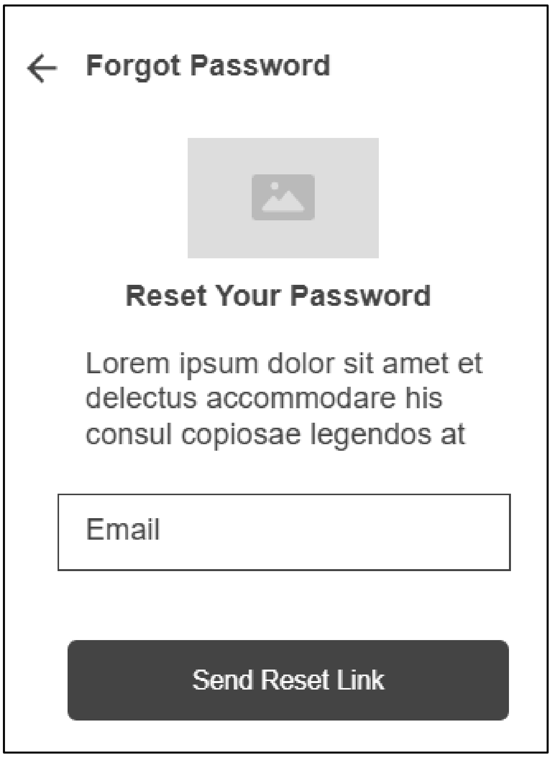


Figure 4.7.5 Forgot Password Page Prototype

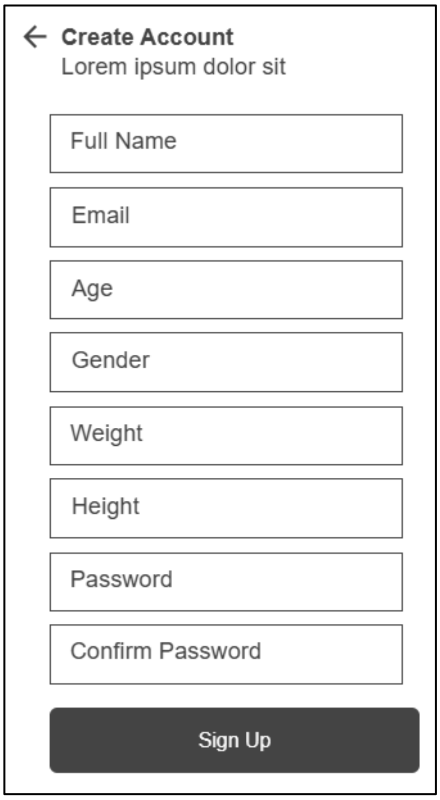


Figure 4.7.4 Sign Up Page Prototype

Chapter 5
System Implementation

In this chapter, the project implementation is discussed in detail. A cardiac monitoring mobile application named CardioCare has been developed. First, the hardware and software setup is presented along with the configuration required to deploy and run the application. The installation and setup steps are also included. In addition, the application operation is described in detail for each function together with the corresponding application interface.

5.1 Hardware Setup

The hardware used in this project consists of a laptop, an Android mobile device and a smartwatch. The laptop is used for system development tasks, including dataset preparation, model training, algorithm integration, and backend application programming interface (API) deployment. It also serves as the platform for coding, debugging, and preliminary testing. Table 5.1.1 shows the specifications of the laptop used for this project.

Table 5.1.1 Specifications of Laptop

Description	Specifications
Model	Dell Latitude 3420
Processor	Intel Core i7-1165G7
Operating System	Windows 11
Graphics Processing Unit (GPU)	NVIDIA GeForce MX450, 2 GB
Random-Access Memory (RAM)	8GB RAM
Storage	376GB SSD

An Android mobile device is used to deploy and test the application on a physical smartphone. It mainly serves for testing the application during the project development. Table 5.1.2 shows the specifications of the Android Mobile Devices.

Table 5.1.2 Specifications of Android Mobile Device

Description	Specifications

Model	Huawei Mate 10 (ALP-L29)
Processor	HiSilicon Kirin 970
Operating System	Android 12
Memory	4 GB
Storage	64 GB
Main Camera	Dual 12 MP + 20 MP
Video Recording	4K (2160p) at 30 fps, 1080p at 30/60 fps

A smartwatch is used as a reference device to validate the heart rate (HR) monitoring algorithm during the project review. Table 5.1.3 shows the specifications of the smartwatch.

Table 5.1.3 Specifications of Smartwatch Device

Description	Specifications
Model	Apple Watch SE
Processor	S8 SiP with 64-bit dual-core processor.
Operating System	watchOS 26.3
Sensors	Second-generation optical heart sensor, Compass, Always-on altimeter, High-g accelerometer, Gyroscope, Ambient light sensor.

5.2 Software Setup

A variety of software tools and technologies were needed to support the development process in order to develop the system. The frontend of the application was developed using Flutter version 3.38.3 with Dart version 3.10.1 as the programming language. Android Studio version 21.0.6 was used to run and debug the application on a physical Android smartphone. The backend relied on Google Firebase services including Firebase Authentication and Cloud Firestore.

In addition, Visual Studio Code was used as the primary code editor. Google Colab was used as the model training platform for the PPG signal quality assessment model, as well as the heart rate (HR), heart rate variability (HRV) and blood pressure (BP) estimation models. The models were developed using the Python programming language with the supporting libraries such as FastAPI, NumPy, SciPy, Pandas, Pydantic, and HeartPy. JavaScript Object

Notation (JSON) format was used as the data interchange format while HyperText Transfer Protocol (HTTP) was used as the communication protocol between the application and backend services.

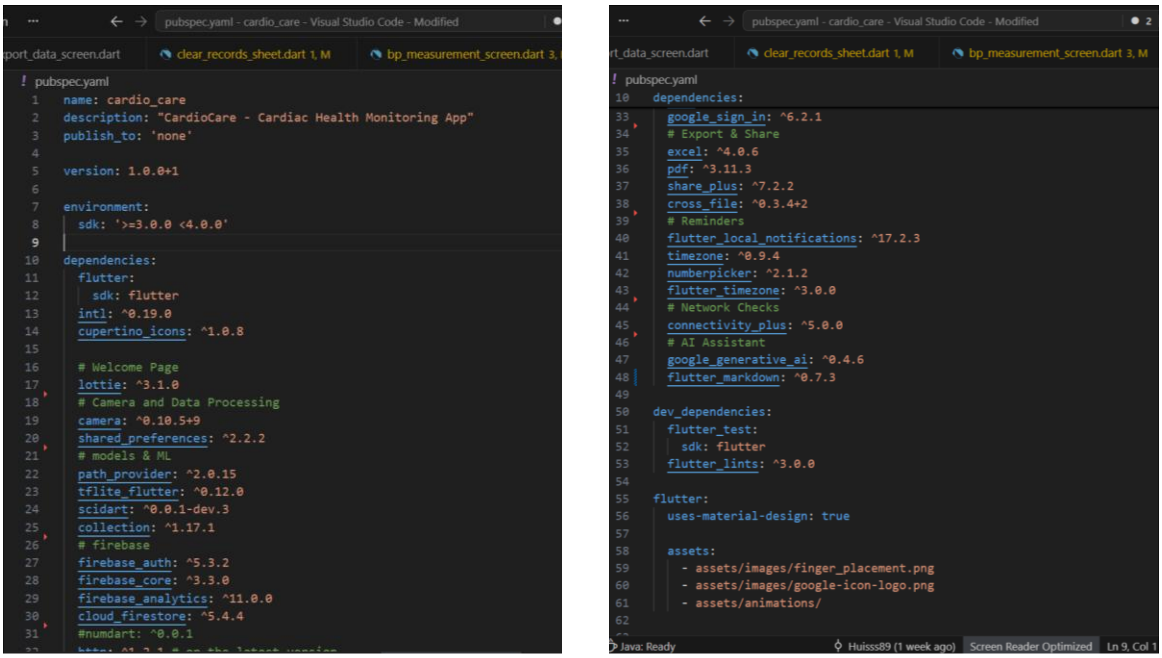
Additionally, Render was used to host the models while Google AI Studio was used to integrate the Gemini AI model for the AI assistant chatbot feature. The project was managed and deployed using GitHub with version control handled using Git version 2.51.2.

5.3 Setting and Configuration

This section describes the setup and configuration process required to deploy and execute the developed cardiac monitoring mobile application, CardioCare. It outlines the installation procedures, environment configuration and execution steps.

5.3.1 Application Dependency Configuration

Figure 5.3.1.1 displays the "pubspec.yaml" configuration for the CardioCare application. This file is mainly used to manage the application's dependencies, assets and environment settings required for development. The configuration includes the application metadata, SDK environment constraints and various dependencies for features such as UI design, camera input, machine learning processing, Firebase services, data export, reminders, network connectivity, AI integration and asset management.



(a) (b)

Figure 5.3.1.1 Pubspec.yaml Configuration: (a) to (b) Configuration Code

5.3.2 Application Permission Configuration

Figure 5.3.1.2 displays the permission configuration for the CardioCare application. It is mainly used to allow access to the camera, flashlight, notifications, alarm features and internet connectivity.

```xml
    <uses-sdk
        android:minSdkVersion="24"
        android:targetSdkVersion="36" />
    <!--
         The INTERNET permission is required for development. Specifically,
         the Flutter tool needs it to communicate with the running application
         to allow setting breakpoints, to provide hot reload, etc.
    -->
    <uses-permission android:name="android.permission.INTERNET" />
    <!-- Add permissions -->
    <uses-permission android:name="android.permission.CAMERA" />
    <uses-permission android:name="android.permission.POST_NOTIFICATIONS" />
    <uses-permission android:name="android.permission.SCHEDULE_EXACT_ALARM" />
    <uses-permission android:name="android.permission.FLASHLIGHT" />

    <uses-feature
        android:name="android.hardware.camera"
        android:required="false" />
    <uses-feature
        android:name="android.hardware.camera.flash"
        android:required="false" />
```

Figure 5.3.1.2 AndroidManifest.xml Configuration

5.3.3 Application Installation and Setup

The developed cardiac monitoring mobile application, CardioCare project is hosted on GitHub and can be accessed through the following repository: https://github.com/Huisss89/CardioCare. To begin the setup process, the repository is first cloned into the local development environment using Git. After cloning, the project is opened using Visual Studio Code and accessing the project directory to continue with the configuration steps.

Before executing the application, Firebase must be configured to enable the authentication and database services. First, create a new project in the Firebase Console using the following link: https://console.firebase.google.com/u/0/. Then select the "Settings" icon and click the "General" tab in the Firebase console as shown in Figure 5.3.3.1.

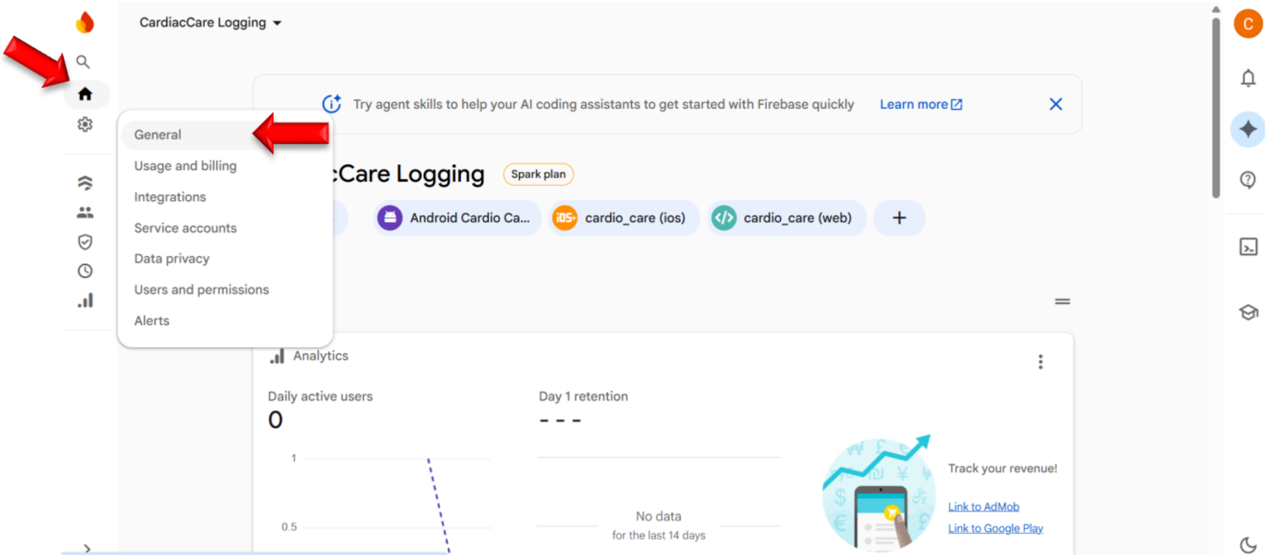


Figure 5.3.3.1 Firebase Configuration to Download JSON file

Next, download the "google-service.json" file as shown in Figure 5.3.3.2 and place it into the android/app/ directory of the CardioCare project. This configuration allows the application to connect to the Firebase services correctly. In addition, the SHA-1 and SHA-256 fingerprints must be added in the Firebase Console to enable the authentication features.

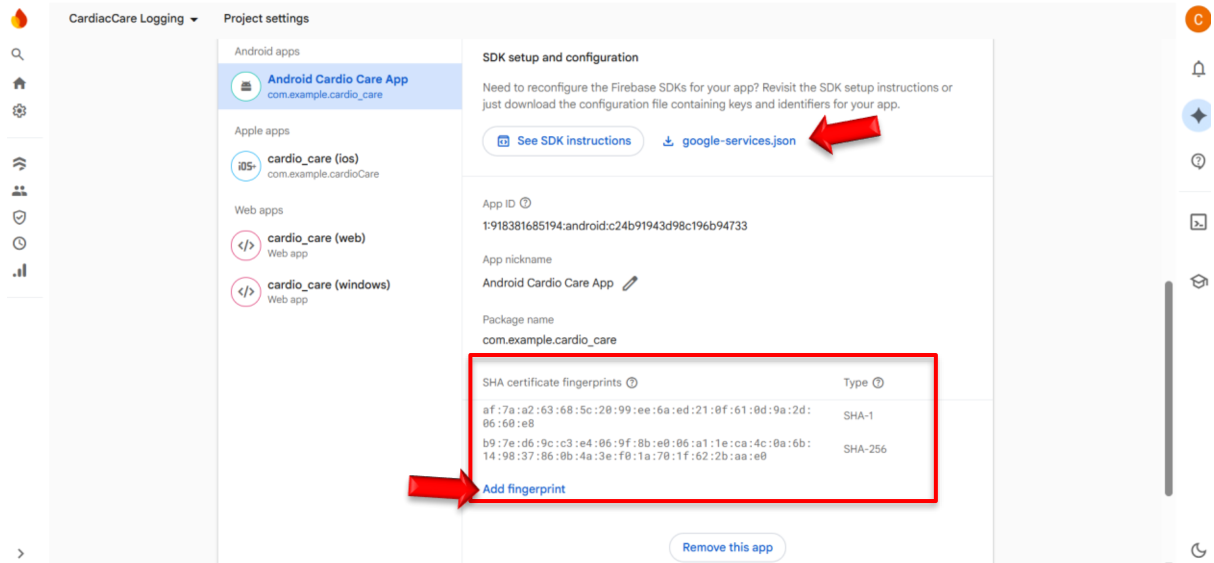


Figure 5.3.3.2 Firebase Configuration to Add SHA Fingerprint

To generate the fingerprints, open the command prompt and navigate to the CardioCare project's Android directory. Then execute the command "gradlew signingReport" and the output is displayed in Figure 5.3.3.3. Copy the SHA1 and SHA-256 values and add them to the Firebase setting by selecting the "Add fingerprint" option as shown in Figure 5.3.3.2.

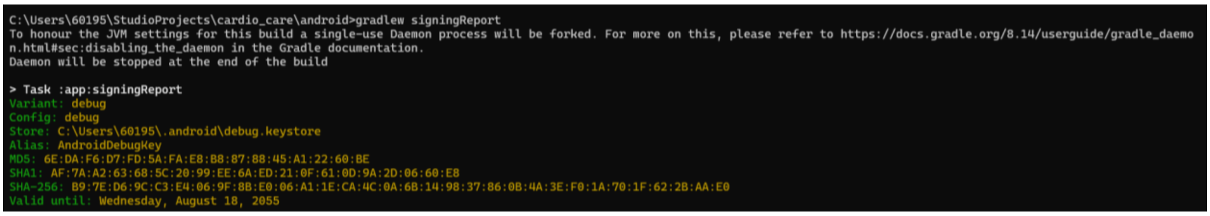


Figure 5.3.3.3 Generate SHA fingerprint

Next, a physical Android device is connected to the computer using a USB cable while Android Studio is used to ensure that the device is properly detected and ready for deployment. This step allows the application to be tested directly on a real device. Then, the Google AI Studio setup is performed by generating an API key using the available free tier. This API key is required for the AI chatbot assistant features in the application.

Once all configurations are completed, execute the command “flutter pub get” in Visual Studio Code to install the required Flutter dependencies. Lastly, the application is run using the command "flutter run --dart-define=GEMINI_API_KEY=your_api_key_here" where the API key is replaced with the previously generated Gemini API key value.

5.3.4 License

The developed CardioCare application is distributed under the MIT License. The MIT License is selected as it permits users to freely use, modify, and distribute the software with minimal restrictions. This license allows both academic and commercial use and it provides a proper attribution to the original author. As a result, the inclusion of this license ensures that the project remains open and accessible while protecting the rights of the author.

5.4 System Operation

In this section, the developed CardiaCare application is presented. Each page will be displayed and explained with a brief description.

Welcome Page

The welcome page is displayed when the user opens the CardioCare application, as shown in Figure 5.4.1. The application name CardioCare is presented with the slogan of “Your Health Companion”. The application automatically navigates to the next page after 3 seconds.

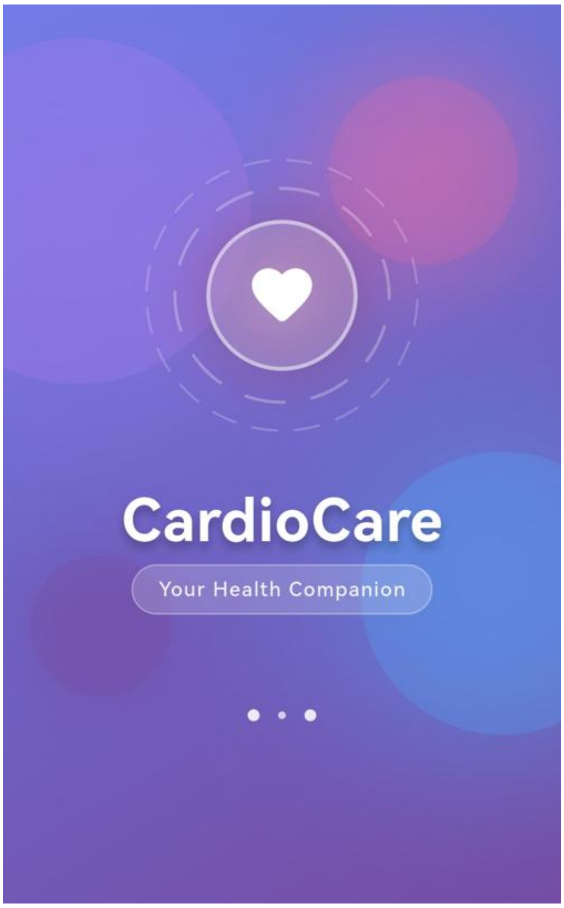
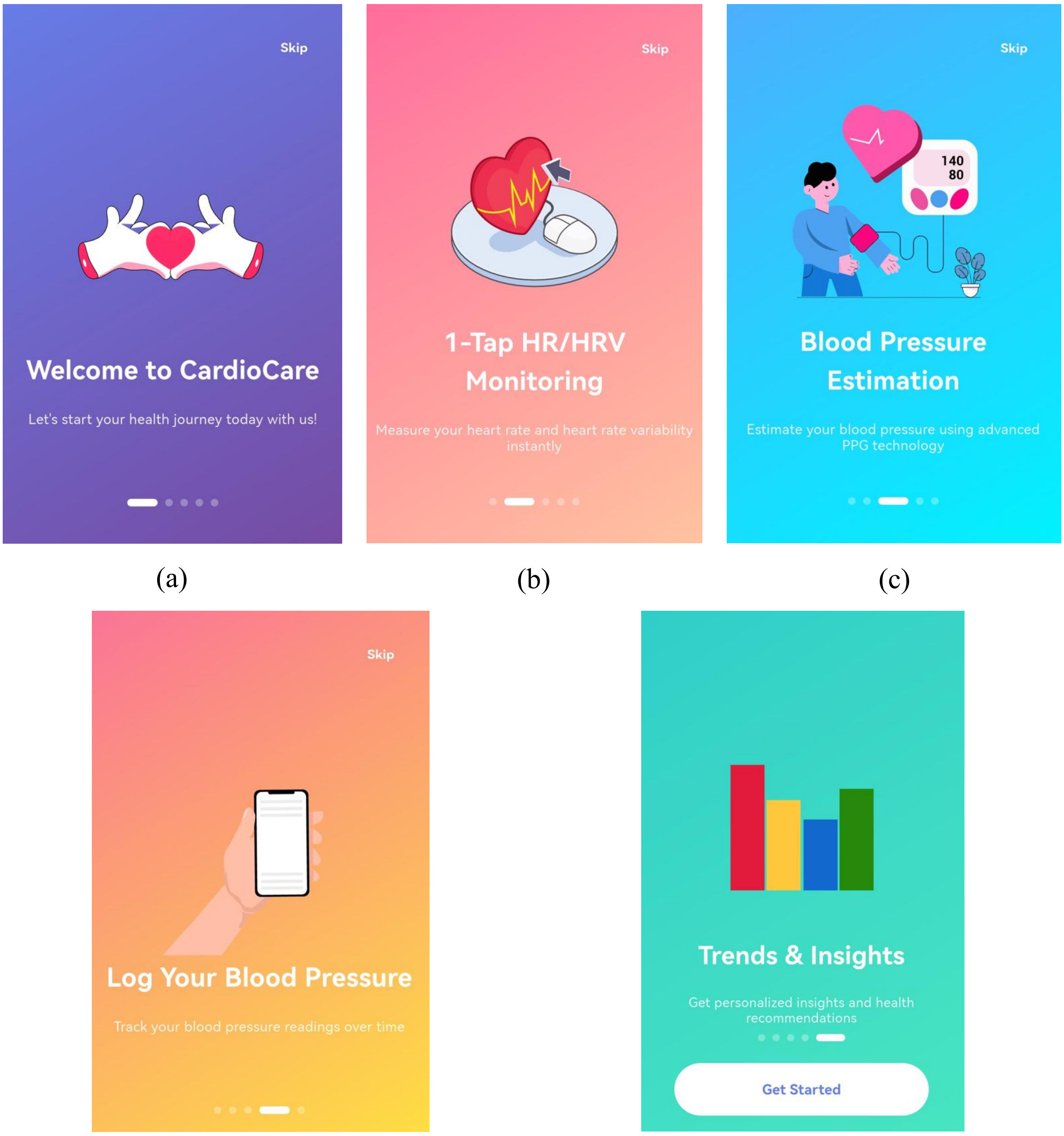


Figure 5.4.1 Welcome Page

Onboarding Page

When the application is launched for the first time, the onboarding Page appears as shown in Figure 4.6.1. It introduces the main features of the application including heart rate (HR) and heart rate variability (HRV) measurement, blood pressure (BP) estimation, BP logging and viewing health trends and insights. Users can swipe through the pages or tap the “Skip” button to proceed to the Login Page. If the app has been launched previously, the onboarding page will not be displayed.



(a) (b) (c)

(d) (e)

Figure 5.4.2 Onboarding Page: (a) to (e) Displaying Each Onboarding Page

Login Page

Figure 5.4.3 shows the Login Page, which allows users to sign in using a registered account or sign in with a Google account. When the user selects the sign in using Google account option, the application prompts the user to choose a preferred Google account to proceed as shown in Figure 5.4.4. The user can also sign up for a new account or reset their password by clicking the “Forgot password” button if they have forgotten it.

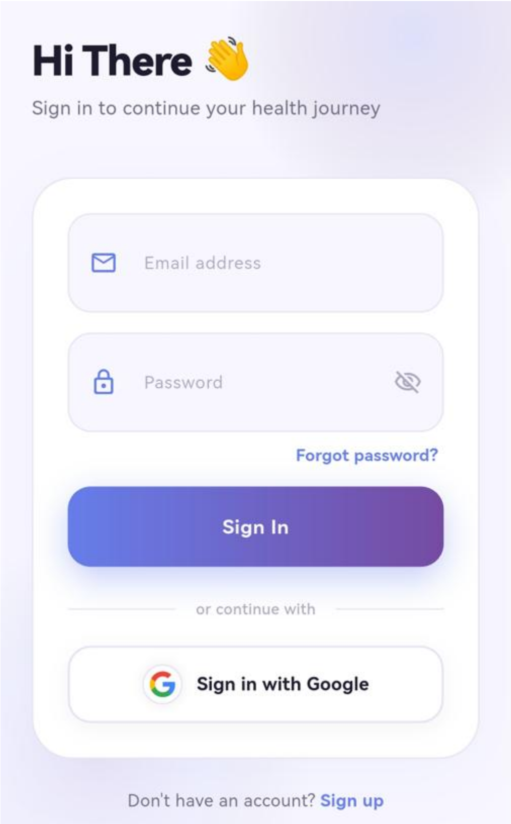


Figure 5.4.3 Login Page

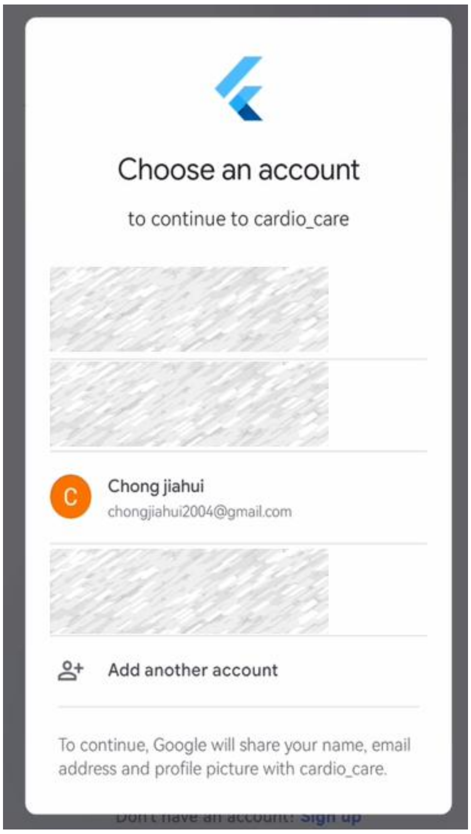
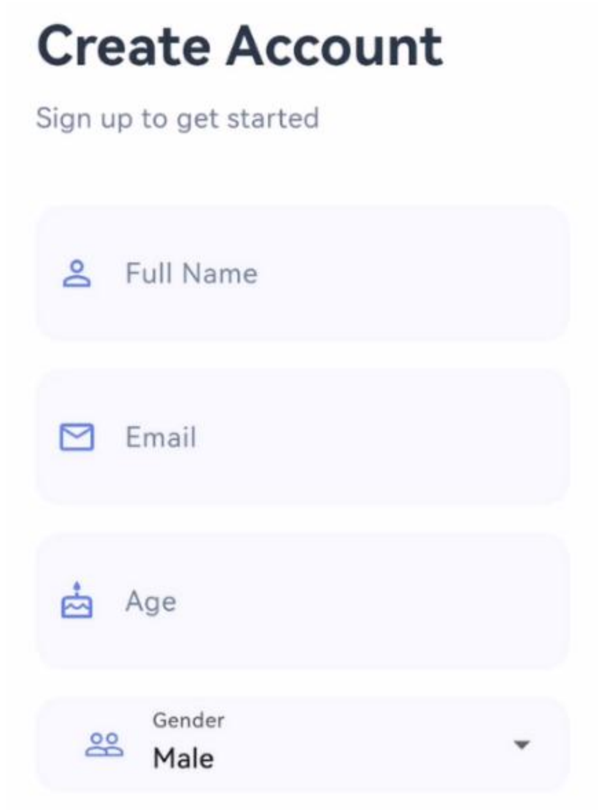
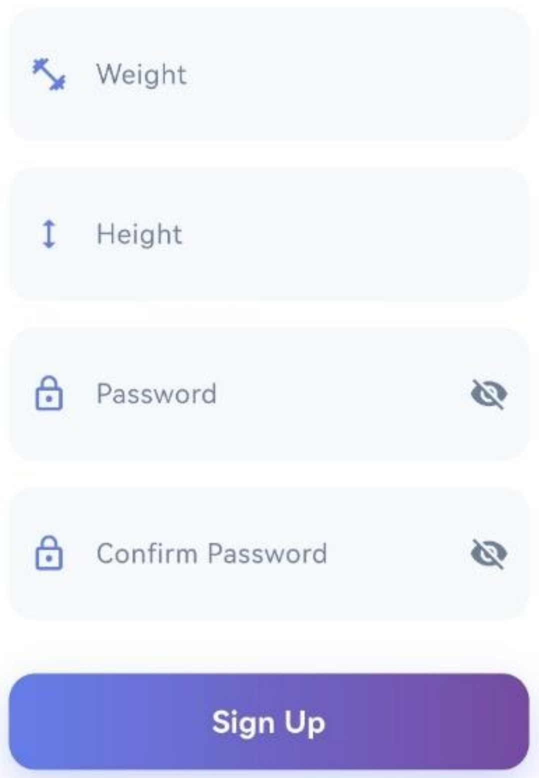


Figure 5.4.4 Login using Google Account

Register Page

Figure 5.4.5 show the Registration Page that collects users' basic details such as full name and email. Demographic information such as age, gender, weight and height is also needed as it supports the blood pressure (BP) estimation. Next, a password confirmation step is included to ensure both password inputs match. The password must contain at least eight characters including a special character and a number.



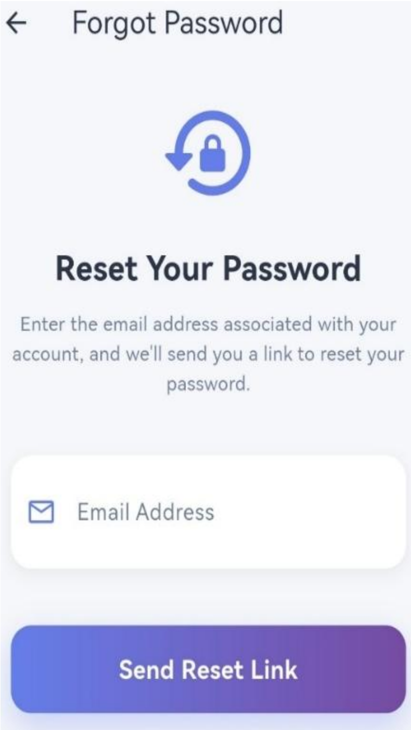


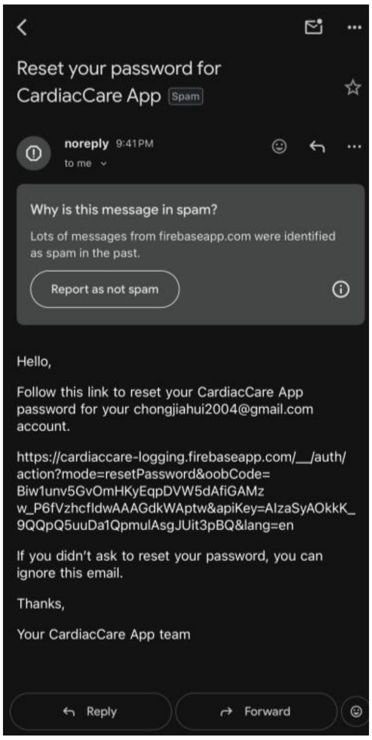
(a) (b)

Figure 5.4.5 Register Page (a) and (b) Requires Users to Fill In Personal Data.

Forget Password Page

The Forgot Password Page requires the user to enter their registered email as shown in Figure 5.4.6. A password reset link as shown in Figure 5.4.7 will then be sent to the user's email. When the user clicks the link, they are able to reset a new password as shown in Figure 5.4.8.





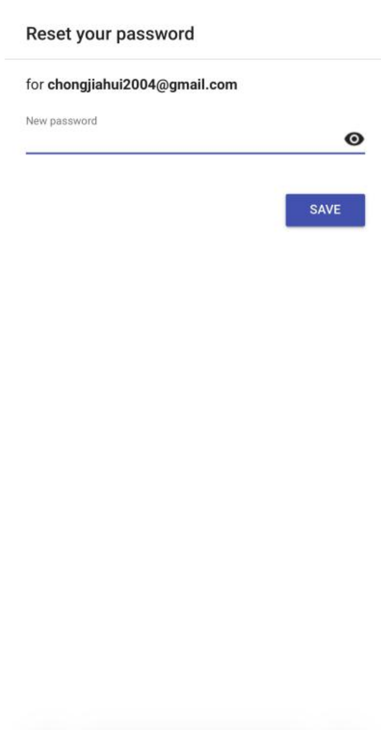


Figure 5.4.6 Forget Password Page

Figure 5.4.7 Reset Password Email

Figure 5.4.8 Reset Password Page

Home Page

If the user logs in using a Gmail account and has not registered before, a message prompting the user to complete their profile is displayed as shown in Figure 5.4.9 .

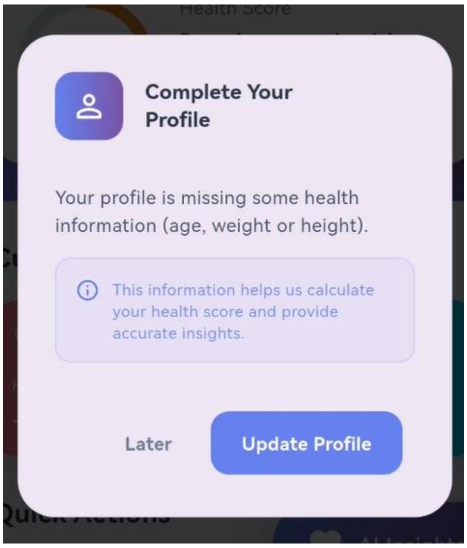


Figure 5.4.9 Profile Completion Prompt

If the user chooses to proceed by clicking the "Update Profile" button, the Edit Profile page is displayed as shown in Figure 5.4.10. If the user clicks the "Later" button, the prompt will appear every time the user accesses the Home Page. After the user completes their profile by entering their age, weight, and height, they are redirected to the Home Page with a confirmation message indicating the profile has been updated as shown in Figure 5.4.11.

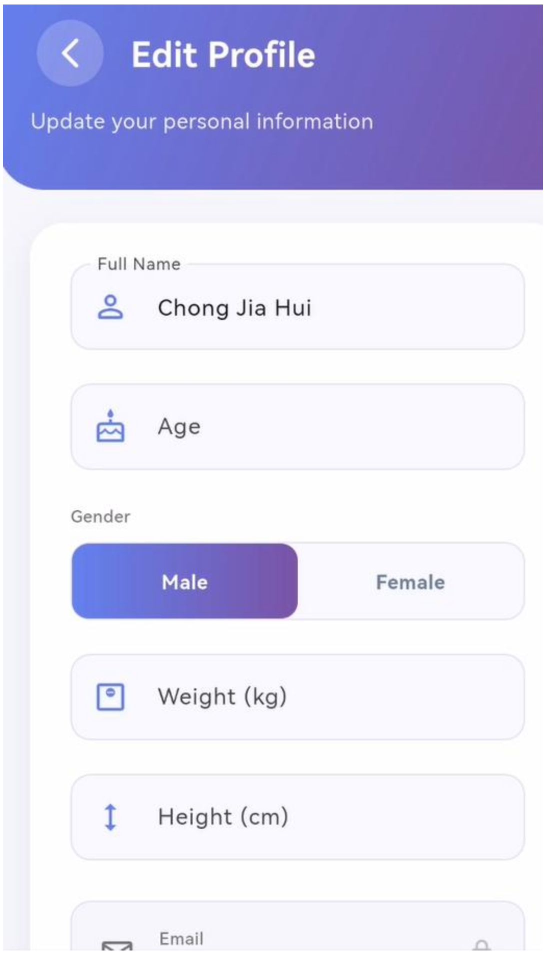


Figure 5.4.10 Edit Profile Page Interface

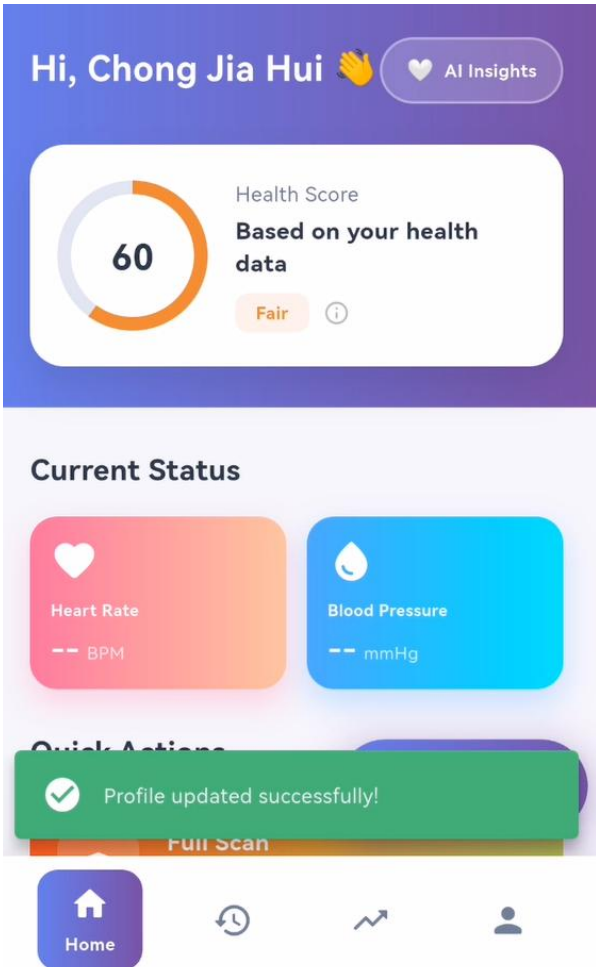
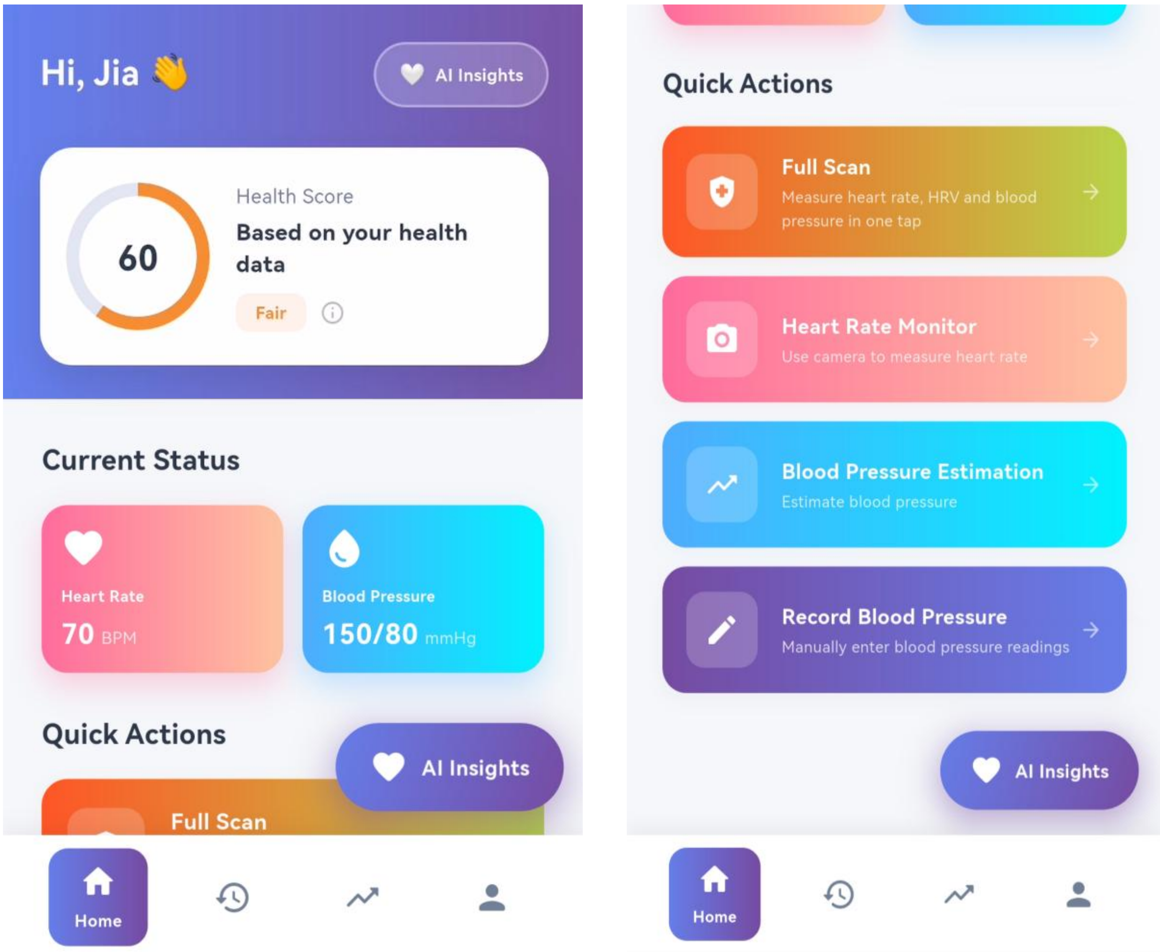


Figure 5.4.11 Home Page with Completed Profile Message

Figure 5.4.12 (a) shows the Home Page which displays the user's overall Health Score generated from their health measurement records including the heart rate (HR) and blood pressure (BP) readings.



(a) (b)

Figure 5.4.12 Home Page: (a) and (b) Home Page of The Application

The initial health score begins at 60. The score is then adjusted based on the user's health metrics including heart rate (HR), heart rate variability (HRV) and blood pressure (BP). For each metric classified as good, 12 points are added with a maximum of +36 points for three metrics. If a metric is classified as poor, 5 points are deducted while 15 points are deducted for alert-level readings. In addition, the score is further adjusted based on generated insights. Each positive insight contributes +4 points, while each alert insight deducts 8 points. The final health score is then clamped within a range of 0 to 100.

The Health Score is clickable as shown in Figure 5.4.13 and provides a summary of the user's latest health measurements. It also indicates that the score is intended as a general reference for overall health status rather than a medical diagnosis.

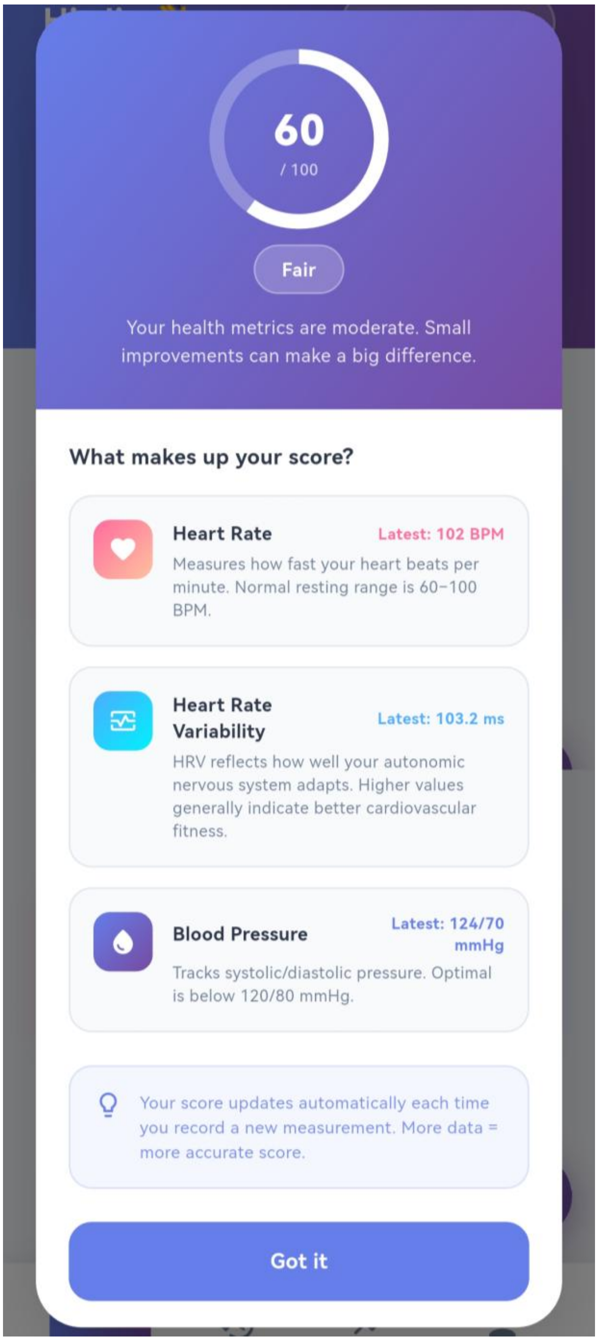


Figure 5.4.13 Displaying the Health Score

Additionally, the Home Page includes a "Current Status" section that displays the most recent HR and BP readings. Figure 5.4.12 (b) shows that users can perform four main functions including Full Scan, HR Monitor, BP Estimation, and Record BP. The Full Scan measures the user's HR, heart rate variability (HRV) and BP in a single scan. The HR Monitor measures the user's heart rate and derives HRV. The BP Estimation function allows users to estimate their BP using the smartphone camera when a BP device is not available. Lastly, the Record BP function enables users to manually record clinically measured BP values for accurate tracking.

A floating icon named "AI Insights" is placed on the Home Page and also placed at the top of the Home Page. This feature acts as an artificial intelligence (AI) chatbot-based cardio assistant that analyzes the user's health measurements and provides personalized insights.

AI Cardio Assistant Page

Figure 5.4.14 shows the AI Cardio Assistant page which is named as CardioAI. At the top of the page, the user's overall Health Score is displayed with a button to clear the chat history. Figure 5.4.15 shows that when the user clicks on the clear chat history button, a confirmation message is prompted to ensure that the chat history is cleared intentionally.

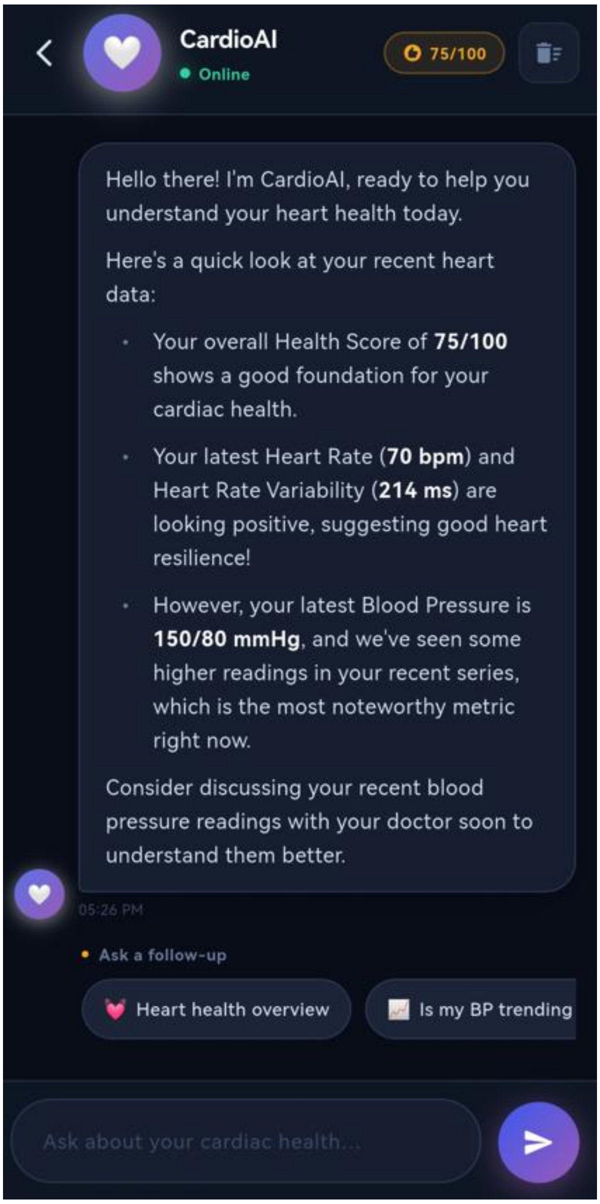


Figure 5.4.14 AI Cardio Assistant Page

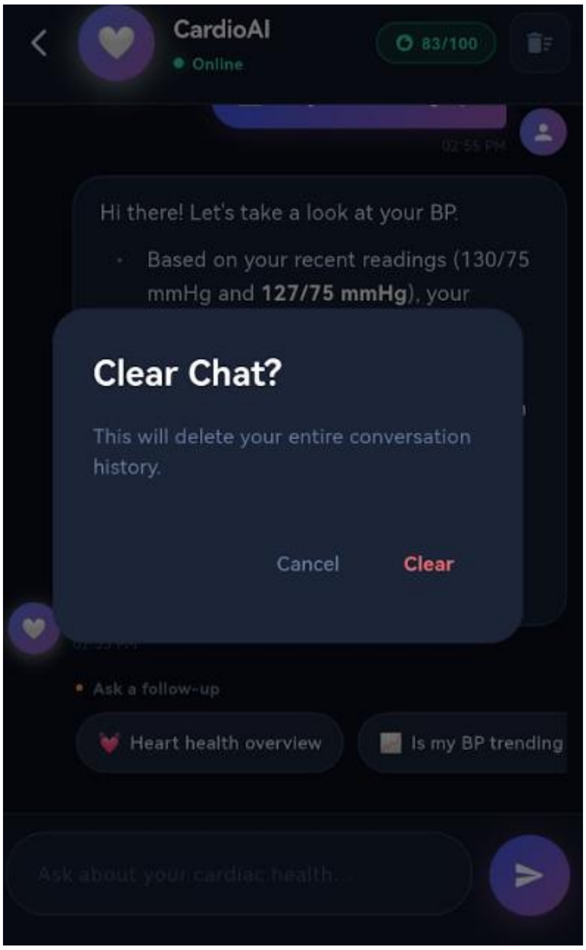


Figure 5.4.15 Delete Chat History of AI Cardio Assistant

Based on Figure 5.4.14, a welcome message is automatically generated. The CardioAI summarizes the user's health measurements and provides basic analysis. Below the summarizing message, several suggested questions are displayed to guide users on what they can ask. The interface is designed as a chatbot to allow users to interact with the application. This design enhances user engagement and enables users to receive personalized insights based on their health measurement records.

Fingertip Positioning Page

Before performing the Full Scan, HR Monitor and BP Estimation, the fingertip positioning page will be displayed first. First, the user needs to allow camera access for recording videos as shown in Figure 5.4.16. Then, the guidance alert is displayed as shown in Figure 5.4.17 which guides the user on how to properly cover the camera lens for capturing the fingertip photoplethysmography (PPG) signal.

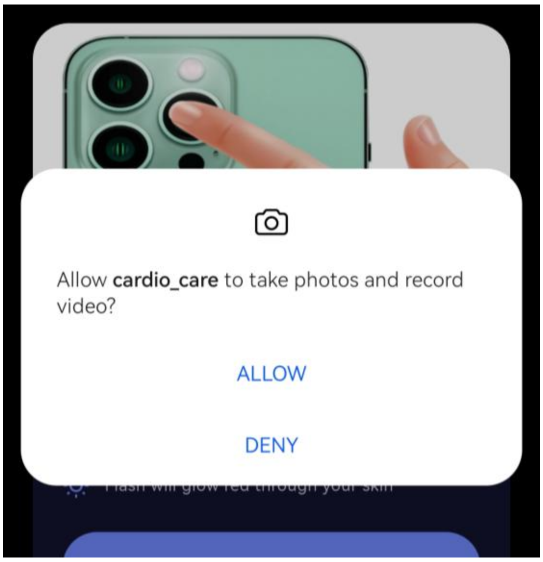


Figure 5.4.16 Permission of Camera Access

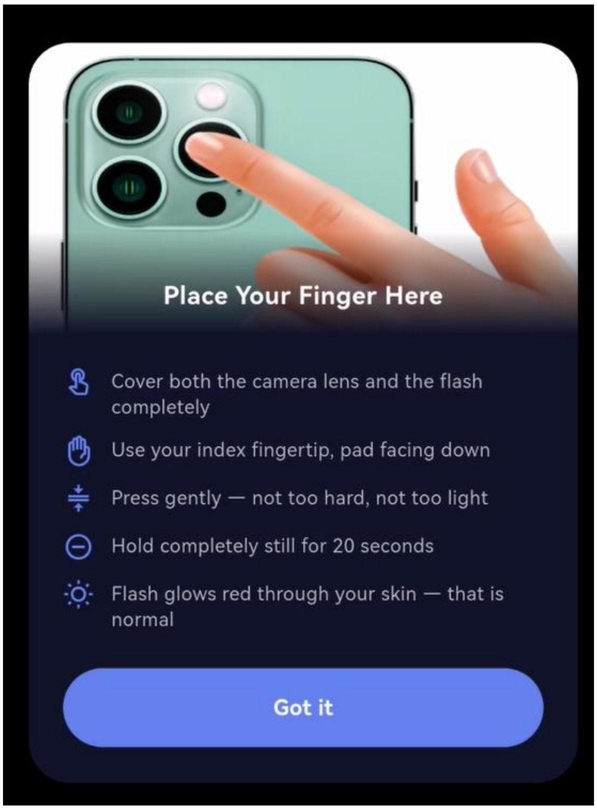
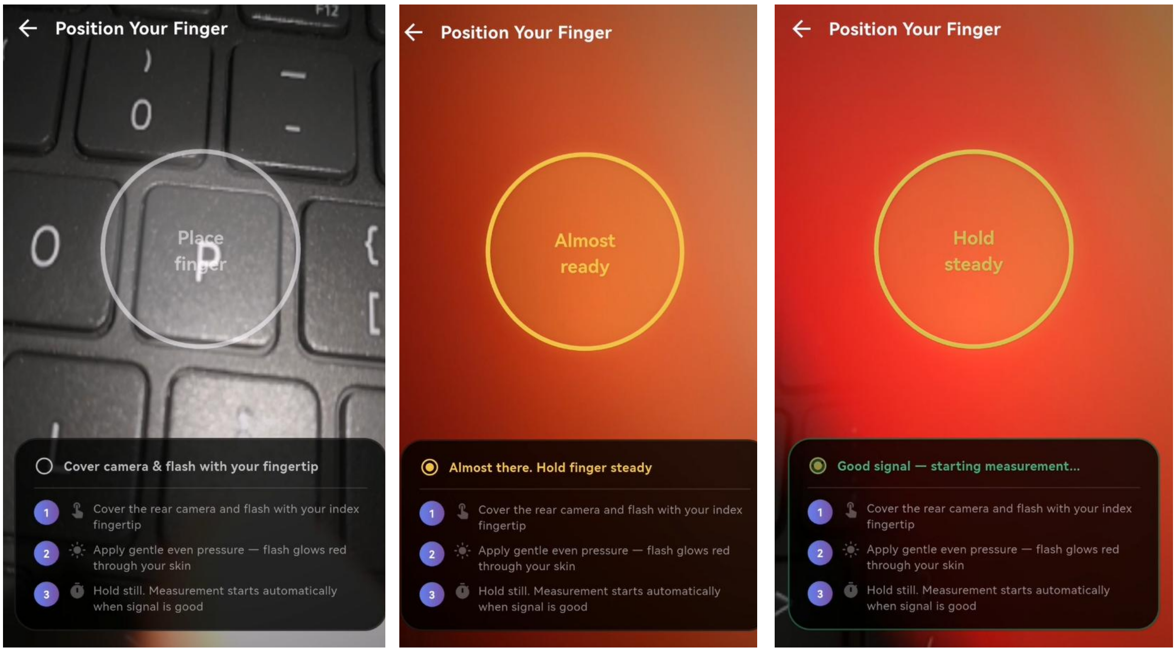


Figure 5.4.17 Fingertip Guidance Window

After the user taps the "Got it" button, the application displays a real-time camera preview as shown in Figure 5.4.18. The application continuously analyzes the red, green, blue (RGB) red channel extracted from the camera frames to detect whether the fingertip is properly covering the lens. A detailed method for detecting the red channel in RGB images has already been discussed in Chapter 4. Then, three fingertip positioning states are displayed in real time including the first state means that no finger has been detected yet, the second state means signals that a finger is detected and the application is preparing for measurement and the third state confirms that the finger is correctly positioned and the lens is fully covered. Once the third state is achieved, the application automatically proceeds to the PPG signal capturing page.

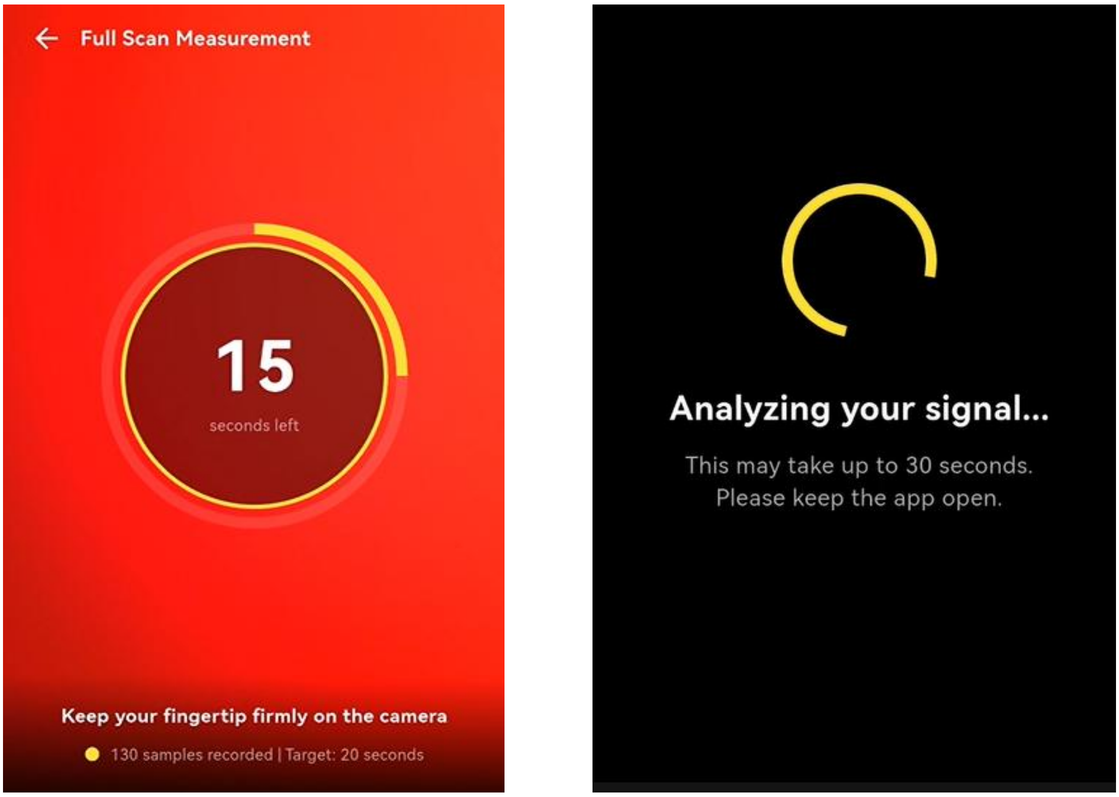


(a) (b) (c)

Figure 5.4.18 Detect User Fingertip Positioning: (a) First State of Fingertip Positioning; (b) Second State of Fingertip Positioning; (c) Third State of Fingertip Positioning

Full Scan Page

After the user achieves the third stage of fingertip positioning, the application starts to collect the user's PPG signals. A countdown timer of approximately 20 seconds begins, and the application displays the number of fingertip samples being collected in real time as shown in Figure 5.4.19 (a). Once the recording is complete, the application provides a processing screen indicating that the PPG signal samples are being processed as shown in Figure 5.4.19 (b).



(a) (b)

Figure 5.4.19 Full Scan Measurement Page: (a) Measuring PPG Signal; (b) Computing Full Scan Results

The application continuously monitors the real-time fingertip positioning during the measurement. If the fingertip is removed, an error message is displayed. It prompts the user to reposition their finger and redirects the user to the fingertip positioning page as shown in Figure 5.4.20. This ensures that only valid PPG signals are captured throughout the signal acquisition process.

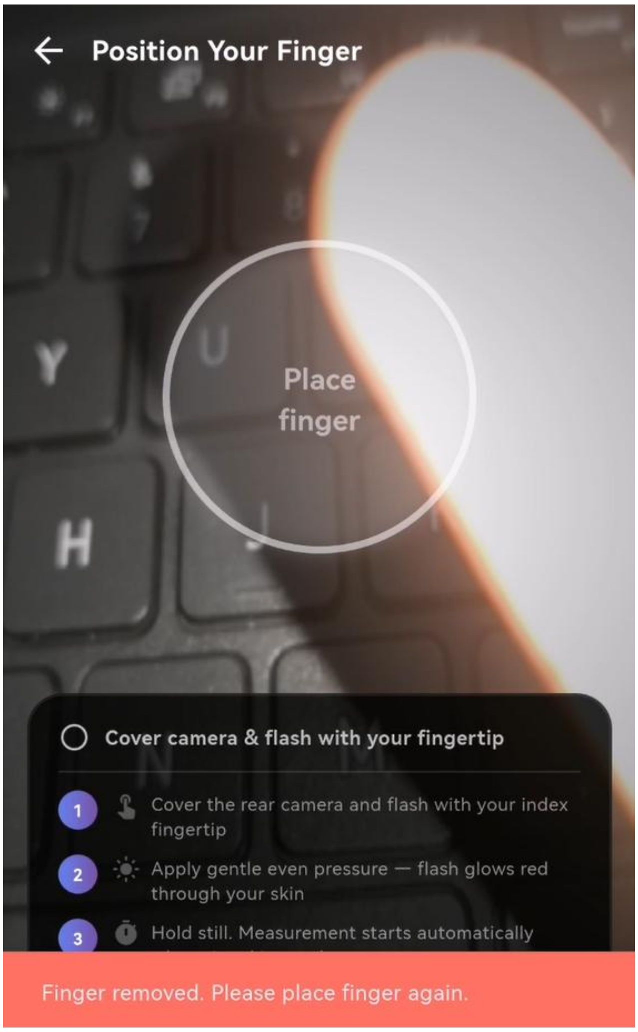


Figure 5.4.20 Error Message on Fingertip Removed

If the captured PPG signal is insufficient for health measurement processing, an alert dialog is displayed as shown in Figure 5.4.21. Additionally, if a connection error occurs or the server fails to respond, an alert dialog will also be displayed as shown in Figure 5.4.22. After the user taps the "OK" button, the application redirects the user to the fingertip positioning page to perform a remeasurement.

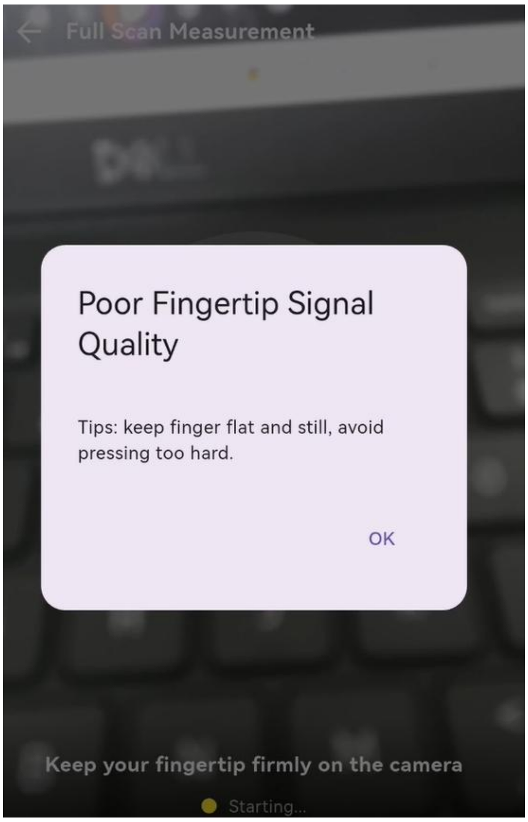


Figure 5.4.21 Alert Dialog on Poor Fingertip Signal Quality Obtained

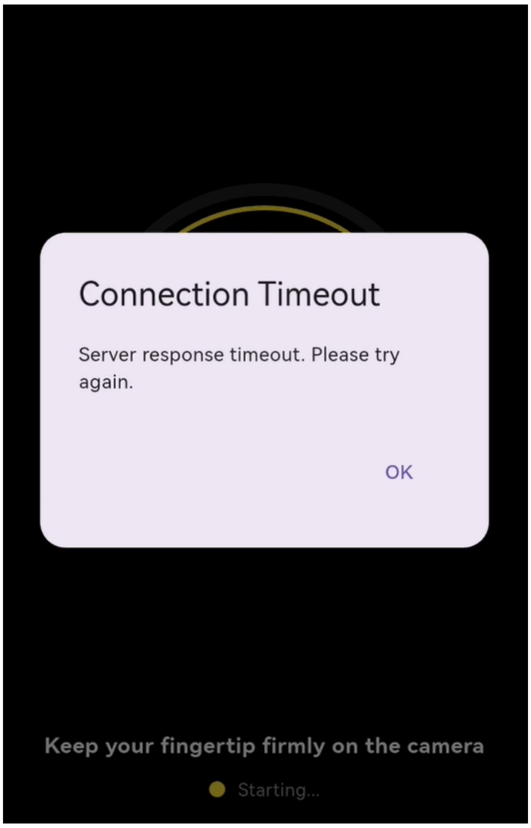


Figure 5.4.22 Alert Dialog on Connection Timeout Error

If the captured PPG signal is sufficient for health measurement processing, the HR, HRV and BP results are displayed as shown in Figure 5.4.23. Each health measurement is automatically categorized which can help the user better understand the results. A short explanation is also provided for each measurement. In addition, a blood pressure category guide is included so users can interpret their BP values more easily based on the given ranges. Lastly, a brief recommendation is provided based on the user's health measurement results.

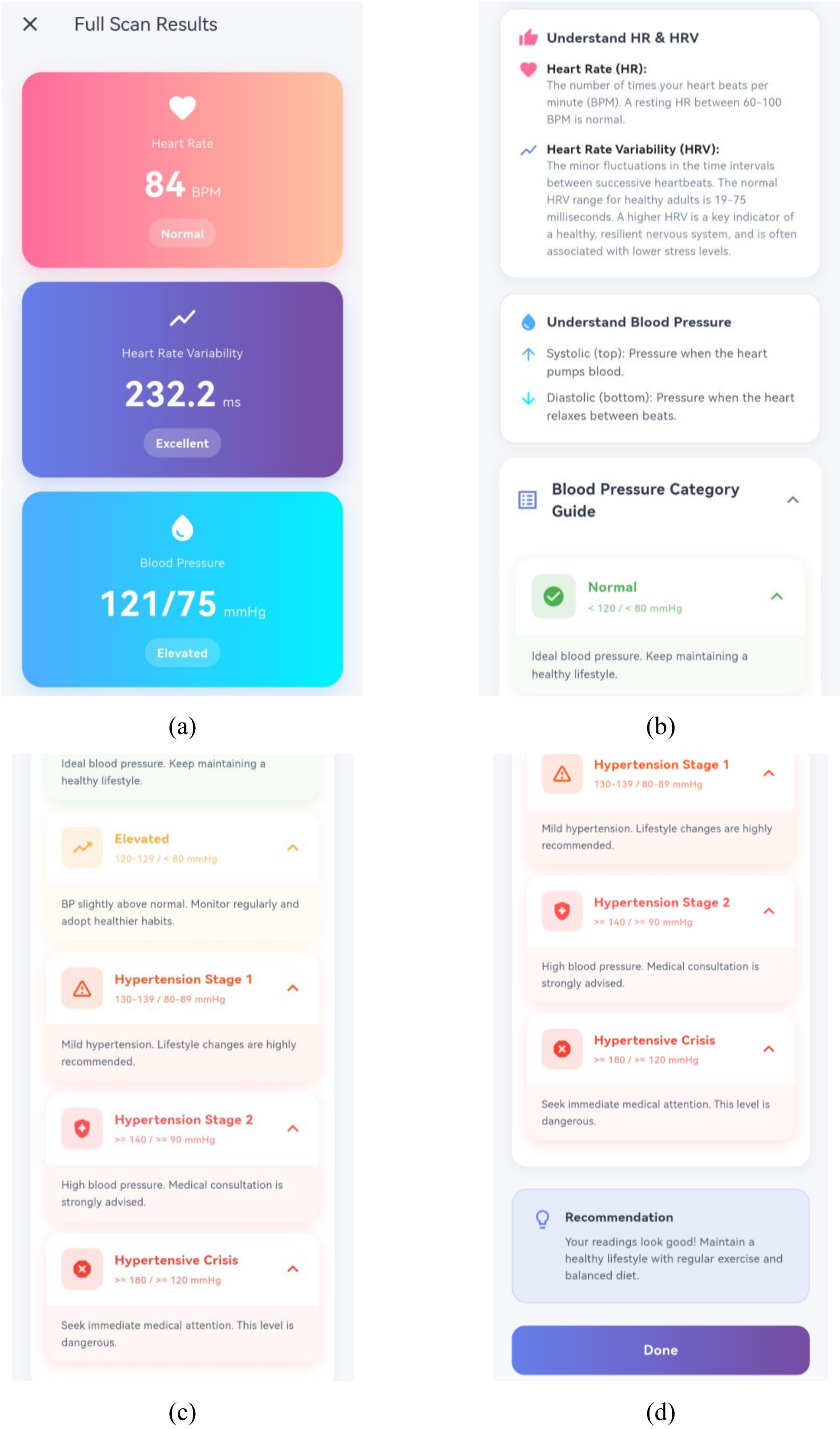
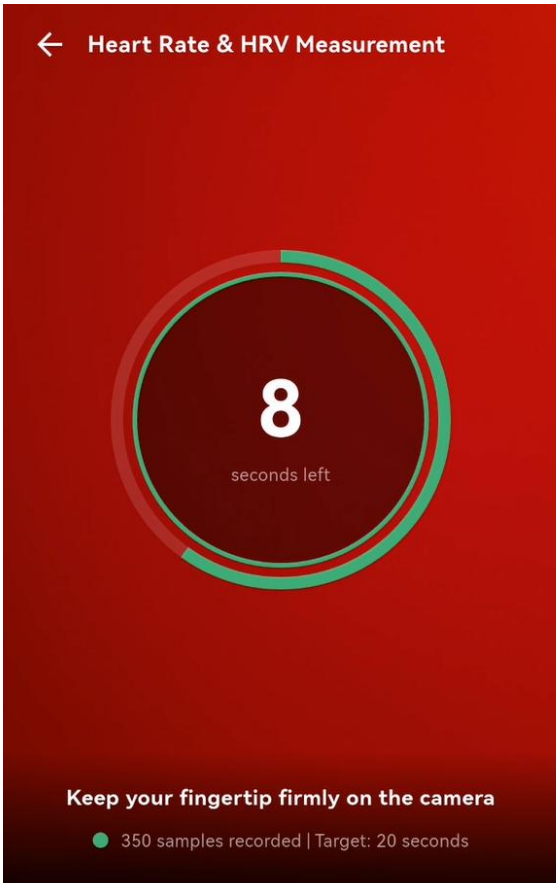


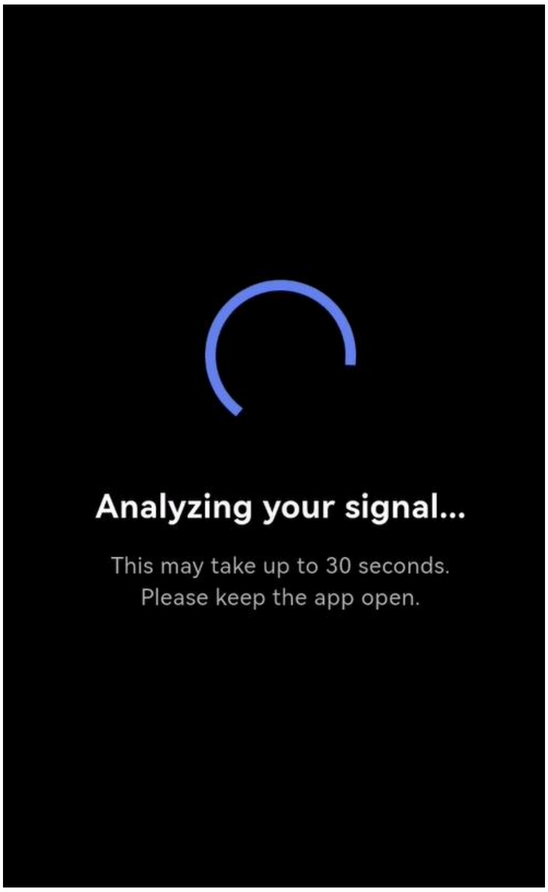
Figure 5.4.23 Full Scan Result Page: (a) to (d) Displaying the Full Scan Results

Heart Rate Monitor Page

After the application detects the user's fingertip, a countdown timer of approximately 20 seconds begins, and the application displays the number of fingertip samples being collected in real time as shown in Figure 5.4.21 (a). Once recording is complete, the application provides a processing screen indicating that the PPG signal samples are being processed as shown in Figure 5.4.24 (b).



(a)

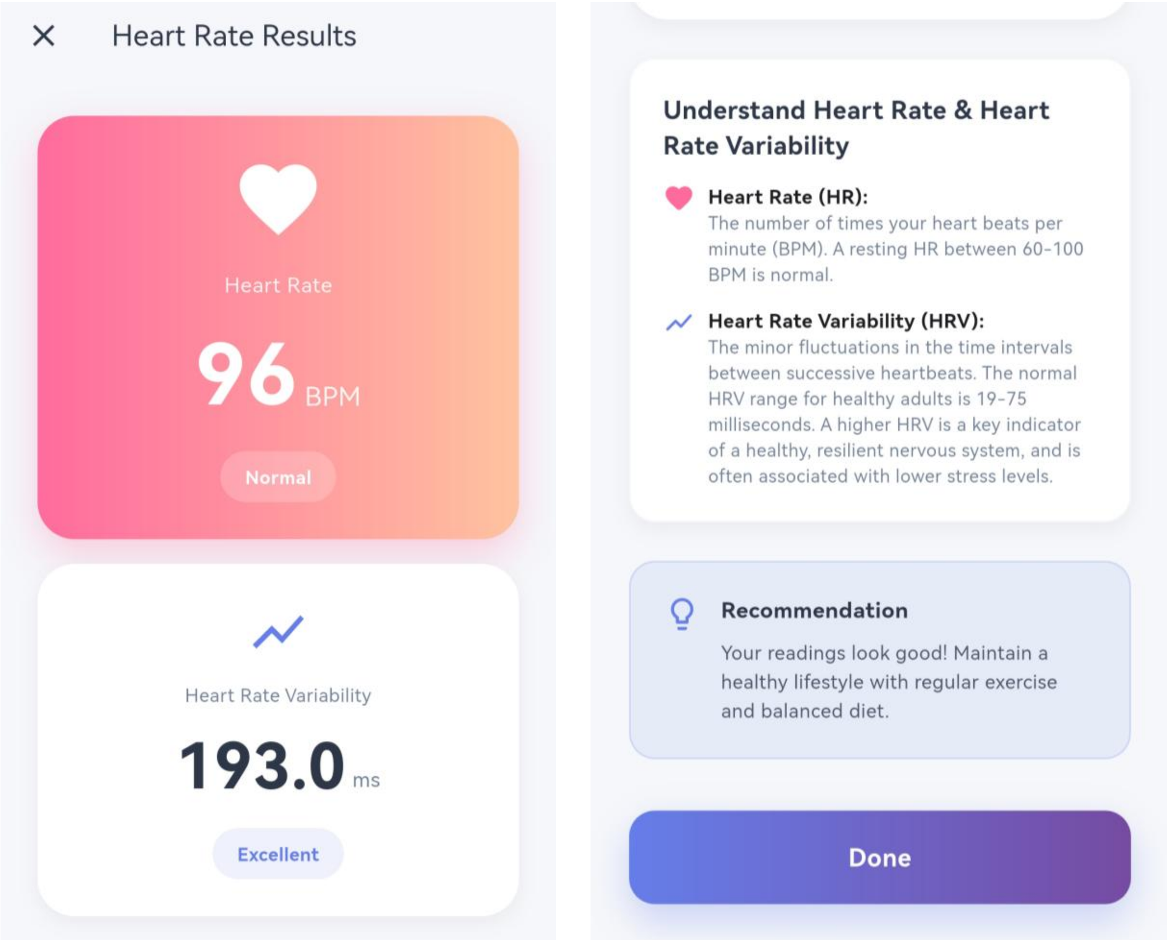


(b)

Figure 5.4.24 Heart Rate and Heart Rate Variability Measurement Page: (a) Measuring PPG Signal; (b) Computing Heart Rate and Heart Rate Variability Results

Similar to the Full Scan Measurement, if the fingertip is removed during PPG signal recording, an error message is displayed and the user is redirected to the fingertip positioning page to remeasure. Besides, if the captured PPG signal is insufficient for further processing, an alert dialog is displayed and the user is redirected to perform a remeasurement. Furthermore, if a connection error occurs during the health measurement process, an alert dialog is displayed and the user is likewise redirected to remeasure the PPG signal.

If the captured PPG signal is sufficient for health measurement processing, the heart rate (HR) and heart rate variability (HRV) results are displayed as shown in Figure 5.4.25. Each health measurement is automatically categorized which can help the user better understand the results. A short explanation is also provided for each measurement. Lastly, a brief recommendation is provided based on the user's health measurement results.

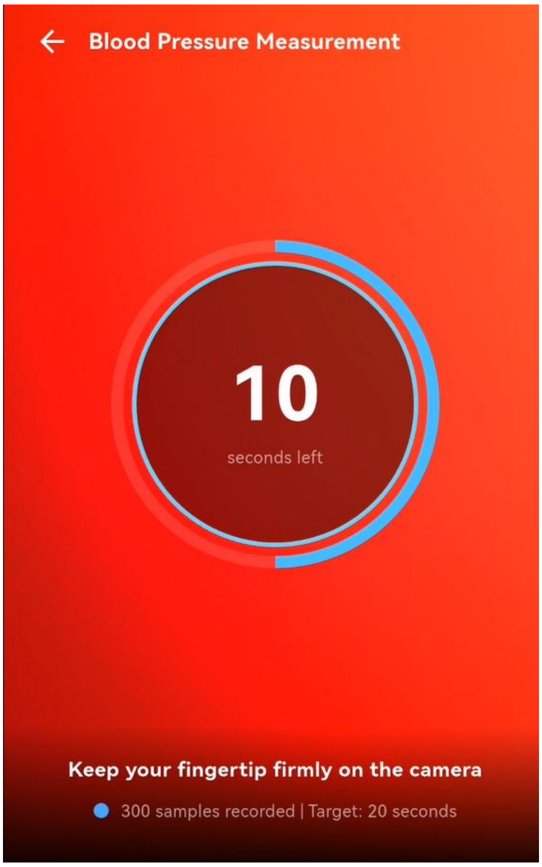


(a) (b)

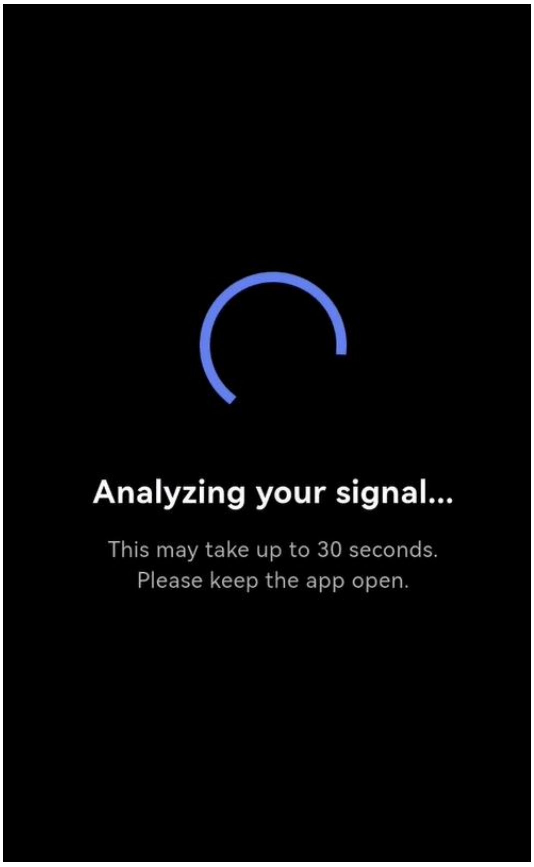
Figure 5.4.25 Heart Rate and Heart Rate Variability Measurement Result Page: (a) to (b) Displaying the Heart Rate and Heart Rate Variability Measurement Results

Blood Pressure Estimation Page

After the application detects the user's fingertip, a countdown timer of approximately 20 seconds begins, and the application displays the number of fingertip samples being collected in real time as shown in Figure 5.4.26 (a). Once recording is complete, the application provides a processing screen indicating that the PPG signal samples are being processed as shown in Figure 5.4.26 (b).



(a)

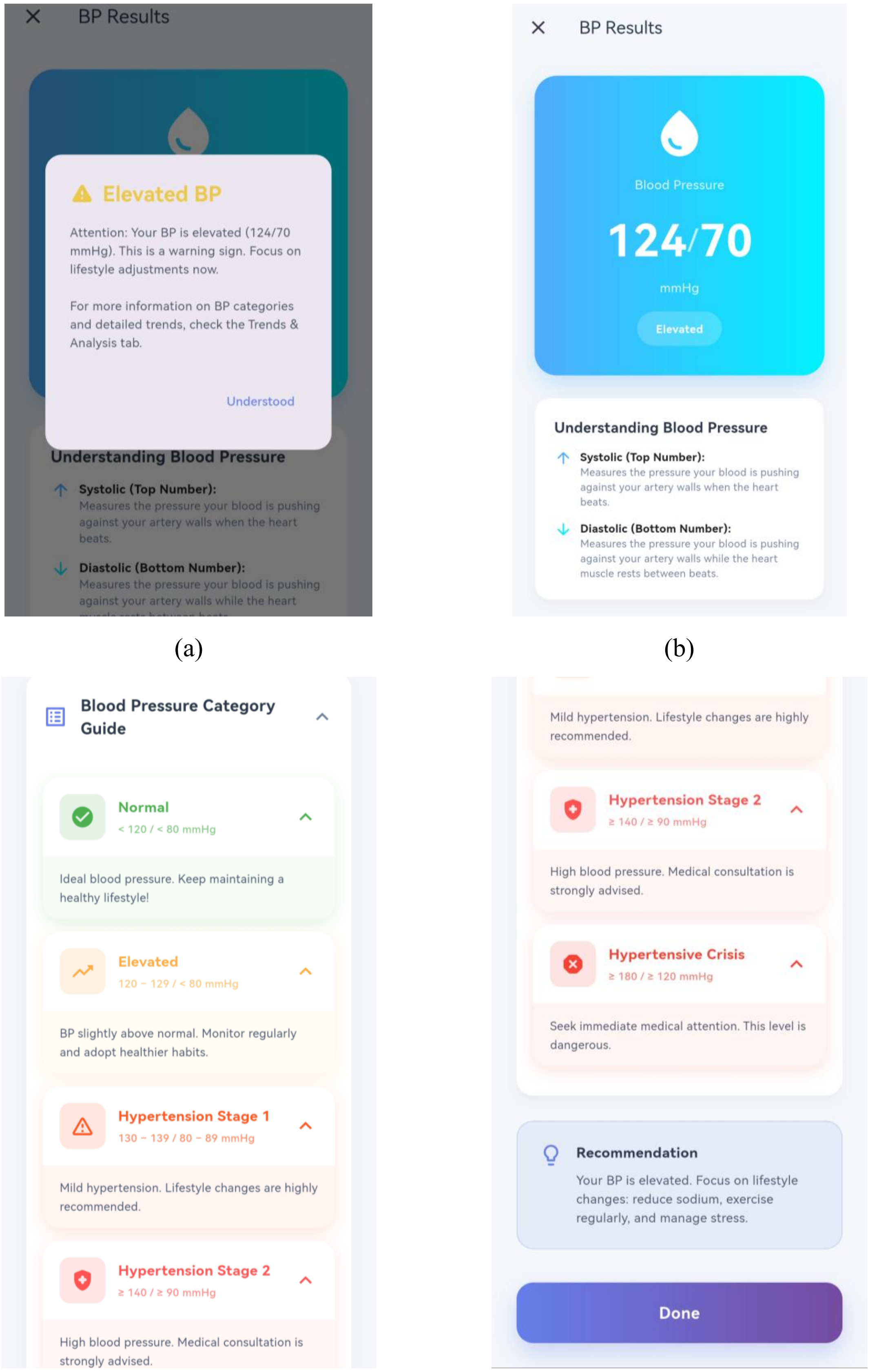


(b)

Figure 5.4.26 Blood Pressure Estimation Page: (a) Measuring PPG Signal; (b) Computing Blood Pressure Estimation Results

Similar to the previous measurement, if the fingertip is removed during PPG signal recording, an error message is displayed and the user is redirected to the fingertip positioning page to remeasure. Besides, if the captured PPG signal is insufficient for further processing, an alert dialog is displayed and the user is redirected to perform a remeasurement. Furthermore, if a connection error occurs during the health measurement process, an alert dialog is displayed and the user is likewise redirected to remeasure the PPG signal.

If the captured PPG signal is sufficient for health measurement processing, the blood pressure (BP) results are displayed as shown in Figure 5.4.27. An alert showing the categorized BP results is presented in Figure 5.4.27 (a) including a short explanation of the BP category along with a recommendation. The BP is automatically categorized to help users better understand the results. A short explanation is also provided for each measurement. Lastly, a brief recommendation is given based on the user's health measurement results.



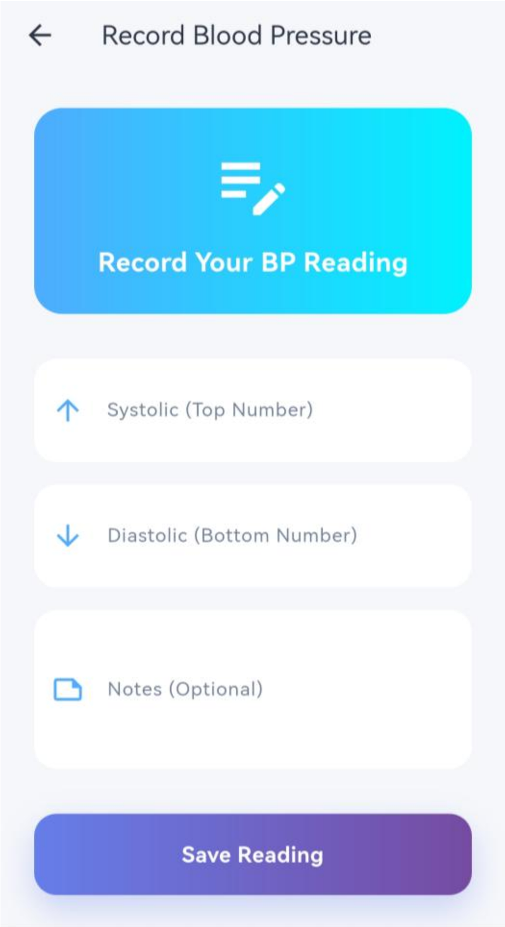
(a) (b)

(c) (d)

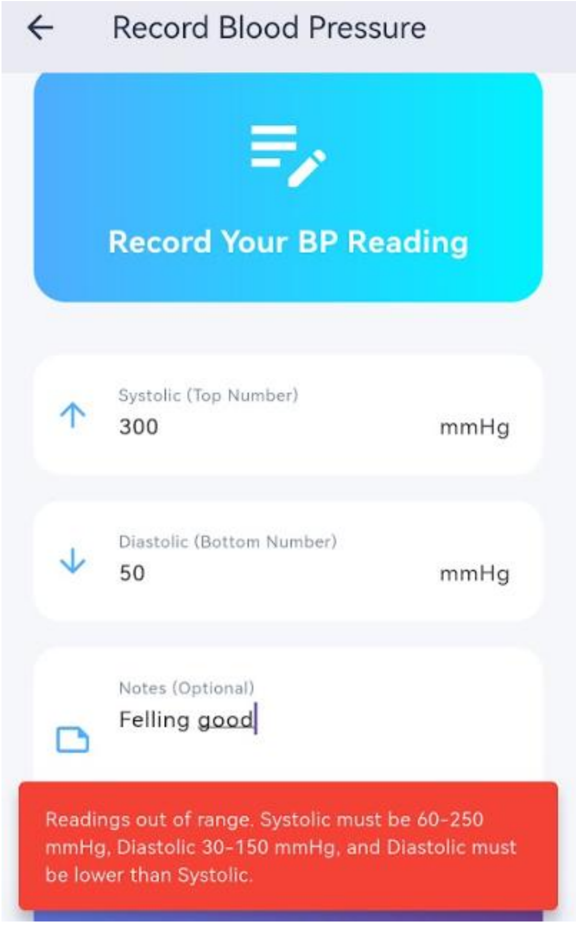
Figure 5.4.27 Blood Pressure Estimation Result Page: (a) Displaying Categorized Blood Pressure Result Window ; (b) to (d) Displaying Blood Pressure Estimation Results

Record Blood Pressure Page

This page allows users to manually enter valid systolic and diastolic readings with the optional notes for personal health tracking as shown in Figure 5.4.25 (a). The application also validates user input to ensure that a valid range is entered for systolic and diastolic BP values as shown in Figure 5.4.28 (b).



(a)

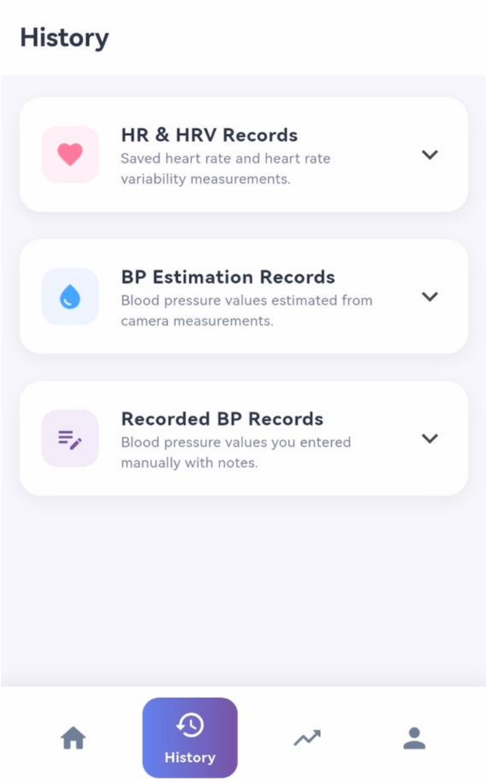


(b)

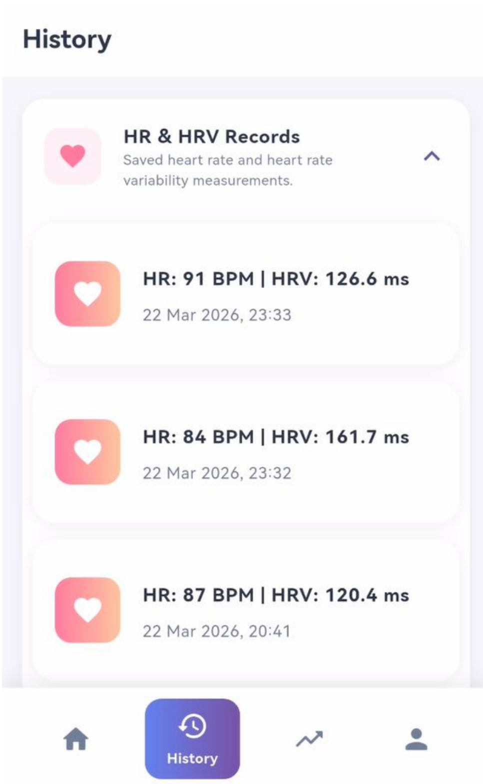
Figure 5.4.28 Blood Pressure Recording Page: (a) Displaying Blood Pressure Recording Page; (b) Displaying Invalid Range Input in Blood Pressure Recording Page

History Page

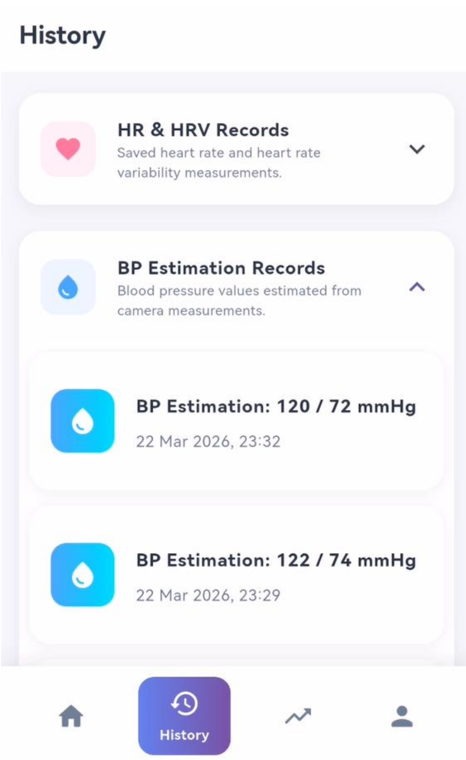
Figure 5.4.29 shows the history page which includes HR and HRV records, estimated BP records and recorded BP records. Each record is clickable as shown in Figures 5.4.29 (b) to 5.4.29 (d). The records are saved along with their respective values, dates and times.



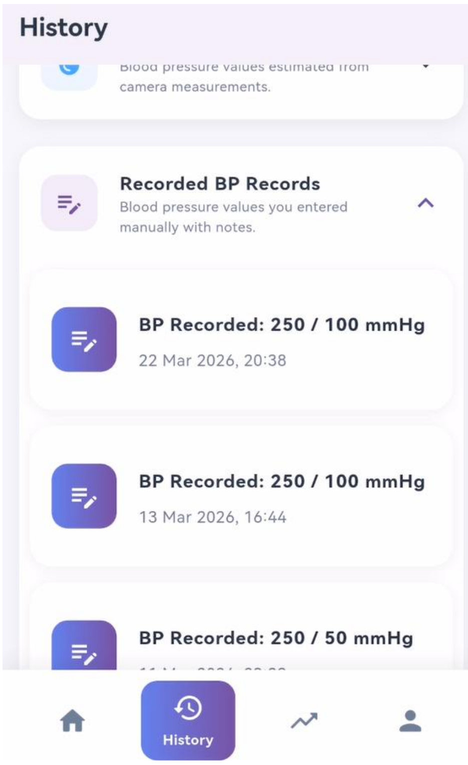
(a)



(b)



(c)



(d)

Figure 5.4.29 History Page: (a) History Page; (b) Expanded Heart Rate and Heart Rate Variability Records; (c) Expanded Estimated Blood Pressure Records; (d) Expanded Manually Recorded Blood Pressure Records

Trends and Analysis Page

Since the application records four health measurements such as HR, HRV, estimated BP and manually recorded BP, thus the Trends and Analysis page consists of four metrics for the user to track their respective health measurements. First, Figure 5.4.30 shows a filter feature at the top of the page that allows users to select their preferred month and year based on the corresponding readings which also shown in Figure 5.4.31. The application provides both 7 day and 30 day reading analyses.

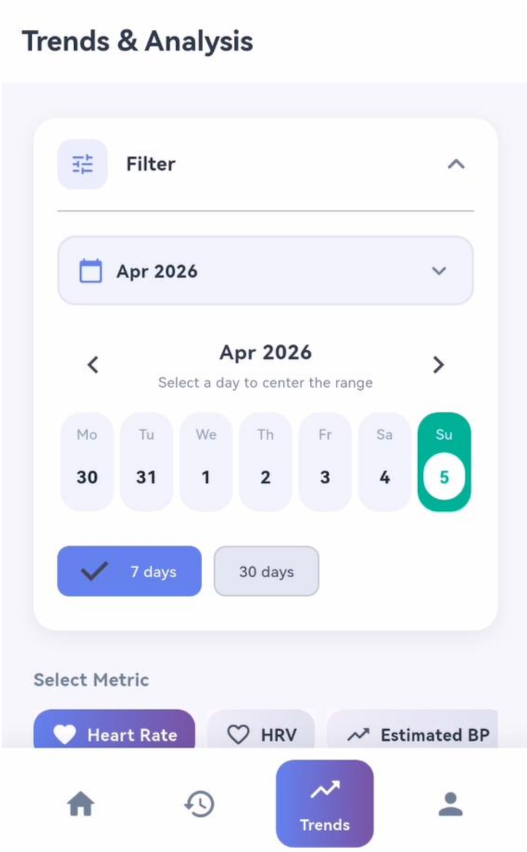


Figure 5.4.30 Date Filter in Trends and Analysis Page

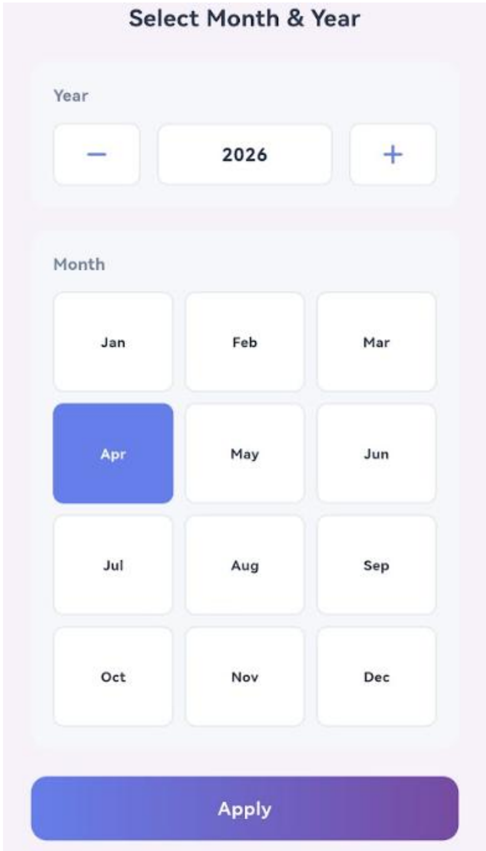
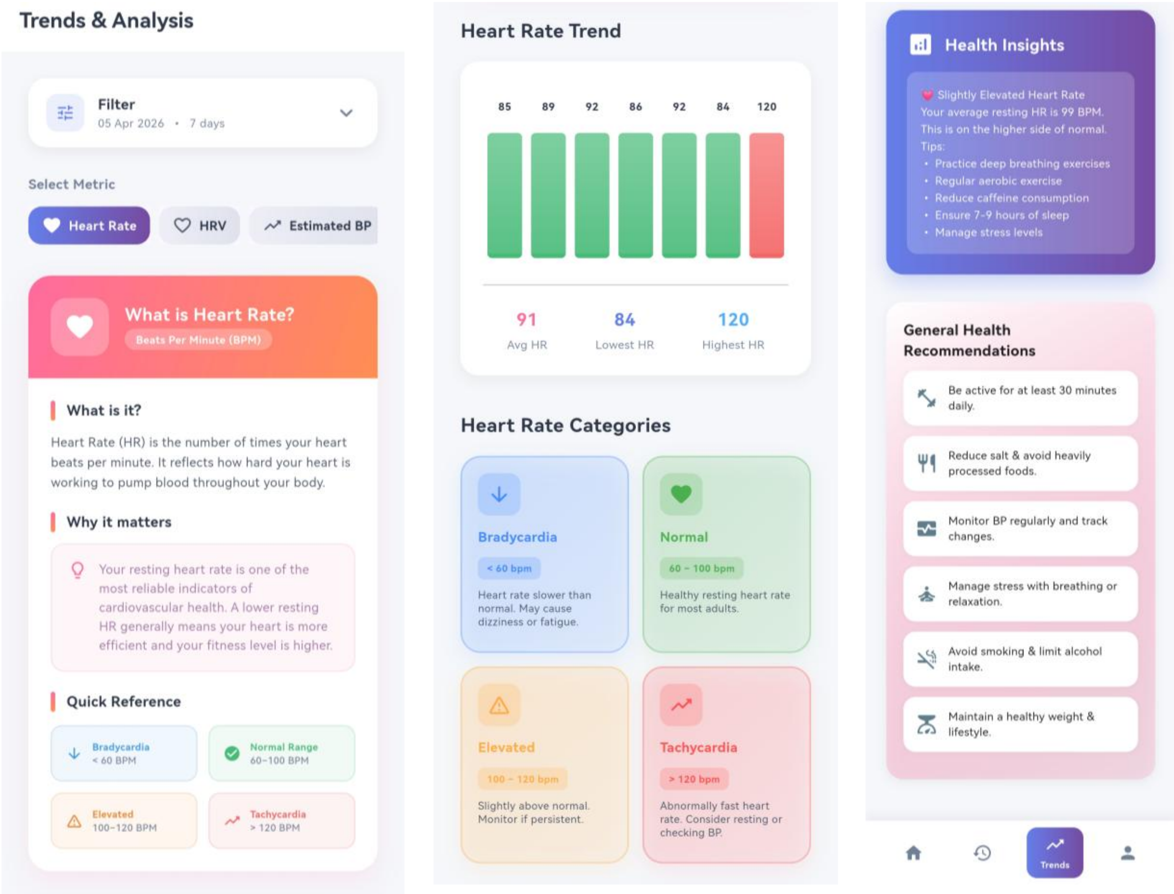


Figure 5.4.31 Select Month and Year in Trends and Analysis Page

Then, the four metrics are provided. Figure 5.4.32 shows the selected Heart Rate metric. It begins with a short introduction to heart rate, including its definition, why it matters and a quick reference to the heart rate range. If the user does not set a filter date and time, the latest measurement will be shown by default.

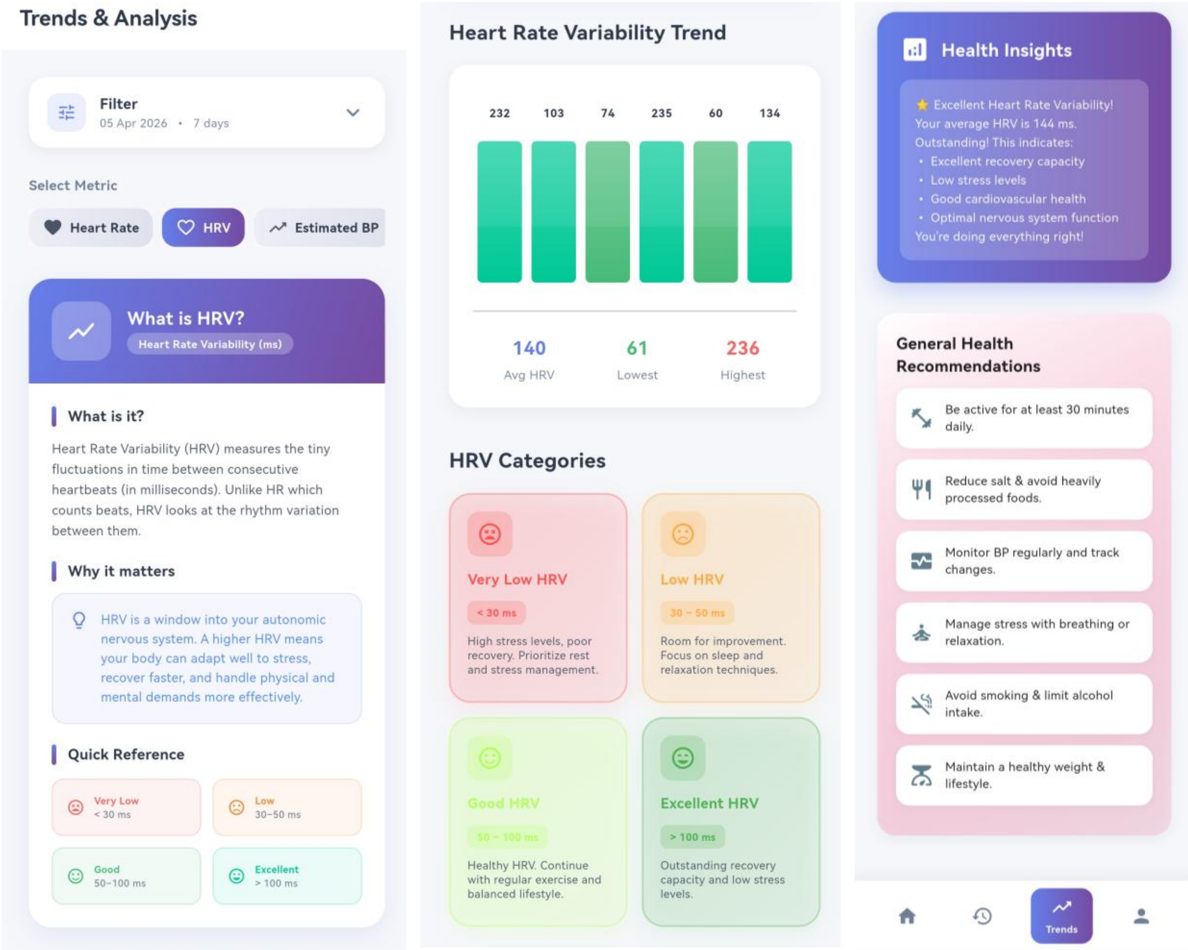


(a) (b) (c)

Figure 5.4.32 Heart Rate Analysis in Trends and Analysis Page: (a) to (c) Displaying Heart Rate Trends and Analysis

The trend is displayed in a bar chart with colored bars to distinguish the heart rate ranges. Red bars indicate a high heart rate, yellow indicates a slightly elevated heart rate while green indicates a normal heart rate and a blue bar indicates an abnormal range. Below the chart, a summary of the average, lowest, and highest heart rate is provided. A heart rate category section is also included to help users better understand the range. Next, health insights are generated based on the user's past records along with general health recommendations.

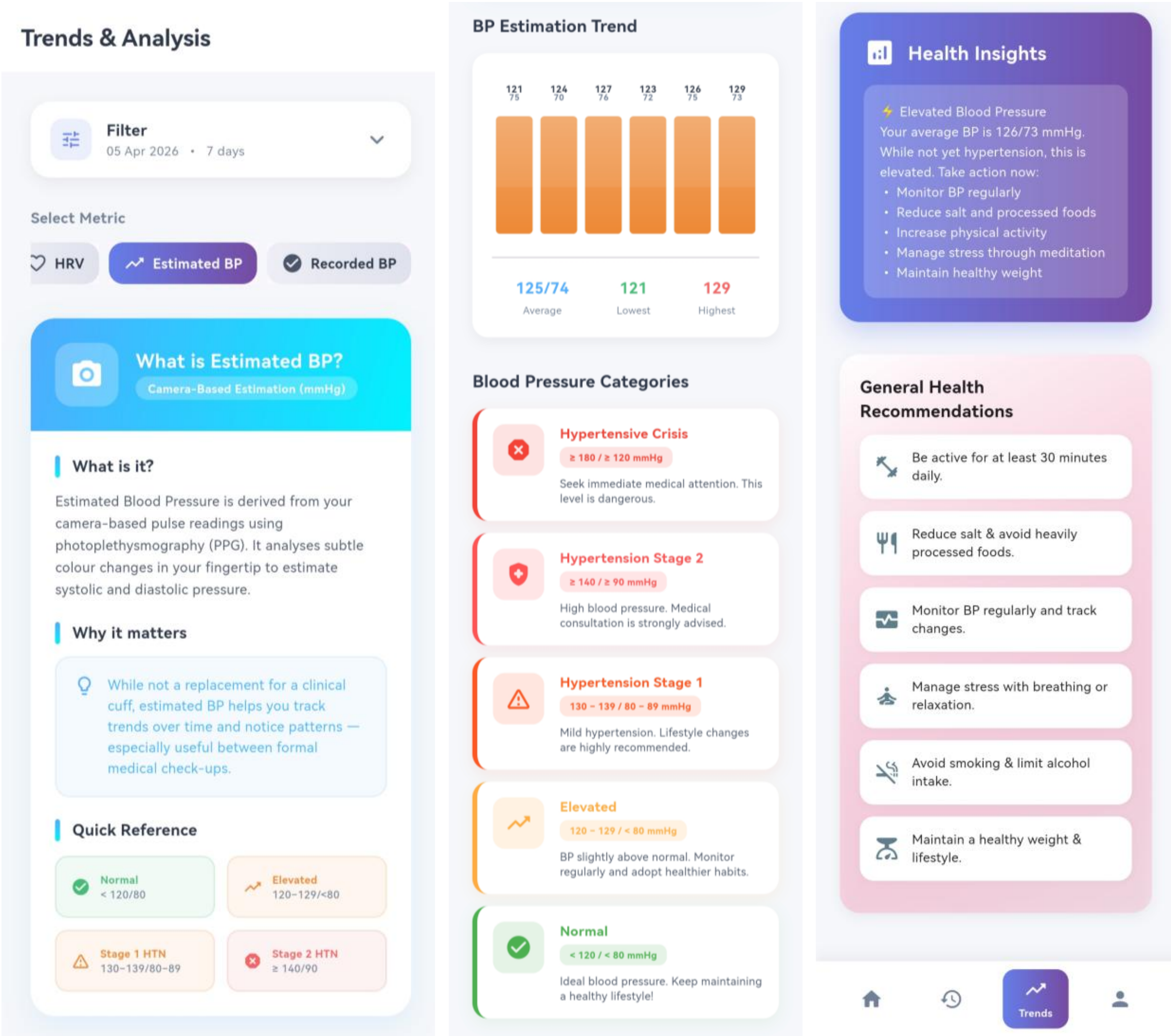
The HRV metric in the Trends and Analysis page follows a similar structure to the HR metric as shown in Figure 5.4.33.



(a) (b) (c)

Figure 5.4.33 Heart Rate Variability Analysis in Trends and Analysis Page: (a) to (c) Displaying Heart Rate Variability Trends and Analysis

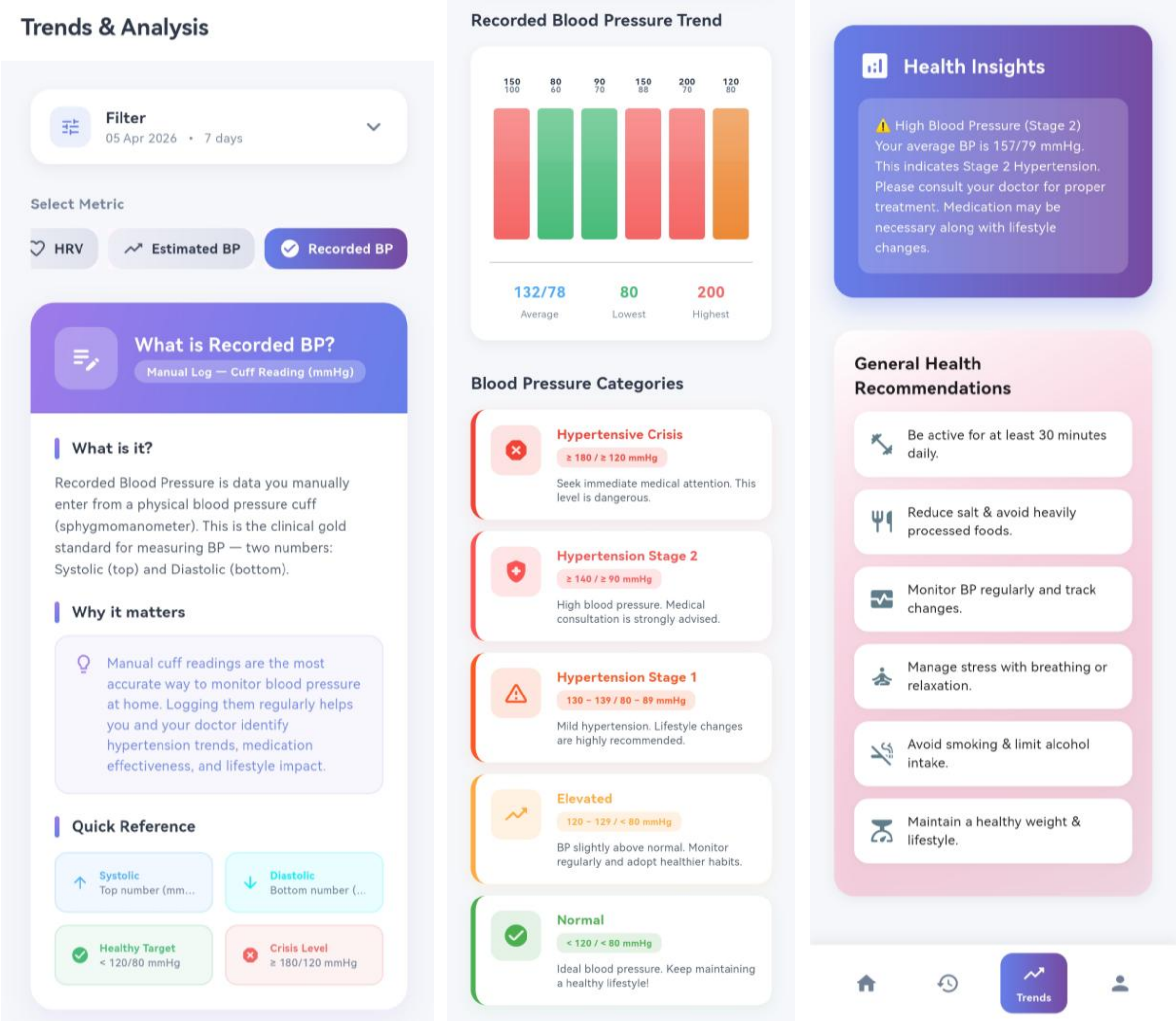
The estimated BP metric in the Trends and Analysis page also follows a similar structure to the HR metric as shown in Figure 5.4.34.



(a) (b) (c)

Figure 5.4.34 Estimated Blood Pressure Analysis in Trends and Analysis Page: (a) to (c) Displaying Estimated Blood Pressure Trends and Analysis

The manually recorded BP metric in the Trends and Analysis page also follows a similar structure to the HR metric as shown in Figure 5.4.35.

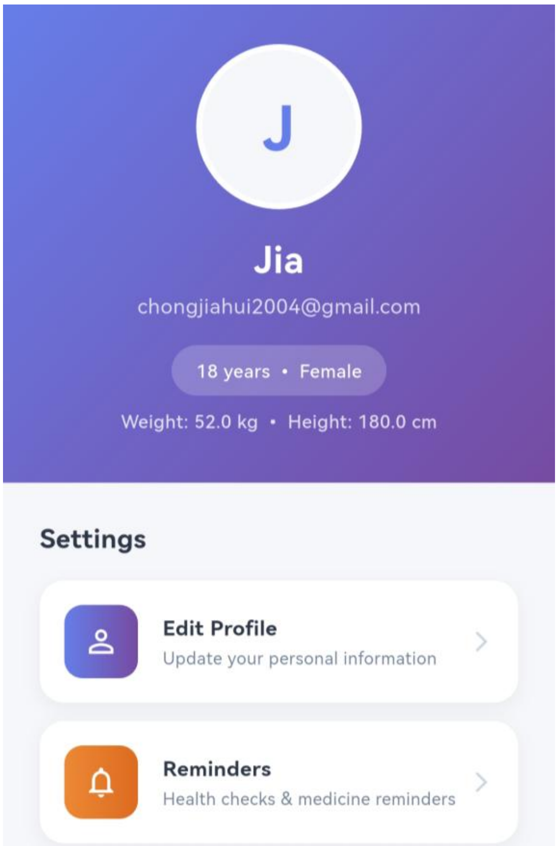


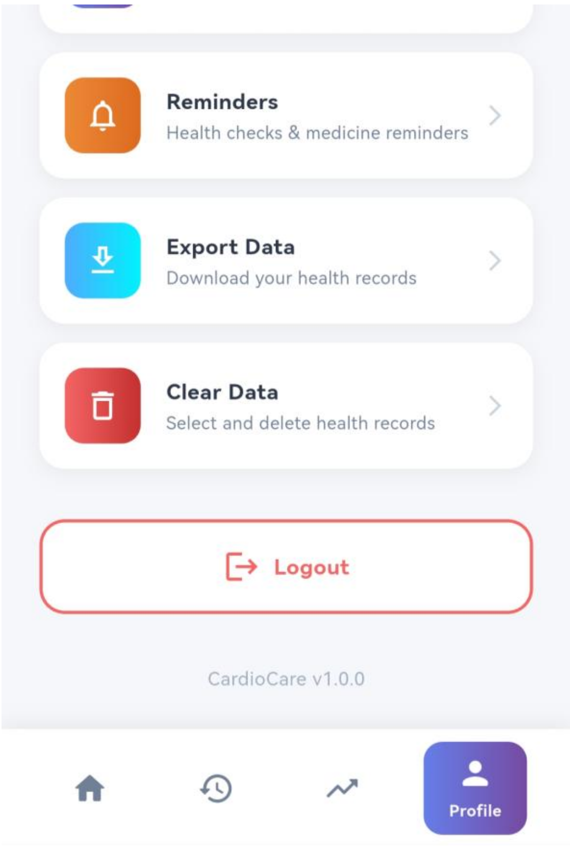
(a) (b) (c)

Figure 5.4.35 Recorded Blood Pressure Analysis in Trends and Analysis Page: (a) to (c) Displaying Recorded Blood Pressure Trends and Analysis

Profile Page

Figure 5.4.36 displays the Profile Page which begins by showing the user's personal information such as name, email address, age, gender, weight and height. There are a total of six functions provided in the Profile Page including edit profile, set reminders, export health data, clear health data and log out.



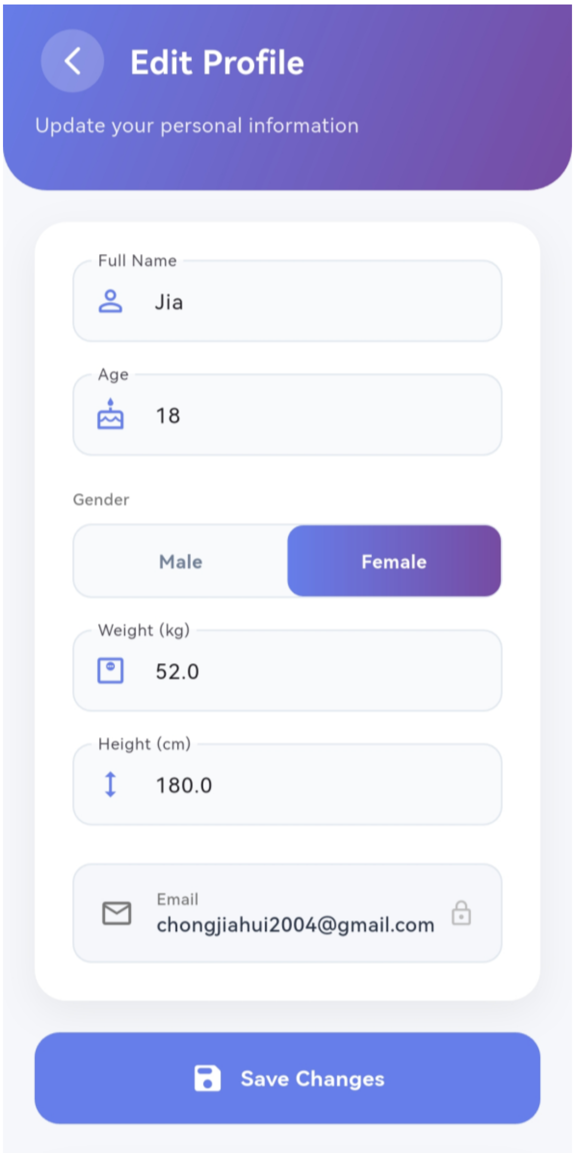


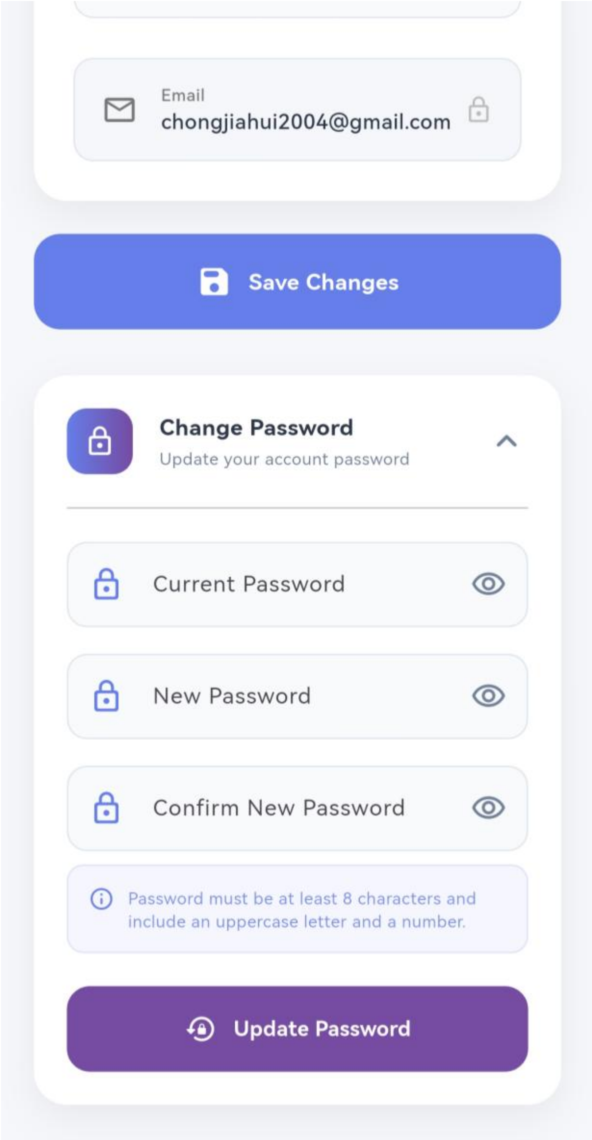
(a) (b)

Figure 5.4.36 Profile Page: (a) to (b) Displaying Profile Page

Edit Profile Page

Figure 5.4.37 shows the Edit Profile Page, which allows users to update their personal information such as name, age, gender, weight and height. In addition, users can also change their password which must contain at least eight characters including a special character and a number.





(a) (b)

Figure 5.4.37 Edit Profile Page: (a) to (b) Displaying Edit Profile Page

Reminders Page

Figure 5.4.38 shows the Reminder Page where the user can add reminders for daily health measurement tracking or medication by clicking the add icon. After clicking the add icon, a clock interface pops up as shown in Figure 5.4.39. The user scrolls the clock to the preferred time and clicks “OK” to set the reminder. For health measurement reminders, the application provides two options which are daily or weekly reminders. The user can choose either option based on their preference after setting the time as shown in Figure 5.4.40.

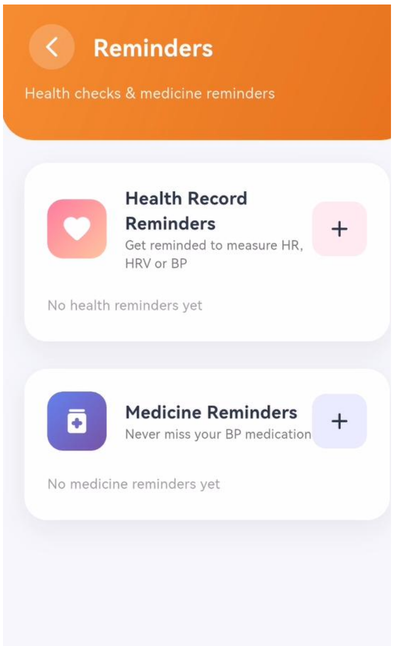


Figure 5.4.38 Reminders Page

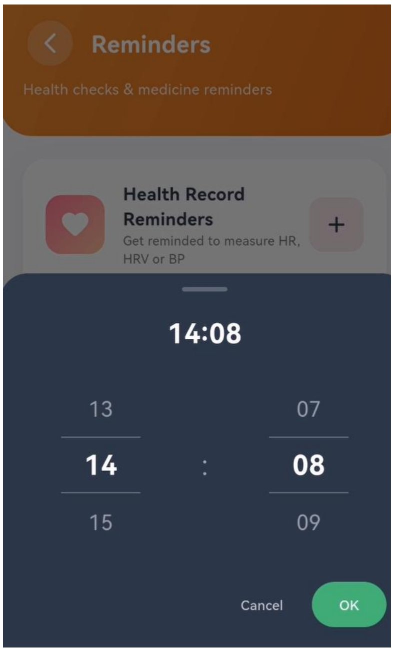


Figure 5.4.39 Set Reminder Time

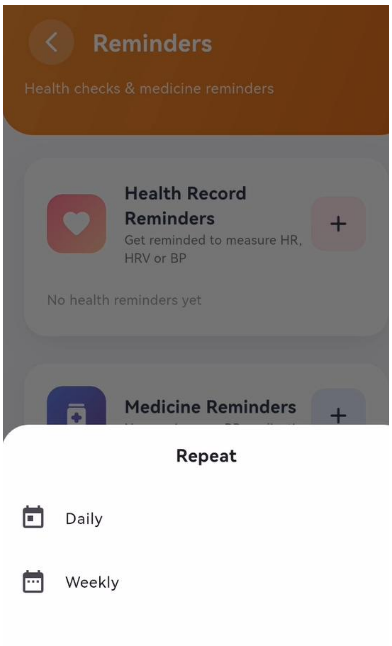
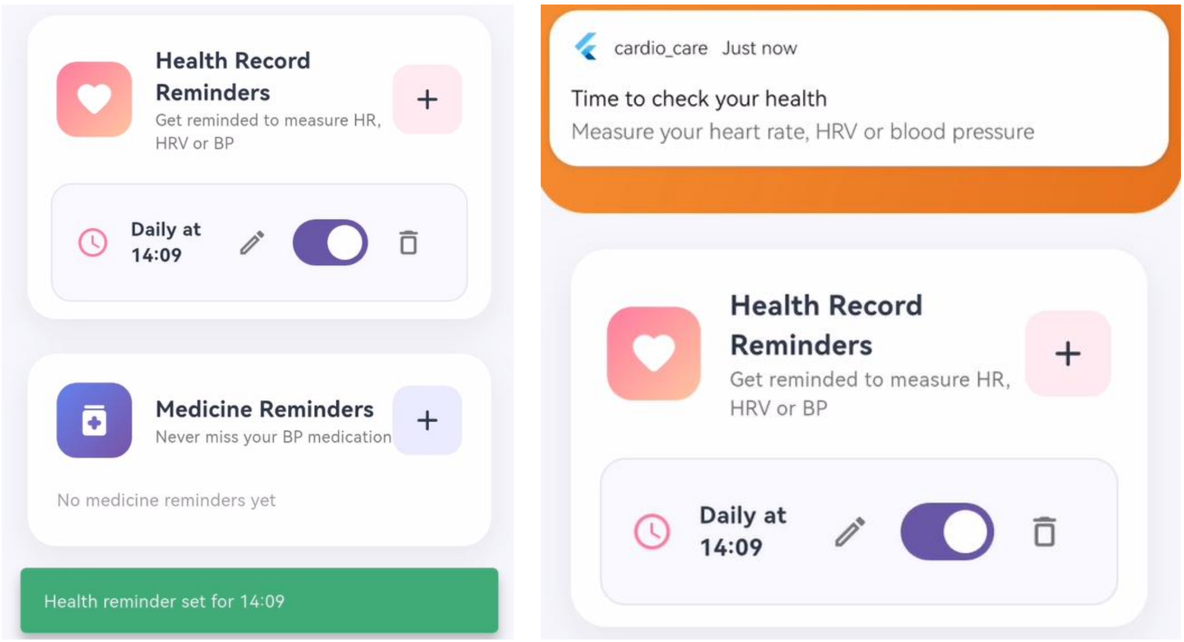


Figure 5.4.40 Set Reminder Repeat Frequency

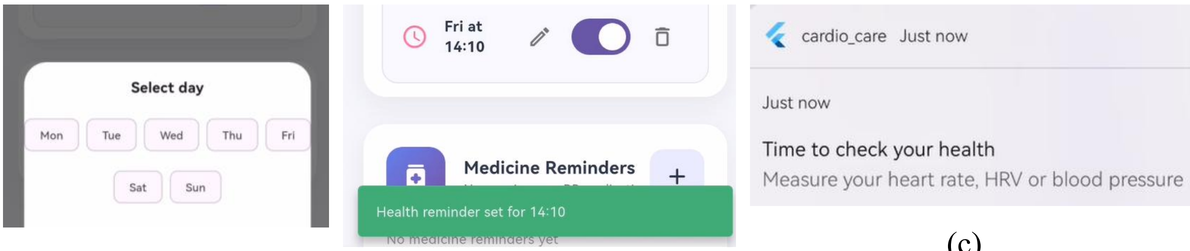
Figure 5.4.41 (a) shows that a daily reminder set at 14:09 is successfully created and a notification pops up at the specified time as displayed in Figure 5.4.41 (b).



(a) (b)

Figure 5.4.41 Set Daily Reminder: (a) Daily Reminder Set Successfully; (b) Daily Reminder is Functioning

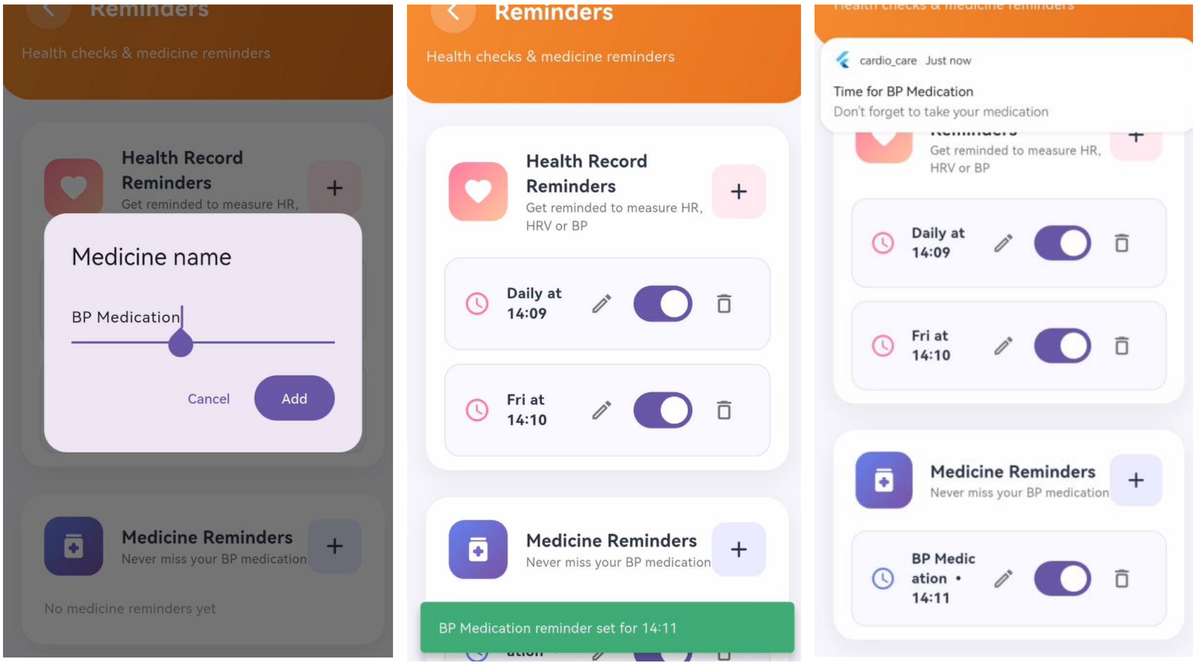
To set a weekly health measurement reminder, the same steps are followed which include clicking the add icon, selecting the preferred time, and choosing the weekly option. The application then prompts the user to select the preferred day to receive the notification each week as shown in Figure 5.4.42 (a). After selecting the day, a confirmation message is displayed as shown in Figure 5.4.42 (b) indicating that the reminder has been successfully set. Figure 5.4.42 (c) also demonstrates that the weekly reminder functions correctly by sending notifications to the user.



(a) (b) (c)

Figure 5.4.42 Set Weekly Reminder: (a) Prompt User Select A Day for Weekly Reminder; (b) Weekly Reminder Set Successfully; (c) Daily Reminder is Functioning

For medication reminders, the process is similar. The user clicks the add icon, sets the preferred time and is required to enter the medicine name as shown in Figure 5.4.43 (a). After entering the medicine name, the user clicks the add button. Figure 5.4.43 (b) shows that the medication reminder is successfully added and Figure 5.4.43 (c) shows the reminder functions properly by sending notifications to the user.



(a) (b) (c)

Figure 5.4.43 Set Medicine Reminder: (a) Prompt User to Enter Medicine Name; (b) Medicine Reminder Set Successfully; (c) Medicine Reminder is Functioning

Besides, edit and delete reminder functions are also provided. The user can click the edit icon beside the reminder and follow similar steps as when creating a reminder to update it. After the reminder is successfully updated, a confirmation message is displayed as shown in Figure 5.4.44. Next, the user can click the delete icon beside the reminder to remove it. A confirmation message is prompted as shown in Figure 5.4.45 asking the user to confirm the deletion of the reminder.

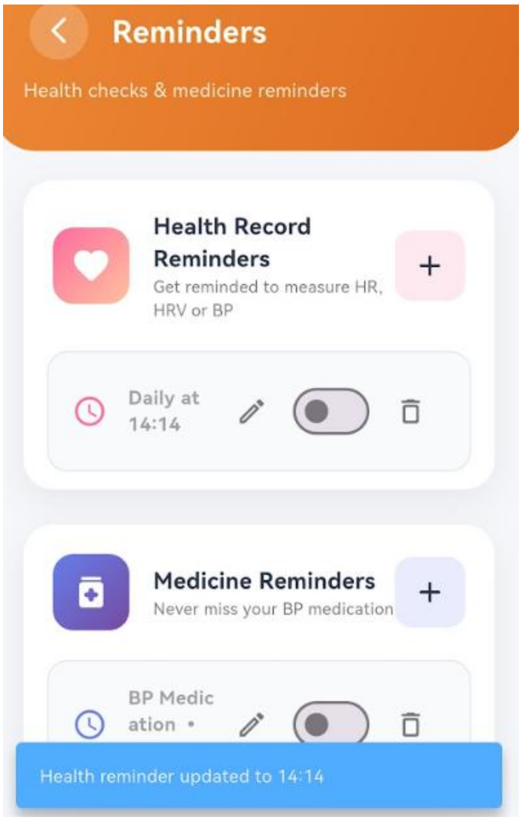


Figure 5.4.44 Reminder Updated Successfully Message

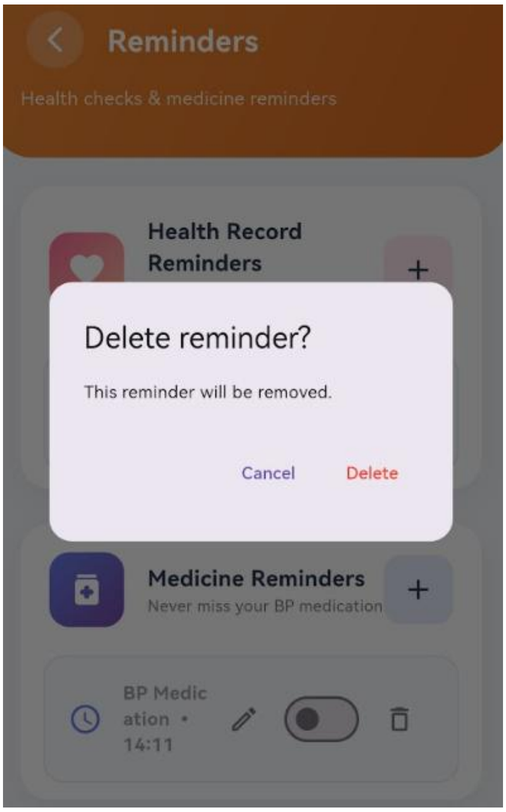


Figure 5.4.45 Delete Reminder Confirmation Message

Export Data Page

Figure 5.4.46 shows the Export Data Page which includes an export range that allows users to export all records or select a specific date range. The data can be exported in either Excel or PDF format and the total number of records is calculated and displayed to the user.

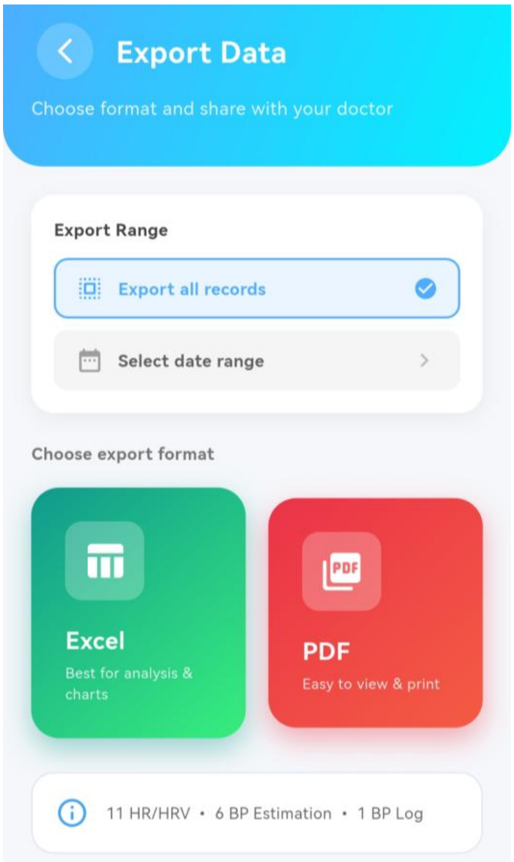
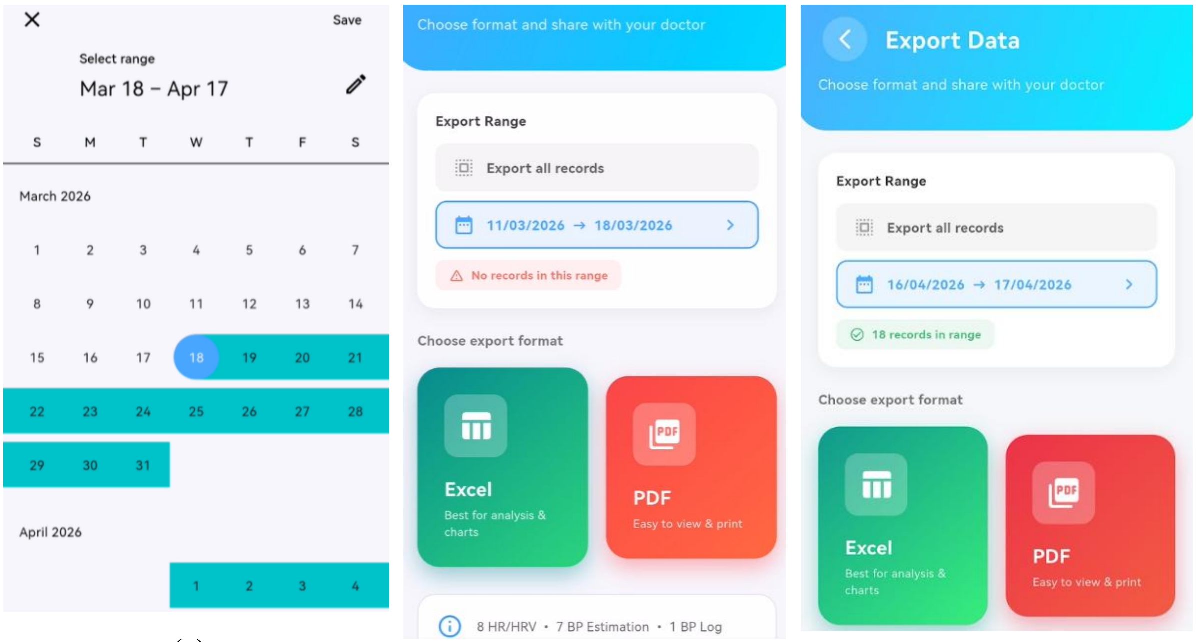


Figure 5.4.46 Delete Reminder Confirmation Message

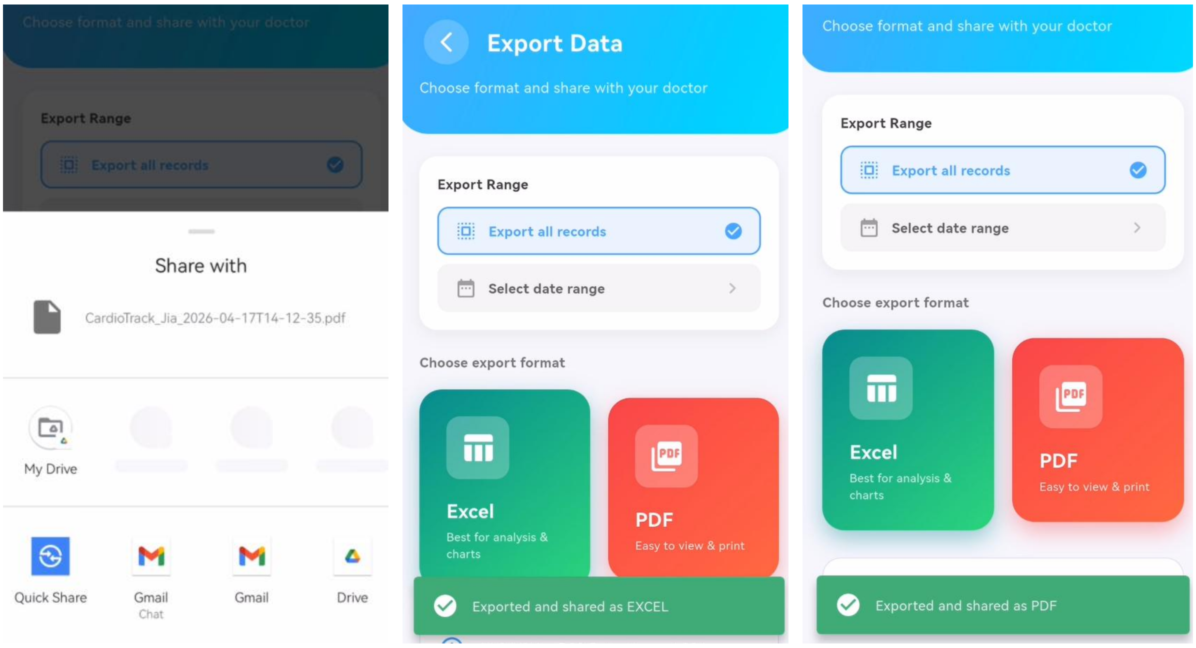
The application exports all data records by default. If the user wants to select a specific date range, click the "Select Date Range" option and a calendar interface will pop up as shown in Figure 5.4.47 (a). The user can click the edit icon to manually enter the date range or click on the date fields to select the start and end dates using the calendar interface. If the selected date range does not contain any records, the application will display a message indicating that no records were found as shown in Figure 5.4.47 (b). If records are available within the selected range, the application will indicate accordingly as shown in Figure 5.4.47 (c) and the user can proceed with exporting the data.



(a) (b) (c)

Figure 5.4.47 Set Date Range for Export Data: (a) Prompt User to Select Date Range; (b) Displaying No Record Found in the Date Range; (c) Displaying Records Found in the Date Range

To export the data, the user can click either the Excel or PDF icon to generate the corresponding file format. Figure 5.4.48 (a) shows the file sharing interface with social media icons. Figure 5.4.48 (b) demonstrates that the data has been successfully exported and shared in Excel format while Figure 5.4.48 (c) shows the data successfully exported in PDF format.



(a) (b) (c)

Figure 5.4.48 Export Data: (a) Displaying File Sharing Interface; (b) Displaying Exported in Excel Successfully; (c) Displaying Exported in PDF Successfully

Lastly, if the file is not successfully exported, an error message indicating that the file is not shared as shown in Figure 5.4.49 and Figure 5.4.50.

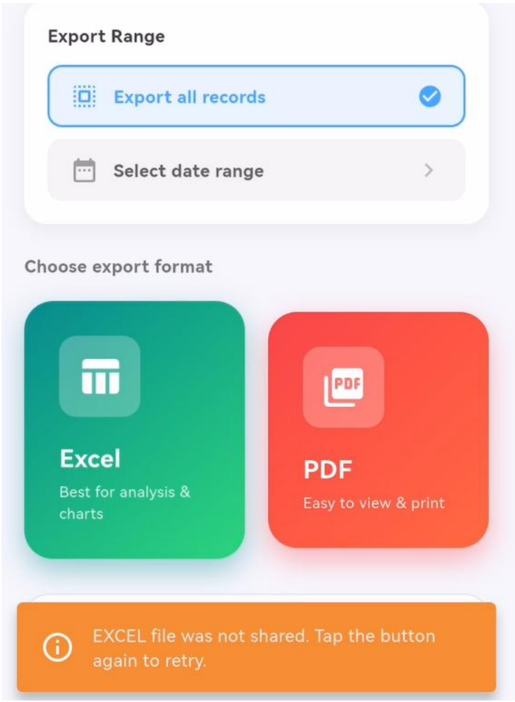


Figure 5.4.49 Error Message of Exporting Excel File

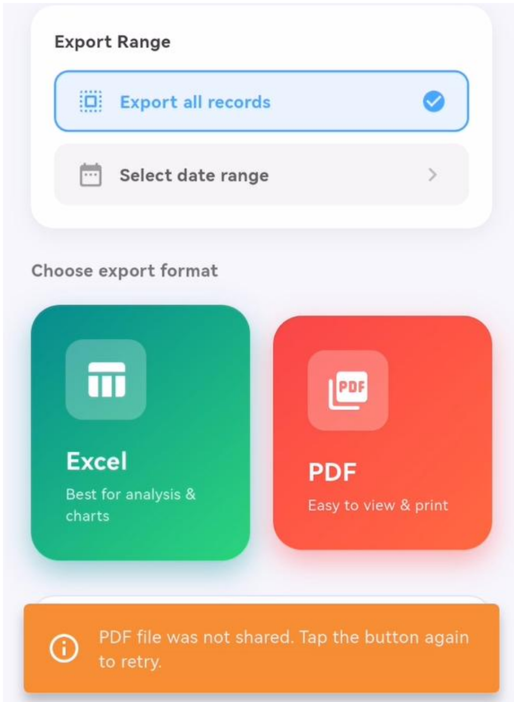
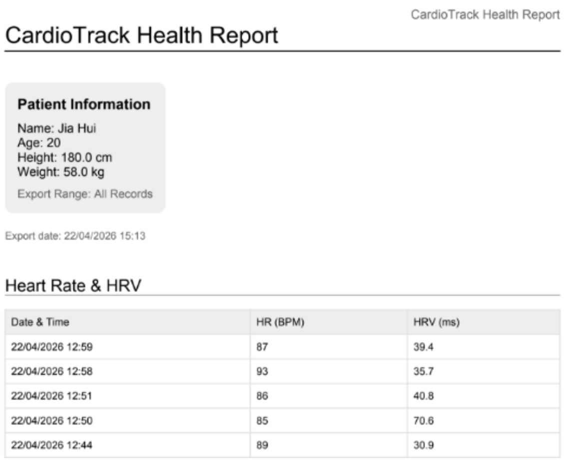


Figure 5.4.50 Error Message of Exporting PDF File

Figure 5.4.51 displays the exported health data in PDF format. It includes patient information such as name, age, height, and weight. The health data includes HR, HRV, BP estimation, and recorded BP. Each record includes a timestamp.



CardioTrack Health Report

CardioTrack Health Report

Patient Information

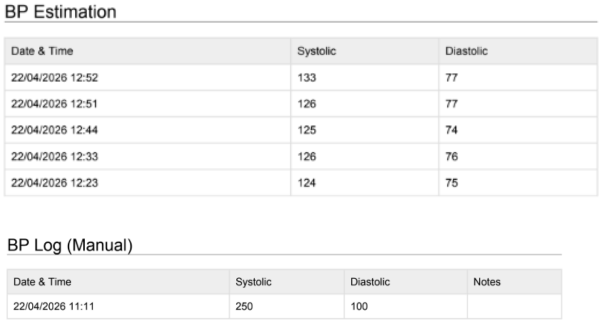
Name: Jia Hui
Age: 20
Height: 180.0 cm
Weight: 58.0 kg
Export Range: All Records

Export date: 22/04/2026 15:13

Heart Rate & HRV

Date & Time	HR (BPM)	HRV (ms)
22/04/2026 12:59	87	39.4
22/04/2026 12:58	93	35.7
22/04/2026 12:51	86	40.8
22/04/2026 12:50	85	70.6
22/04/2026 12:44	89	30.9

(a)



BP Estimation

Date & Time	Systolic	Diastolic
22/04/2026 12:52	133	77
22/04/2026 12:51	126	77
22/04/2026 12:44	125	74
22/04/2026 12:33	126	76
22/04/2026 12:23	124	75

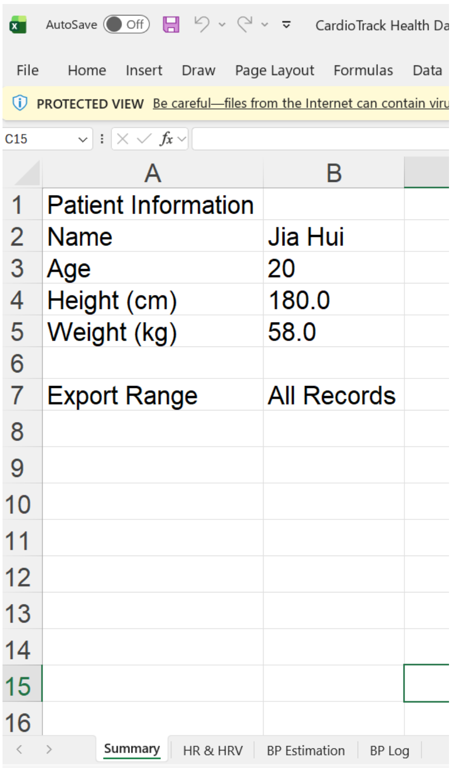
BP Log (Manual)

Date & Time	Systolic	Diastolic	Notes
22/04/2026 11:11	250	100	

(b)

Figure 5.4.51 Exported Data in PDF Format: (a) and (b) Displaying Exported PDF File

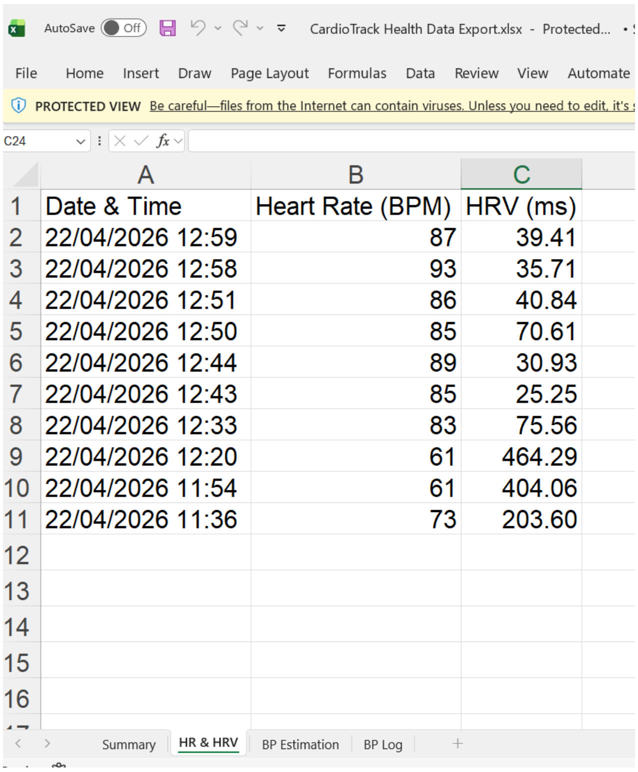
Figure 5.4.52 displays the exported health data in Excel format. The Excel file includes four sheets which are the patient summary, HR and HRV Records, Estimated BP Records, and Recorded BP Records.



	A	B
1	Patient Information	
2	Name	Jia Hui
3	Age	20
4	Height (cm)	180.0
5	Weight (kg)	58.0
6		
7	Export Range	All Records

Summary | HR & HRV | BP Estimation | BP Log

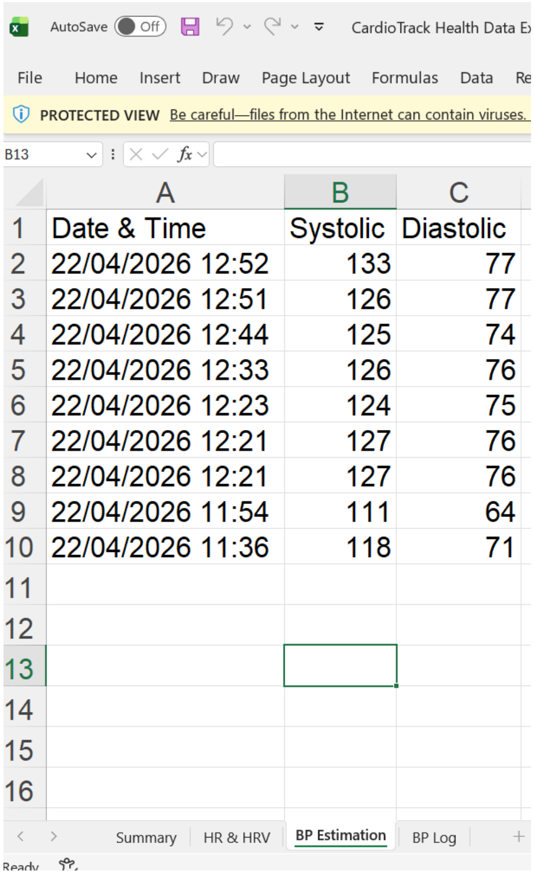
(a)



	A	B	C
1	Date & Time	Heart Rate (BPM)	HRV (ms)
2	22/04/2026 12:59	87	39.41
3	22/04/2026 12:58	93	35.71
4	22/04/2026 12:51	86	40.84
5	22/04/2026 12:50	85	70.61
6	22/04/2026 12:44	89	30.93
7	22/04/2026 12:43	85	25.25
8	22/04/2026 12:33	83	75.56
9	22/04/2026 12:20	61	464.29
10	22/04/2026 11:54	61	404.06
11	22/04/2026 11:36	73	203.60

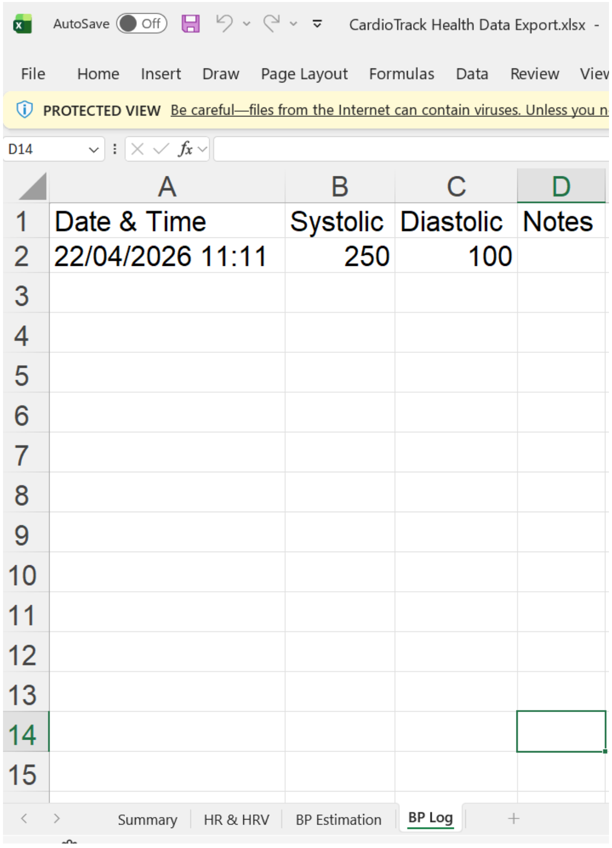
Summary | HR & HRV | BP Estimation | BP Log

(b)



Date & Time	Systolic	Diastolic
22/04/2026 12:52	133	77
22/04/2026 12:51	126	77
22/04/2026 12:44	125	74
22/04/2026 12:33	126	76
22/04/2026 12:23	124	75
22/04/2026 12:21	127	76
22/04/2026 12:21	127	76
22/04/2026 11:54	111	64
22/04/2026 11:36	118	71

(c)



Date & Time	Systolic	Diastolic	Notes
22/04/2026 11:11	250	100	

(d)

Figure 5.4.52 Exported Data in Excel Format: (a) to (d) Displaying Exported Excel File

Clear Data Page

Figure 5.4.53 displays the Clear Data Page which shows records including BP estimation, HR and HRV measurements, and recorded BP. The user can select all records to delete them or manually select specific records for deletion. A sorting function is also provided where the user can click the "Newest" or "Oldest" button to sort the records. The list is sorted with the newest records at the top by default. When the user clicks the sorting button, the list will be rearranged to display the oldest records first as shown in Figure 5.4.54. In addition, a “Delete All” button is also provided to the user for delete all records directly without the need to select them one by one.

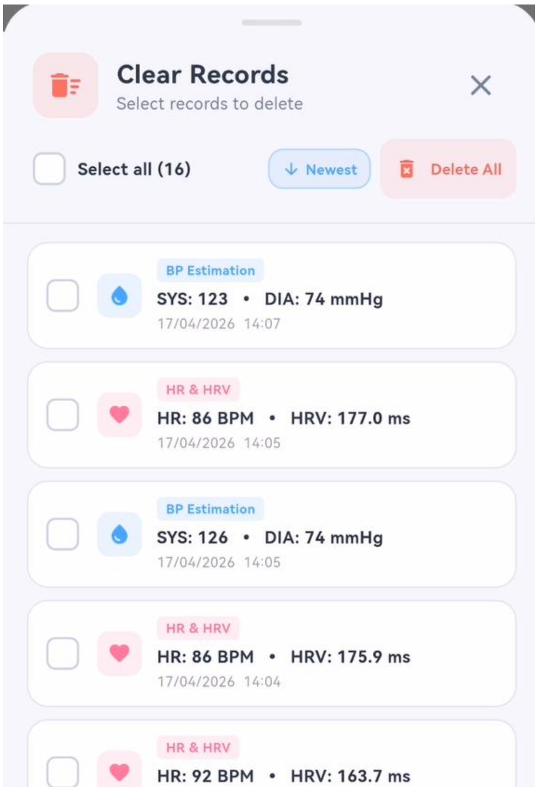


Figure 5.4.53 Clear Data Page

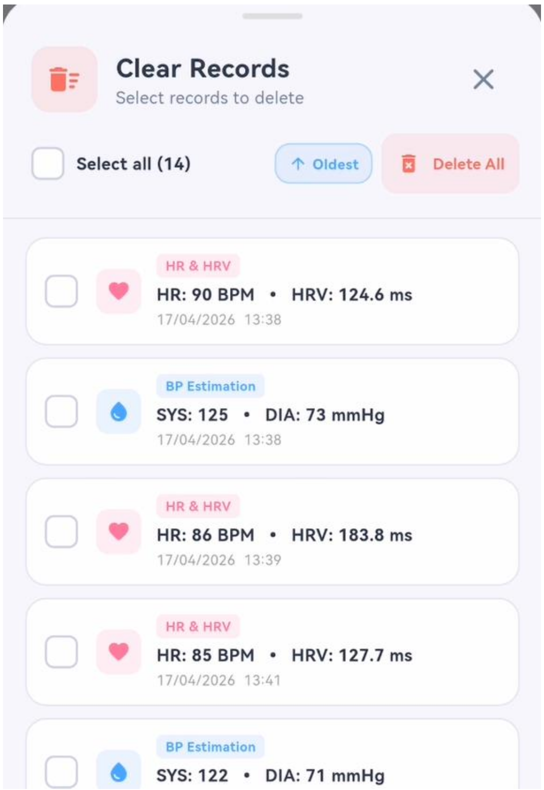


Figure 5.4.54 Records Sorted by Oldest

If the user selects all records, the selected items will be highlighted and the delete button will appear below as shown in Figure 5.4.55. When the user clicks the delete button, a confirmation message is then displayed asking the user to confirm the deletion of the records as shown in Figure 5.4.56. If the user clicks the "Delete" the records will be deleted.

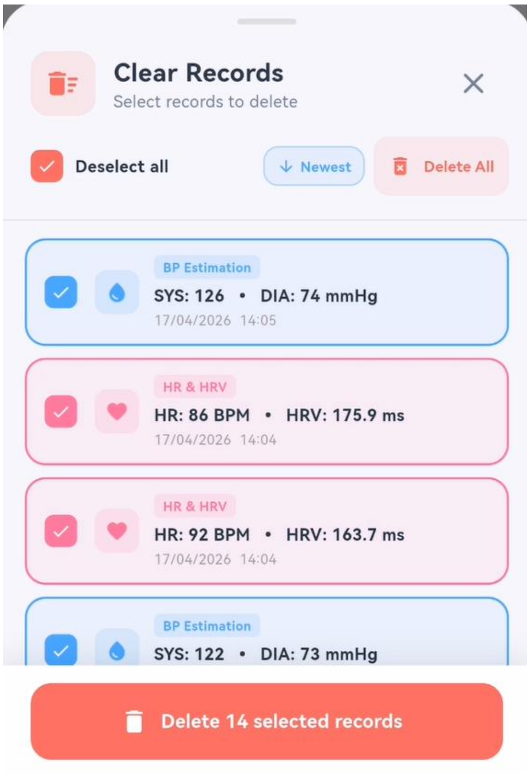


Figure 5.4.55 Select All Records

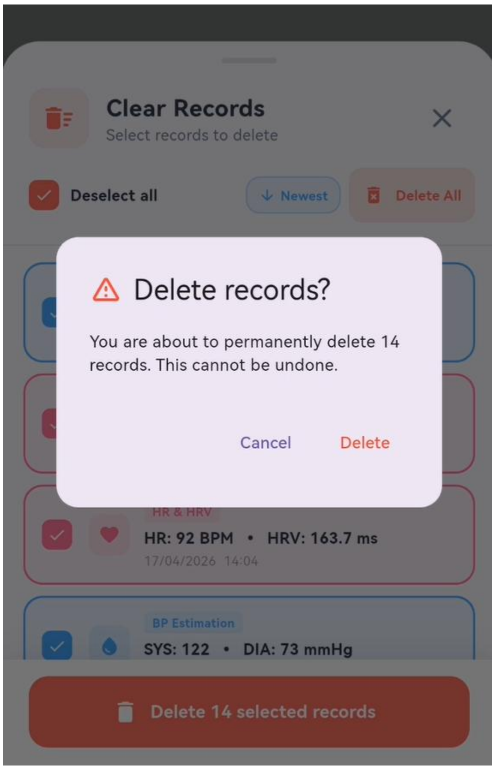


Figure 5.4.56 Delete Records Confirmation Message

Logout Page

Figure 5.4.57 shows the Logout Page which appears when the user clicks the "Logout" button in the Profile Page. A confirmation message is displayed asking the user to confirm the logout action. After the user confirms, the application redirects to the Login Page.

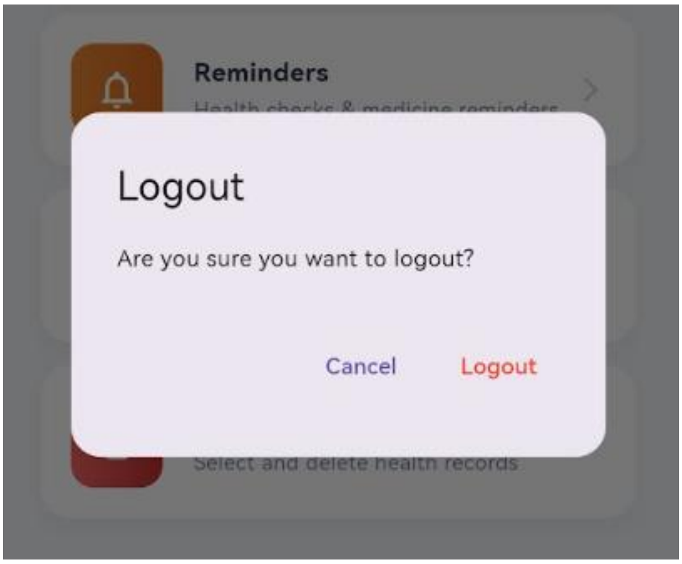


Figure 5.4.57 Logout Confirmation Message

5.5 Implementation Issues and Challenges

One major challenge was during the evaluation of the blood pressure (BP) estimation model using explainable artificial intelligence (XAI) which revealed that it relied heavily on the user's demographic information to predict BP values. This behavior was not aligned with the objective of the project, as the model is expected to prioritize physiological data such as the photoplethysmography (PPG) signals for BP prediction. This issue created a significant implementation challenge due to the tight timeline, requiring rapid refinement of the model and ensuring compliance with the cuff-less BP measurement standards. However, the model was successfully improved within the given timeframe and due to the use of XAI which proved the hidden biases in the original model which helped enhance the reliability of the BP estimation results.

Moreover, several development environment issues also occurred during the implementation phase due to the limited experience with Flutter and Android Studio. At one point, the Flutter Software Development Kit (SDK) became corrupted which was likely caused by accidental modification of the SDK folders and repeated failed builds. This leads to persistent errors such as Flutter daemon crashes and continuous file build failures. To resolve this issue, the Flutter SDK was reinstalled and the Android Studio was reconfigured.

Lastly, the challenges that arose were during the integration of the machine learning models with the Flutter application. First, the PPG signal quality assessment model was placed directly on the device. But it caused a heavy workload on the mobile hardware and resulted in noticeable performance drops. Therefore, all computationally intensive signal processing tasks were moved to the Python backend instead of running them on the mobile device.

5.6 Concluding Remark

In summary, the hardware and software specifications required for the CardioCare application were outlined. Besides, the software setup had also been shown to run the application smoothly. A complete installation guide and setup are provided as well. Lastly, the application is successfully developed according to the system design that was proposed in Chapter 4 and the application operation is presented according to each module. Although some problems were encountered during the development of CardioCare but it has been solved. The application is well prepared and can move to the next evaluation stage.

Chapter 6
System Evaluation and Discussion

In this chapter, a comprehensive evaluation of the developed application is presented, detailing the verification and validation strategies employed. It includes functional testing with test cases evaluated by comparing the expected and actual outputs. The chapter also concludes with an project objective evaluation and a discussion of the project challenges.

6.1 System Testing and Performance Metrics

This section discusses the testing techniques used in the proposed application along with the performance metrics defined for each model to ensure the practicality of the application. These evaluations are conducted to ensure that the developed application not only meets all functional requirements but also produces reliable results.

6.1.1 System Testing

The system testing technique selected for the CardioCare application is functional testing. According to [54], functional testing does not evaluate the source code but focuses on verifying each functionality of the application using appropriate inputs and expected outputs. The actual outputs are compared with the expected outputs to determine whether the system meets its intended objectives. Therefore, this section focuses on validating application functionalities rather than backend services such as API calls or database interactions.

6.1.2 System Performance Metrics

This section outlines the target performance criteria for the proposed application, including the accuracy of photoplethysmography (PPG) signal quality assessment, heart rate (HR), heart rate variability (HRV) and blood pressure (BP) estimation. In addition, mobile application performance is also defined. Table 6.1.2.1 shows the detailed system performance definition for the project.

Table 6.1.2.1 System Performance Definition

System Component	Performance Definition

Photoplethysmography (PPG) Signal Quality Assessment Model	The PPG Signal Quality Assessment model must **achieve at least 80% classification accuracy** and **a precision of at least 0.90** for identifying good quality signals. This ensures that the noisy or unreliable segments are filtered out before physiological analysis.
Blood Pressure (BP) Estimation Model	The BP estimation model aims to comply with standards from the Association for the Advancement of Medical Instrumentation (AAMI), International Organization for Standardization (ISO) and British Hypertension Society (BHS) [24, 25]. **AAMI/ISO Requirements:** • Mean Absolute Error (MAE) less than 5 mmHg • Standard Deviation (SD) at most 8 mmHg **BHS Protocol:** • Achieve Grade A classification for both systolic and diastolic BP predictions which is defined as at least 60%, 85% and 95% of readings within ±5, ±10 and ±15 mmHg respectively.
Heart Rate (HR) Measurement	Performance of HR measurement is evaluated by comparing the estimated values against reference ground truth data. The evaluation is performed using error-based and correlation metrics including: • **Mean Absolute Error (MAE):** measures the average absolute difference between the estimated and reference HR values [18]. • **Root Mean Square Error (RMSE):** Root mean square error between the estimated and ground truth HR values [19]. • **Pearson correlation (r):** measures the linear relationship between the estimated and reference HR values [18]. These metrics are used to assess both the accuracy of heart rate estimation and the consistency of trends produced by the HeartPy algorithm.
Heart Rate Variability (HRV) Measurement	Performance of HRV measurement is evaluated by comparing the estimated values against reference ground truth data. The assessment focuses on statistical agreement and trend consistency using the following metrics: • **Pearson correlation (r)**: measures the linear relationship between the estimated and reference HRV values [55].
Mobile Application Performance	The application **should provide smooth interaction**, **timely data updates and reliable communication with backend services** to ensure a seamless and responsive user experience.

6.1.3 System Verification Plan

This section outlines the verification procedures that were carried out during the review phase of the proposed application and the trained models. The application testing focuses on validating different types of inputs and evaluating the functional performance of each module. Model testing focuses on evaluating performance based on the defined metrics to determine whether the models meet the proposed performance standards.

Input Verification

- **Valid Inputs**

Valid inputs are used to confirm that the application processes the correct data as expected. For instance, enter a valid range for blood pressure (BP) records. For model training, missing or corrupted feature values are handled using appropriate imputation techniques to improve model robustness.

- **Invalid Inputs**

Invalid inputs are used to ensure that the application correctly detects, rejects incorrect data and displays appropriate error messages. For example, invalid BP entries, incorrect personal information and unrealistic value ranges are tested.

Functional Verification

- **Authentication Module**

Registration, login, logout, and incorrect credential handling are tested.

- **Photoplethysmography (PPG) Signal Quality Assessment Module**

The application must capture PPG signals from the smartphone camera and correctly classify them as good or poor quality. The poor quality signals must trigger a re-measurement prompt.

- **Heart Rate (HR) and Heart Rate Variability (HRV) Measurement Module**

The application must process valid PPG signals to compute reliable HR and HRV values. The results must be displayed in the application and stored in the Firestore database.

- **Blood Pressure (BP) Estimation Module**

The application must process valid PPG signals and generate BP estimation values. These values must be displayed in the application and stored in the Firestore database.

- **BP Recording Module**

Entered BP records must be correctly stored in the Firestore. Automatic BP classification such as normal, elevated and high must be displayed in the application.

- **History Module**

The application must display accurate user measurement history.

- **Trends and Analysis Module**

The application must visualize the user data through charts and summaries. Health insights and lifestyle recommendations must be generated and displayed in the application.

- **AI Cardio Assistant**

The application must analyze the user's past measurements and connect to the Google Gemini API to generate insights. It should provide meaningful feedback based on the user's records.

- **Profile Management Module**

The application must allow users to update their personal information.

- **Error Handling and Success Message**

The application must display appropriate error and success messages for user actions.

Model Verification Plan

- **Photoplethysmography (PPG) Signal Quality Assessment Model**

The photoplethysmography (PPG) signal quality assessment model is verified using an external dataset consisting of 51 fingertip PPG videos [38]. These videos are used to evaluate the model's ability to distinguish between good and poor quality signals. The evaluation is performed based on classification performance with emphasis on accuracy and precision, particularly for the identification of good quality signals. This ensures that only reliable PPG segments are passed to subsequent physiological analysis stages.

- **Blood Pressure (BP) Estimation Model**

The blood pressure (BP) estimation model is evaluated using a subject-wise calibration approach. For each subject, a global PPG-based model first predicts BP values. The first K samples are used for calibration using a Ridge regression model, while the remaining samples are used for testing. Performance is evaluated using Mean Error (ME), Standard Deviation (SD), Mean Absolute Error (MAE), and BHS grading percentages. The results are compared against AAMI/ISO and BHS standards to assess clinical acceptability. In addition, the BP estimation model is integrated into the mobile application and validated using an Ouson arm-type electronic blood pressure monitor as the reference device for real-world comparison

- **Heart Rate (HR) and Heart Rate Variability (HRV) Measurement Model**

The heart rate (HR) and heart rate variability (HRV) measurements are implemented using the open source HeartPy algorithm. The performance of this module is evaluated through both dataset-based testing and real-world validation.

For HR evaluation, an external dataset that consists of 51 fingertip PPG videos with reference ground truth values is used [38]. HR is computed using HeartPy and compared against the reference values. The performance is assessed using Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Pearson correlation coefficient (r) as defined in the performance metrics. In addition, the HR measurement is further validated by comparing the results with readings from an Apple Watch SE which serves as a reference device in real-world conditions.

For HRV evaluation, ECG recordings [37] are used as the reference ground truth values. R-peak detection is applied to extract RR intervals and the HRV metrics root mean square of successive differences (RMSSD) are computed. These reference values are then compared with the HRV outputs derived from PPG signals using HeartPy. The evaluation is performed using Pearson correlation to assess statistical agreement with the reference measurements.

6.2 Testing Setup and Result

This section presents the testing setup and corresponding results used to evaluate the performance of the developed models and the proposed application. It includes evaluation using datasets as well as real-world validation for each model to assess the reliability and effectiveness of the system. For the proposed application, each test case is discussed by comparing the expected output with the actual output.

6.2.1 Model Verification Testing Results

Photoplethysmography (PPG) Signal Quality Assessment Model

For validation, the trained model was evaluated using a dataset that consisted of 51 fingertip PPG videos [38]. Each video was processed using the signal quality assessment model to classify the signals as either good or poor quality. Figure 6.2.1.1 shows the sample outputs including the predicted class and corresponding confidence scores.

```
Found 51 videos in 'DatasetVideoFiles'.
------------------------------------------------------------
[1/51] ❌ 1.mp4 -> POOR Quality (Low Conf) (Conf: 0.3774)
[2/51] ✅ 10.mp4 -> GOOD Quality (Conf: 0.9354)
[3/51] ✅ 11.mp4 -> GOOD Quality (Conf: 0.9236)
[4/51] ❌ 12.mp4 -> POOR Quality (Low Conf) (Conf: 0.3774)
[5/51] ✅ 13.mp4 -> GOOD Quality (Conf: 0.8875)
[6/51] ✅ 14.mp4 -> GOOD Quality (Conf: 0.9326)
[7/51] ✅ 15.mp4 -> GOOD Quality (Conf: 0.8363)
[8/51] ✅ 16.mp4 -> GOOD Quality (Conf: 0.9402)
[9/51] ✅ 17.mp4 -> GOOD Quality (Conf: 0.9429)
[10/51] ❌ 18.mp4 -> POOR Quality (Low Conf) (Conf: 0.3774)
```

Figure 6.2.1.1 Display 10 Sample Results on PPG Signal Quality Assessment Validation

Based on Figure 6.2.1.2, out of the 51 videos, 36 were classified as good quality signals while 15 were identified as poor quality signals. The model achieved an average confidence score of 90% for good quality signals and 41% for poor quality signals. These results indicate that the model is capable of reliably identifying usable PPG signals while filtering out low-quality inputs. This evaluation complements the quantitative performance metrics such as accuracy, precision, recall, and F1-score that were reported in Chapter 4. As a result, this demonstrates the model's effectiveness under real-world signal conditions.

```
======================================
BATCH VALIDATION SUMMARY
======================================
Total Videos Processed: 51
✅ GOOD Signals: 36
❌ POOR Signals: 15
⚠️ERRORS:       0
--------------------------------------
📊 Overall Dataset Score: 0.7575
👍 Avg Confidence (GOOD): 0.9034
👎 Avg Confidence (POOR): 0.4076
```

Figure 6.2.1.2 Overall Result on PPG Signal Quality Assessment Validation

Blood Pressure (BP) Estimation Model

The blood pressure (BP) estimation model is integrated into the proposed application and further validated using an Ouson arm-type electronic blood pressure monitor as the reference device. Both the application and the reference device measurements are recorded simultaneously and the comparison results are shown in Figure 6.2.1.3.

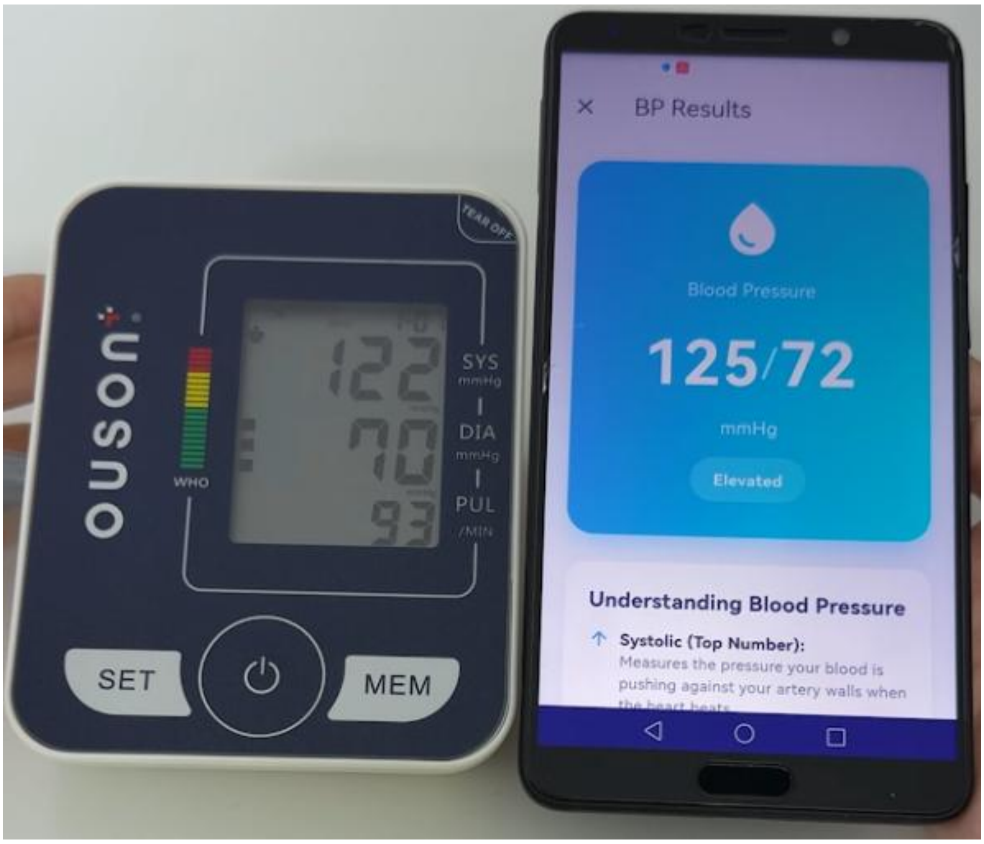


Figure 6.2.1.3 Result on Validating XGBoost BP Estimation Model using Ouson arm-type electronic BP monitor.

The estimated blood pressure values show a close agreement with the reference device readings indicating the practical reliability of the proposed system. This real-device validation supports the model-level evaluation that were reported in Chapter 4 where the model achieved a mean absolute error (MAE) of approximately 4–5 mmHg and satisfied the AAMI/ISO requirement of a standard deviation below 8 mmHg.

Heart Rate (HR) and Heart Rate Variability (HRV) Measurement Model

The heart rate (HR) measurement is validated using an Apple Watch SE as the reference device. Both the proposed application and the Apple Watch record HR simultaneously. As shown in Figure 6.2.1.4, the application records 93 BPM while the Apple Watch records 95

BPM and resulting in a difference of 2 BPM. This small deviation indicates that the HR estimation is reasonably accurate and suitable for practical use.

Figure 6.2.1.4 Comparing HR Recorded by Apple Watch SE 3 and Proposed Application

In addition, the HR measurement performance of the HeartPy algorithm is evaluated using the 50 fingertip PPG videos in the dataset [38] with one video excluded due to signal processing failure. The evaluation results include Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Pearson correlation coefficient as shown in Figure 6.2.1.5. The HeartPy algorithm achieves a MAE of 7.28 BPM and a RMSE of 11.47 BPM. The mean error of −0.81 ± 11.44 BPM indicates the absence of systematic bias. This implies the model does not consistently overestimate or underestimate heart rate values.

```
==================================================
       EVALUATION SUMMARY
==================================================
  Total videos processed : 51
  Successful             : 50
  Failed (HeartPy error) : 1
  Mean Error (ME)        : -0.81 ± 11.44 BPM
  MAE                    : 7.28 BPM
  RMSE                   : 11.47 BPM
  Pearson r              : 0.7467  (p = 0.0000)
```

Figure 6.2.1.5 Evaluation Summary of HR

A Pearson correlation coefficient of r = 0.7467 ($p < 0.001$) demonstrates a statistically significant moderate-to-strong agreement between the HeartPy-derived HR values and the ground truth measurements. This indicates that the algorithm is capable of reliably tracking heart rate trends across different subjects.

The higher RMSE compared to MAE implies the presence of a small number of outliers. It is likely caused by motion artifacts or low-quality PPG signals. Furthermore, the Bland–Altman analysis shows wide limits of agreement (−23.25 to +21.62 BPM) as shown in Figure 6.2.1.6 indicating variability in individual measurements. Nevertheless, given the absence of systematic bias and the moderate-to-strong correlation, the HeartPy HR is considered suitable for general wellness and cardiac monitoring applications.

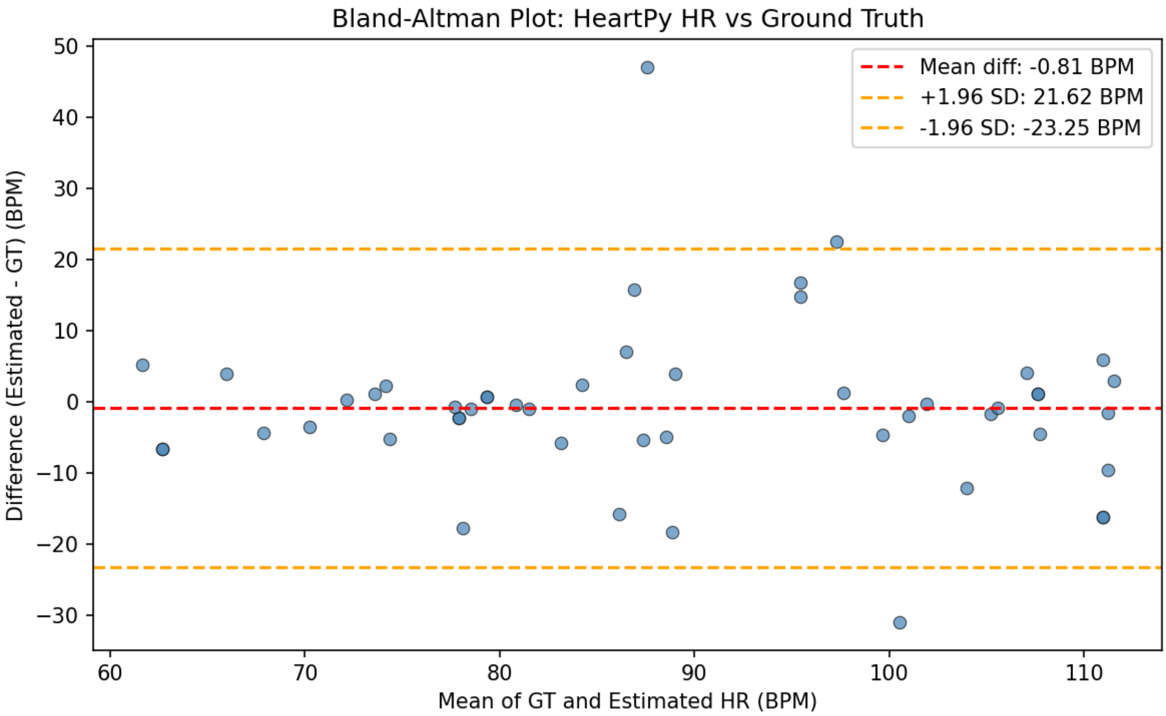


Figure 6.2.1.6 Bland-Altman Plot on HeartPy HR vs Ground Truth

The heart rate variability (HRV) measurement is validated using the electrocardiography (ECG)-based reference datasets [37]. The evaluation is performed by comparing RMSSD values derived from PPG signals with reference root mean square of successive differences (RMSSD) values obtained from ECG recordings. Statistical agreement is assessed using Pearson correlation coefficient and Figure 6.2.1.7 shows the sample codes on HRV validation.

```python
try:
    # 2. Load PPG and ECG Annotations (Ground Truth)
    rec = wfdb.rdrecord(ppg_path)
    # Load ECG Annotations to get REAL RMSSD
    ann = wfdb.rdann(ppg_path.replace('_PPG', ''), 'qrs')

    ppg_raw = rec.p_signal[:, 1].astype(float) if rec.p_signal.ndim > 1 else rec.p_signal.flatten().astype(float)

    # Check for short or flat signals
    if len(ppg_raw) < MIN_POINTS or np.std(ppg_raw) == 0:
        continue

    # 3. Calculate Reference (ECG) RMSSD
    ecg_rr = np.diff(ann.sample) * (1000.0 / 1000.0) # ECG is 1000Hz, so diff is already ms
    ref_rmssd = np.sqrt(np.mean(np.diff(ecg_rr)**2))

    # 4. Preprocess PPG
    ppg_clean, fs_new = preprocess_ppg(ppg_raw, original_fs=FS_PPG, target_fs=TARGET_FS)
    if ppg_clean is None: continue

    # 5. HeartPy Processing
    working_data, measures = hp.process(ppg_clean, sample_rate=fs_new,
                                        report_time=False)

    ppg_bpm = measures['bpm']
    ppg_rmssd = measures['rmssd']
```

Figure 6.2.1.7 Sample Codes on HRV Validation

The evaluation results show in Figure 6.2.1.8, which a low correlation (r = 0.0846) between PPG-derived and ECG-derived RMSSD values. This indicates that HRV estimation from smartphone-based PPG signals remains challenging due to sensitivity to noise, motion artifacts and sampling limitations. In this project, HRV results are interpreted based on trend consistency rather than absolute accuracy. The HRV measurement is used primarily as a supportive physiological indicator rather than a clinically precise diagnostic metric.

```
Validated 149108: ECG RMSSD 12.2 | PPG RMSSD 19.4

Final Correlation (r): 0.0846
```

Figure 6.2.1.8 HRV Validation Results

6.2.2 Functional Testing Results on Proposed Application

This section presents the test cases for each module in the proposed application. The actual results are compared with the expected results to determine the test outcomes and evaluate whether each function behaves as intended. Table 6.2.2.1 and Appendix A, A.4.1 to A.4.18 display all the test cases for each module.

Welcome Page and Onboarding Page Module

Table 6.2.2.1 Functional Test Cases for Welcome Page and Onboarding Page Module

Activity: **Welcome Page and Onboarding Page**				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User launches the proposed application.	Display the Welcome Page within 5 seconds.	The Welcome Page is displayed within 5 seconds.	Pass
TC02	User swipes through the Onboarding Page.	Display each OnBoarding Page.	The Onboarding Pages are displayed sequentially.	Pass
TC03	User clicks the "Skip" button at the top right of the Onboarding Page.	Display the Login Page.	The Login Page is displayed.	Pass
TC04	User clicks the "Get Started" button on the last Onboarding Page.	Display the Login Page.	The Login Page is displayed.	Pass

6.3 Project Challenges

Two main challenges and limitations were identified throughout the development and testing stages. The first challenge involves the heart rate (HR), heart rate variability (HRV), and blood pressure (BP) model services deployed on the Render cloud platform. Since the application is registered under Render's free-tier plan, the model services automatically enter a sleep state when they are not in use to conserve resources. As a result, the application attempts to wake up the model services when the user launches it. However, the wake-up process is not instantaneous. The user may need to wait approximately two minutes after launching the application before the model services become available. If the services fail to wake up within the expected time, an alert dialog is displayed to notify the user of a connection error and prompt them to retry the measurement.

The second challenge is related to the BP estimation model which combines an XGBoost model with a personal calibration layer using Ridge Regression . As the Ridge Regression enhances personalization by incorporating more user's recorded BP samples over time, the accuracy of the BP estimation improves with each subsequent measurement. Therefore, the initial BP estimation may be less accurate than the later attempts as the personalization layer requires sufficient historical data to refine its predictions.

6.4 Objectives Evaluation

A total of three project objectives were defined in Chapter 1.4. In this section, these objectives are evaluated to determine whether the project has achieved the predefined objectives.

i. To develop a computer vision–based model for cardiac monitoring.

This project utilizes fingertip photoplethysmography (PPG) signals as the primary source for cardiac monitoring. A computer vision–based approach is employed which a smartphone camera with flash is used to capture fingertip PPG signals and perform heart rate (HR), heart rate variability (HRV) and blood pressure (BP) estimation. Moreover, a PPG signal quality assessment model is implemented to ensure a reliable PPG signal extraction and allows only high quality signals to be used for cardiac monitoring.

ii. To implement a smartphone-based application integrating HR, HRV and BP monitoring pipeline for preventive hypertension management.

A mobile application named CardioCare has been developed using Flutter. A full scan measurement feature has been implemented, enabling users to measure heart rate (HR), heart rate variability (HRV) and blood pressure (BP) with a single tap by capturing fingertip PPG signals. Each health measurement is automatically classified into categories such as low, elevated and high. Additional features including trend analysis, personalized health insights, a chatbot-based AI assistant, reminders for hypertension management and data export for further consultation have been successfully implemented in CardioCare to support the early prevention and monitoring of hypertension.

iii. **To integrate explainable artificial intelligence (XAI) as a transparency and evaluation component within the hypertension monitoring pipeline.**

Explainable Artificial Intelligence (XAI) has been applied to interpret and evaluate the BP estimation model. The global permutation importance technique is used to identify the most influential factors affecting the BP estimation. The analysis reveals that the previous XGBoost models tended to over-rely on demographic features when predicting BP.

To address this limitation, a PPG-based XGBoost model combined with a personal calibration layer using Ridge Regression is adopted. The PPG-based XGBoost model focuses on physiological signal features for BP estimation while the Ridge Regression calibration incorporates user demographics to improve personalization and align with the requirements of a cuffless BP estimation system.

Furthermore, the PPG-based XGBoost model is validated using the Tree SHapley Additive exPlanations (TreeSHAP) to analyze how the PPG-derived features contribute to the BP prediction outcomes. This enables feature-level validation against established cardiovascular knowledge, ensuring that the model predictions are primarily driven by meaningful physiological signals rather than unrelated factors. Overall, the XAI techniques enhance the reliability, interpretability and trustworthiness of the BP estimation model.

6.5 Concluding Remark

In summary, the system performance metrics were defined together with the system verification plan. The trained models, including the photoplethysmography (PPG) signal quality assessment model, heart rate (HR) and heart rate variability (HRV) measurement model, and blood pressure (BP) estimation model were evaluated based on the verification plan and compared against the defined performance metrics. The results showed that the PPG signal quality model using Logistic Regression with physiological checks achieved 81% accuracy and 92% precision and was able to function effectively using real-time PPG data. Meanwhile, the BP estimation model integrated into the proposed application showed a good agreement with measurements obtained from the Ouson arm-type electronic blood pressure monitor. The HR estimation using the HeartPy algorithm also demonstrated good agreement with the reference measurements, while HRV showed low correlation with ECG and was therefore used only as a trend indicator. In addition, the developed mobile application, CardioCare, was evaluated using functional testing techniques. The results demonstrated that the application operated as expected, as the actual outputs matched the expected outputs. CardioCare was further assessed against the project objectives, confirming that the system successfully achieved them. Lastly, the project challenges were also discussed.

Chapter 7
Conclusion and Recommendation

This section concludes the report by summarizing the key achievements of the project, reflecting on its limitations, and identifying opportunities for future improvements. It highlights the practical contributions of the system and discusses potential future enhancements to enable the application to be used in real-world environments.

7.1 Conclusion

In conclusion, an accessible and affordable smartphone-based application named CardioCare has been developed to support preventive hypertension management. CardioCare successfully achieved the project objectives by integrating a computer vision–based technique that uses a smartphone camera with flash to capture fingertip photoplethysmography (PPG) signals. These signals are then processed to generate heart rate (HR), heart rate variability (HRV), and blood pressure (BP) estimation results.

A robust machine learning pipeline is implemented by incorporating a Logistic Regression-based signal quality assessment mechanism and reliable fingertip positioning using real-time RGB value analysis to ensure accurate and trustworthy fingertip PPG signal acquisition. Meanwhile, HR and HRV measurements are performed using the open-source HeartPy algorithm and the BP estimation is carried out using an XGBoost model with personal calibration via Ridge Regression to incorporate users' demographics. The BP estimation model is validated using explainable artificial intelligence (XAI) techniques including Permutation Importance and Tree SHapley Additive exPlanations (TreeSHAP) to confirm that the model predictions are primarily driven by meaningful physiological signals rather than unrelated factors.

Additional functionalities include BP recording for daily monitoring, personalized trend analysis, and lifestyle recommendations based on individual health patterns. A chatbot-based AI assistant is also integrated to answer user queries while analyzing the health records. Furthermore, reminder features for daily measurements and data export functions for medical consultation are provided. Through testing and evaluation, the proposed application was found to function effectively support users in managing hypertension and maintaining cardiac health.

7.2 Recommendation

Despite the current application meeting its primary objectives, several improvements can still be made. One key consideration is improving the blood pressure (BP) estimation accuracy. For instance, a more diverse user dataset can be collected and used to enhance the reliability of the BP estimation model as the current dataset does not exceed 4000 of datas. Therefore, a more diverse user group should be included in the future to further improve the model's generalization performance.

Another important recommendation is enhancing the real-time performance and reliability of the application. As the application currently depends on the Render cloud platform and may experience a cold start when the health measurement services are not in use. Therefore, a future enhancement is to introduce an offline fallback mode for essential services. This would reduce dependency on the cloud platform and improve the overall user experience.

Lastly, a potential improvement to the application is the integration of a location-based navigation feature that allows users to search for the nearest clinics or healthcare facilities. This feature would be particularly useful when abnormal health readings are detected or when users feel unwell and users can quickly locate a medical assistance when needed. By integrating a map-based service, the application can further enhance user support in preventive healthcare and encourage timely medical consultation.

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APPENDIX

A.1 Use Case Description

UC02 - Login Account

Table A.1.1 Use Case Description of Login Account

<table>
<tr><td>Use Case Name: Login Account</td><td>ID: UC02</td><td>Importance Level: High</td></tr>
<tr><td>Primary Actor: User</td><td colspan="2">Use Case Type: Detail, Essential</td></tr>
<tr><td colspan="3">Stakeholders and Interests:
User - wants to log in to the system.</td></tr>
<tr><td colspan="3">Brief Description:
This use case describes how the registered user logs in to the system using email and password.</td></tr>
<tr><td colspan="3">Trigger: The new user selects the “Login” option on the application login page.
Type: External</td></tr>
<tr><td colspan="3">Relationships:
Association: User
Include: None
Extend: Login Account Using Google Account
Generalization: None</td></tr>
<tr><td colspan="3">Normal Flow of Events:
1. The system displays the login form.
2. The user enters their registered email and password.
3. The user submits the login form.
4. The system checks whether all required fields are completed.
If any field is empty,
The S-1: Empty Field Alert is performed.
5. The system validates the format of the entered information.
If any input format is invalid,
The S-2: Invalid Format Alert is performed.
6. The system checks whether the user credentials match the records in the database.
If the credentials are not found,
The S-3: Invalid Credential Alert is performed.</td></tr>
</table>

7. Upon successful authentication, the system redirects the user to the application home page.
SubFlows: S-1: Empty Field Alert 1. The system displays an error message requesting the user to complete all required fields. 2. The user re-enters the missing information and resubmits the form. S-2: Invalid Format Alert 1. The system displays an error message for the invalid input format in the respective fields. 2. The user re-enters the correct input and resubmits the form. S-3: Invalid Credentials Alert 1. The system displays an error message for email or password is incorrect. 2. The user re-enters the correct credentials and resubmits the form.
Alternate/Exceptional Flows: 6a. If a network failure occurs during the authentication, the system displays an error message “Network error. Please check your internet connection and try again.” User reconnects to the internet and resubmits the login form.

UC03 - Login Account Using Google Account

Table A.1.2 Use Case Description of Login Account

Use Case Name: Login Account Using Google Account	ID: UC03	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to log in to the system using a Google Account.		
Brief Description: This use case describes how the user logs in to the system using a Google account.		
Trigger: The new user selects the “Login using Google Account” option on the application login page. Type: External		

Relationships: Association: User Include: None Extend: None Generalization: None
Normal Flow of Events: 1. The user clicks the “Login using Google Account” option on the application login page. 2. The system prompts the user to select a Google account. 3. The user selects a Google account. 4. The system authenticates the user via Google and verifies the authentication. 5. The system logs the user into the application. 6. The system redirects the user to the application home page. 7. The system checks whether the user has completed their profile. If the profile is incomplete, The S-1: Incomplete Profile Handling is performed.
SubFlows: S-1: Incomplete Profile Handling 1. The system prompts the user to complete their profile. 2. The user clicks the “Update Profile” button. 3. The system redirects the user to the Edit Profile page. 4. The user enters the personal information and clicks “Save”. 5. The system updates the user information to the database. 6. The system redirects the user to the application home page with a success message.
Alternate/Exceptional Flows: 4a. If a network failure occurs during the authentication, the system displays an error message “Network error. Please check your internet connection and try again.” User reconnects to the internet and clicks the “Login using Google Account” option on the application login page. 4b. If Google authentication fails, the system displays an error message “Google login failed.” The user returns to the login page.

S-1, 1a. The user clicks the "Later" button, the system allows the user access to the application home page. The system prompts the user to complete their profile whenever the user accesses the home page until the profile is completed.

UC04 – Reset Password

Table A.1.3 Use Case Description of Reset Password

Use Case Name: Reset Password	ID: UC04	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to reset their password to regain access to the application.		
Brief Description: This use case describes how the registered user resets their password through the "Forgot Password" option.		
Trigger: The user selects the "Forgot Password" option on the application login page. Type: External		
Relationships: Association: User Include: None Extend: None Generalization: None		
Normal Flow of Events: 1. The user selects the "Forgot Password" option on the login page. 2. The system prompts the user to enter their registered email address. 3. The user enters their email address. 4. The user clicks "Submit". 5. The system checks whether the required fields are completed. If the field is empty, The S-1: Empty Field Alert is performed. 6. The system validates the format of the entered email address. If the email format is invalid, The S-2: Invalid Format Alert is performed. 7. The system sends a password reset link to the registered email address. 8. The system displays "A password reset link has been sent to your email address".		

9. The user accesses their email and clicks the password reset link. 10. The system prompts the user to enter a new password. 11. The user enters and confirms the new password. 12. The system updates the password in the database and displays a confirmation message "Password successfully changed".
SubFlows: S-1: Empty Field Alert 1. The system displays an error message requesting the user to enter the required email address. 2. The user re-enters the email address and resubmits the request. S-2: Invalid Format Alert 1. The system displays an error message that the email format is invalid. 2. The user re-enters the correct email address and resubmits the request.
Alternate/Exceptional Flows: 4a. If a network failure occurs during the reset password process, the system displays an error message "Network error. Please check your internet connection and try again." User reconnects to the internet and resubmits the request.

UC05 – Full Scan Measurement

Table A.1.4 Use Case Description of Full Scan Measurement

Use Case Name: Full Scan Measurement	ID: UC05	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to measure their heart rate (HR), heart rate variability (HRV) and blood pressure (BP) simultaneously.		
Brief Description: This use case describes how the user measures their HR, HRV and BP using fingertip-based Photoplethysmography (PPG) signal capture.		
Trigger: The user selects the "Full Scan" option on the application home page. Type: External		
Relationships: Association: User		

Include: None

Extend: None

Generalization: None

Normal Flow of Events:

1. The user selects the “Full Scan” option on the home page.
2. The system displays the fingertip placement guide message for positioning the fingertip on the phone camera lens.
3. The user clicks the “Got it” button and places their fingertip on the camera lens.
4. The system checks whether the user’s fingertip fully covers the camera lens.
   If not fully covered,
   The S-1: Fingertip Placement Guide is performed.
5. The system starts a 20 second countdown timer and captures the user’s PPG signal data.
6. The system evaluates the quality of the captured PPG signals via the backend service.
   If the signal does not pass the quality assessment,
   The S-2: Insufficient PPG Signal Alert is performed.
7. The system analyses the PPG signal and performs HR, HRV and BP measurements via the backend service.
8. The backend service returns the HR, HRV and BP values to the application.
9. The system stores the measured results in the database.
10. The system displays the measurement results with automatic categorization.
11. The user can view the categorized results, view the definitions of the measurements with normal category range and view health recommendations based on the measurement results.

SubFlows:

S-1: Fingertip Placement Guide

1. The system displays the fingertip placement guide screen and instructs the user to cover the camera lens fully.
2. The user adjusts their fingertip position until the camera lens is fully covered.
3. The system evaluates whether the camera lens is completely covered. If the coverage is sufficient, the system proceeds to the measurement process.

S-2: Insufficient PPG Signal Alert 1. The backend service returns a failed response to the application. 2. The system displays an error message that the captured PPG signal quality is insufficient and prompts the user to try again. 3. The user selects the "OK" button. 4. The system redisplays the fingertip placement guide and prompts the user to retry the measurement.
Alternate/Exceptional Flows: 6a. If the system or network error occurs during signal analysis, the system displays an error message and prompts the user to retry the measurement.

UC06 – Heart Rate and Heart Rate Variability Measurement

Table A.1.5 Use Case Description of Heart Rate and Heart Rate Variability Measurement

Use Case Name: Heart Rate and Heart Rate Variability Measurement	ID: UC06	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to measure their heart rate (HR) and heart rate variability (HRV).		
Brief Description: This use case describes how the user measures their HR and HRV using fingertip-based photoplethysmography (PPG) signal capture.		
Trigger: The user selects the "Heart Rate Monitor" option on the application home page. Type: External		
Relationships: Association: User Include: None Extend: None Generalization: None		
Normal Flow of Events: 1. The user selects the "Heart Rate Monitor" option on the home page. 2. The system displays the fingertip placement guide for positioning the fingertip on the phone camera lens. 3. The user clicks the "Got it" button and places their fingertip on the camera lens.		

4. The system checks whether the user's fingertip fully covers the camera lens. If not fully covered, The S-1: Fingertip Placement Guide is performed. 5. The system starts a 20 second countdown timer and captures the user's PPG signal data. 6. The system evaluates the quality of the captured PPG signals via the backend service. If the signal does not pass the quality assessment, The S-2: Insufficient PPG Signal Alert is performed. 7. The system analyses the PPG signal and performs HR and HRV measurements via the backend service. 8. The backend service returns the HR and HRV values to the application. 9. The system stores the measured results in the database. 10. The system displays the measurement results with automatic categorization. 11. The user can view the categorized results, view the definitions of the measurements with normal category range and view health recommendations based on the measurement results.
SubFlows: S-1: Fingertip Placement Guide 1. The system displays the fingertip placement guide screen and instructs the user to cover the camera lens fully. 2. The user adjusts their fingertip position until the camera lens is fully covered. 3. The system evaluates whether the camera lens is completely covered. If the coverage is sufficient, the system proceeds to the measurement process. S-2: Insufficient PPG Signal Alert 1. The backend service returns a failed response to the application. 2. The system displays an error message that the captured PPG signal quality is insufficient and prompts the user to try again. 3. The user selects the "OK" button. 4. The system redisplays the fingertip placement guide and prompts the user to retry the measurement.
Alternate/Exceptional Flows:

6a. If the system or network error occurs during signal analysis, the system displays an error message and prompts the user to retry the measurement.

UC07 – Blood Pressure Estimation

Table A.1.6 Use Case Description of Blood Pressure Estimation

Use Case Name: Blood Pressure Estimation	ID: UC07	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to estimate their blood pressure (BP).		
Brief Description: This use case describes how the user estimates their BP using fingertip-based Photoplethysmography (PPG) signal capture.		
Trigger: The user selects the "Blood Pressure Estimation" option on the application home page. Type: External		
Relationships: Association: User Include: None Extend: None Generalization: None		
Normal Flow of Events: 1. The user selects the "Blood Pressure Estimation" option on the home page. 2. The system displays the fingertip placement guide for positioning the fingertip on the phone camera lens. 3. The user clicks the "Got it" button and places their fingertip on the camera lens. 4. The system checks whether the user's fingertip fully covers the camera lens. If not fully covered, The S-1: Fingertip Placement Guide is performed. 5. The system starts a 20 second countdown timer and captures the user's PPG signal data. 6. The system evaluates the quality of the captured PPG signals via the backend service. If the signal does not pass the quality assessment,		

The S-2: Insufficient PPG Signal Alert is performed. 7. The system analyses the PPG signal and performs BP estimation via the backend service. 8. The backend service returns the estimated systolic and diastolic BP values to the application. 9. The system stores the estimation results in the database. 10. The system displays the estimation results with automatic categorization. 11. The user can view the categorized results, view the definitions of the BP, view the BP normal category range and view health recommendations based on the estimation results.
SubFlows: S-1: Fingertip Placement Guide 1. The system displays the fingertip placement guide screen and instructs the user to cover the camera lens fully. 2. The user adjusts their fingertip position until the camera lens is fully covered. 3. The system evaluates whether the camera lens is completely covered. If the coverage is sufficient, the system proceeds to the measurement process. S-2: Insufficient PPG Signal Alert 1. The backend service returns a failed response to the application. 2. The system displays an error message that the captured PPG signal quality is insufficient and prompts the user to try again. 3. The user selects the “OK” button. 4. The system redisplays the fingertip placement guide and prompts the user to retry the measurement.
Alternate/Exceptional Flows: 6a. If the system or network error occurs during signal analysis, the system displays an error message and prompts the user to retry the measurement.

UC08 – Record Blood Pressure

Table A.1.7 Use Case Description of Record Blood Pressure

Use Case Name: Record Blood Pressure	ID: UC08	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	

Stakeholders and Interests: User - wants to record their actual blood pressure (BP) values manually.
Brief Description: This use case describes how the user manually records their measured systolic and diastolic BP using the application.
Trigger: The user selects the “Record Blood Pressure” option on the application home page. Type: External
Relationships: Association: User Include: None Extend: None Generalization: None
Normal Flow of Events: The user selects the “Record Blood Pressure” option on the home page. The system displays the input fields for systolic BP, diastolic BP and an optional notes field. The user enters their measured systolic and diastolic BP values and may optionally enter additional notes. The user clicks the “Save” button. The system checks whether the required fields are completed. If the required field is empty, The S-1: Empty Field Alert is performed. The system validates the range of the entered BP values. If the value range is invalid, The S-2: Invalid Value Range Alert is performed. The system stores the BP record in the database. The system displays the categorized BP result along with the health recommendations. The user clicks the “OK” button.). The system displays a confirmation message indicating that the BP record has been successfully saved and redirects the user to the home page.
SubFlows: S-1: Empty Field Alert

1. The system displays an error message requesting the user to complete all required fields. 2. The user re-enters the missing information and resubmits the form. S-2: Invalid Value Range Alert 1. The system displays an error message requesting the user to enter the valid systolic and diastolic BP values. 2. The user re-enters the valid BP values and resubmits the form.
Alternate/Exceptional Flows: 4a. If the network error occurs during saving, the system displays an error message and prompts the user to retry.

UC09 – View Health History

Table A.1.8 Use Case Description of View Health History

Use Case Name: View Health History	ID: UC09	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to view the recorded health history.		
Brief Description: This use case describes how the user views the recorded health history in the application.		
Trigger: The user selects the "History" option on the application navigation bar. Type: External		
Relationships: Association: User Include: None Extend: None Generalization: None		
Normal Flow of Events: 1. The user selects the "History" option on the application navigation bar. 2. The system displays the past HR, HRV, estimated BP and recorded BP records. 3. The user selects the respective category and views all the records with the corresponding timestamp. If the user wants to view HR and HRV records,		

The S-1: Display HR and HRV Records is performed. If the user wants to view BP estimation records, The S-2: Display BP Estimation Records is performed. If the user wants to view recorded BP records, The S-3: Display Recorded BP Records is performed.
SubFlows: S-1: Display HR and HRV Records 1. The user selects the "HR & HRV Records" option on the History page. 2. The system displays the user's past HR and HRV records. S-2: Display BP estimation Records 1. The user selects the "BP Estimation Records" option on the History page. 2. The system displays the user's past estimated BP records. S-3: Display Recorded BP Records 1. The user selects the "Recorded BP Records" option on the History page. 2. The system displays the user's past recorded BP records.
Alternate/Exceptional Flows: None

UC10 – View Trends and Analysis

Table A.1.9 Use Case Description of View Trends and Analysis

Use Case Name: View Trends and Analysis	ID: UC10	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to monitor the health measurement trends and receive insights and recommendations.		
Brief Description: This use case describes how the user views their health measurement trends and related analysis in the application.		
Trigger: The user selects the "Trends" option on the application navigation bar. Type: External		
Relationships: Association: User		

Include: None Extend: None Generalization: None
Normal Flow of Events: 1. The user selects the “Trends” option on the application navigation bar. 2. The system displays the trends page with a date selector and range options. 3. By default, the system displays the latest 7 day trend in bar chart format. 4. The user clicks “Filter option”. 5. The user may select a specific date from the date selector and select either a 7 day or 30 day range to view the health measurement trends. 6. The system checks the user’s health records in the database If the health records are insufficient, The S-1: Insufficient Records Alert is performed. 7. The system retrieves the corresponding health records for the selected period in the database. 8. The user clicks the corresponding measurement metrics to view each trend record. 9. The system displays the measurement definitions, health measurement trends on the selected period, the measurement category guide, the user’s health information summary and the general recommendations.
SubFlows: S-1: Insufficient Records Alert 1. The system displays the meaning of each measurement. 2. The system displays“Insufficient records to provide insights”. 3. The trend analysis and recommendations are not displayed.
Alternate/Exceptional Flows: None

UC11 – Update Profile Information

Table A.1.10 Use Case Description of Update Profile Information

Use Case Name: Update Profile Information	ID: UC11	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to update the profile information.		
Brief Description:		

This use case describes how the user updates the profile information.
Trigger: The user selects the "Edit Profile" option on the profile page. Type: External
Relationships: Association: User Include: None Extend: Update Password Generalization: None
Normal Flow of Events: 1. The user selects the "Edit Profile" option on the profile page. 2. The system displays the information of the user profile. 3. The user edits the information that they want to update. 4. The user clicks the "Save Changes" button. 5. The system checks whether all required fields are completed. If any field is empty, The S-1: Empty Field Alert is performed. 6. The system validates the format of the entered information. If any input format is invalid, The S-2: Invalid Format Alert is performed. 7. The system updates the profile information in the database. 8. The system displays a confirmation message indicating that the profile details are updated and redirects the user to the profile page.
SubFlows: S-1: Empty Field Alert 1. The system displays an error message requesting the user to complete the required field. 2. The user completes the required field and resubmits the form. S-2: Invalid Format Alert 1. The system displays an error message that the input format is invalid. 2. The user re-enters the valid format and resubmits the form.
Alternate/Exceptional Flows: 5a. If the network error occurs during saving, the system displays an error message and prompts the user to retry.

UC12 – Update Password

Table A.1.11 Use Case Description of Update Password

<table>
<tr><td>Use Case Name: Update Password</td><td>ID: UC12</td><td>Importance Level: High</td></tr>
<tr><td>Primary Actor: User</td><td colspan="2">Use Case Type: Detail, Essential</td></tr>
<tr><td colspan="3">Stakeholders and Interests:
User - wants to update their password within the application.</td></tr>
<tr><td colspan="3">Brief Description:
This use case describes how a user updates their password after logging into the application.</td></tr>
<tr><td colspan="3">Trigger: The user selects the “Edit Profile” option on the profile page and clicks the “Change Password” button.
Type: External</td></tr>
<tr><td colspan="3">Relationships:
Association: User
Include: None
Extend: None
Generalization: None</td></tr>
<tr><td colspan="3">Normal Flow of Events:
1. The user selects the “Edit Profile” option on the profile page.
2. The user clicks the “Change Password” button.
3. The system prompts users to enter the current password and the new password.
4. The user enters the current password and the new password.
5. The user clicks the “Save” button.
6. The system checks whether all the required fields are completed.
If any field is empty,
The S-1: Empty Field Alert is performed.
7. The system checks that the current password matches the stored password in the database.
If the password does not match the stored password,
The S-2: Authentication Failed is performed.
8. The system validates the new password format.
If the new password format is invalid,
The S-3: Invalid Format Alert is performed.
9. The system updates the password in the database.</td></tr>
</table>

10. The system displays a confirmation message indicating that the password has been updated and redirects the user to the profile page.
SubFlows: S-1: Empty Field Alert 1. The system displays an error message requesting the user to complete the required field. 2. The user completes the required field and resubmits the form. S-2: Authentication Failed Alert 1. The system displays “Authentication failed” and prompts the user to re-enter a valid current password. 2. The user re-enters the valid current password and resubmits the form. S-3: Invalid Format Alert 1. The system displays an error message that the input password format is invalid. 2. The user re-enters the valid password format and resubmits the form.
Alternate/Exceptional Flows: 9a. If the network error occurs during updating the password, the system displays an error message and prompts the user to retry.

UC13 – Set Reminder

Table A.1.12 Use Case Description of Set Reminder

Use Case Name: Set Reminder	ID: UC13	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to set reminders to receive notifications in the application.		
Brief Description: This use case describes how the user sets reminders in the profile page.		
Trigger: The user selects the “Reminders” option on the profile page. Type: External		
Relationships: Association: User Include: None Extend: Edit Reminder Delete Reminder		

Generalization: None
Normal Flow of Events: 1. The user selects the “Reminders” option on the profile page. 2. The system displays the health record reminders and medicine reminders options. If the user selects medicine reminders, The S-1: Medicine Reminders Function is performed. 3. The user clicks “+” icon in the Health Record Reminders section. 4. The system displays the reminder time. 5. The user sets the reminder by scrolling through the reminder time. 6. The user clicks “OK”. 7. The system prompts for the repeating option which is either daily or weekly. 8. The user selects the preferred receive notification time. 9. The system displays a confirmation message that the reminder is set. If the user wants to deactivate the reminder, The S-2: Deactivate Reminder Function is performed.
SubFlows: S-1: Medicine Reminder Function 1. The user clicks the edit icon in the selected medicine reminder. 2. The system displays the reminder time for editing. 3. The user sets the reminder time by scrolling through the time. 4. The user clicks “OK”. 5. The system prompts the user to enter the medicine name. 6. The user enters the medicine name. 7. The user clicks “Add”. The system displays a confirmation message that the reminder is updated. S-2: Deactivate Reminder Function 1. The user clicks the slicer icon to deactivate the reminder. 2. The system deactivates the reminder.
Alternate/Exceptional Flows: None

UC14 – Edit Reminder

Table A.1.13 Use Case Description of Edit Reminder

Use Case Name: Edit Reminder	ID: UC14	Importance Level: High

<table>
<tr><td>Primary Actor: User</td><td>Use Case Type: Detail, Essential</td></tr>
<tr><td colspan="2">Stakeholders and Interests:
User - wants to edit the reminders in the application.</td></tr>
<tr><td colspan="2">Brief Description:
This use case describes how the user edits reminders in the profile page.</td></tr>
<tr><td colspan="2">Trigger: The user selects the “Reminders” option on the profile page and wants to edit the reminders.
Type: External</td></tr>
<tr><td colspan="2">Relationships:
Association: User
Include: None
Extend: None
Generalization: None</td></tr>
<tr><td colspan="2">Normal Flow of Events:
1. The user selects the “Reminders” option on the profile page.
2. The user wants to edit the reminders.
If the user selects medicine reminders,
The S-1: Edit Medicine Reminders Function is performed.
3. The user clicks the edit icon beside the reminder in the Health Record Reminder list that they want to edit.
4. The system displays the reminder time for editing.
5. The user reset the reminder time by scrolling through the time.
6. The user clicks “OK”.
7. The system prompts for the repeating option which is either daily or weekly.
8. The user selects the preferred notification time.
9. The system displays a confirmation message that the reminder is updated.</td></tr>
<tr><td colspan="2">SubFlows:
S-1: Edit Medicine Reminder Function
8. The user clicks the edit icon in the selected medicine reminder.
9. The system displays the reminder time for editing.
10. The user sets the reminder time by scrolling through the time.
11. The user clicks “OK”.
12. The system prompts the user to enter the medicine name.</td></tr>
</table>

13. The user enters the updated medicine name. 14. The user clicks "Save". 15. The system displays a confirmation message that the reminder is updated.
Alternate/Exceptional Flows: None

UC15 – Delete Reminder

Table A.1.14 Use Case Description of Delete Reminder

Use Case Name: Delete Reminder	ID: UC15	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to delete the reminders in the application.		
Brief Description: This use case describes how the user deletes reminders in the profile page.		
Trigger: The user selects the "Reminders" option on the profile page and wants to delete the reminders. Type: External		
Relationships: Association: User Include: None Extend: None Generalization: None		
Normal Flow of Events: 1. The user selects the "Reminders" option on the profile page. 2. The user clicks the delete icon beside the reminder. 3. The system displays the confirmation message asking the user to confirm the deletion of the reminder. 4. The user clicks "Delete". 5. The system deletes the reminder.		
SubFlows: None		
Alternate/Exceptional Flows: None		

UC16 – Export Health Record

Table A.1.15 Use Case Description of Export Health Record

Use Case Name: Export Health Record	ID: UC16	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to export the health measurements records.		
Brief Description: This use case describes how the user exports their health data from the system.		
Trigger: The user selects the “Export Data” option on the profile page. Type: External		
Relationships: Association: User Include: None Extend: None Generalization: None		
Normal Flow of Events: 1. The user selects the “Export Data” option on the profile page. 2. The system displays the export option which can export all records or select a specific date range to export data. If the user selects a specific date range, The S-1: Select Date Range is performed. 3. The user selects “Export all records”. 4. The user can select the export format which is either Excel or PDF format. 5. The user clicks the selected format button. 6. The system displays the available social media sharing options on the page. 7. The user selects the preferred social media platform to share the exported file. 8. The system displays a confirmation message indicating that the health records have been successfully exported and shared.		
SubFlows: S-1: Select Date Range 1. The system displays a calendar interface. 2. The user selects the start date and end date which either by typing them manually or selecting them from the calendar. 3. The user clicks the “Save” button.		

4. The system redirects the user to the export data page to continue the export process.
Alternate/Exceptional Flows: 7a. If the user does not share the exported file and clicks elsewhere in the application, the system displays an error message indicating that the file has not been shared. S-1, 4a. If there are no records within the selected date range, the system displays a message indicating that “No records in the selected date range”.

UC17 – Delete Health Record

Table A.1.16 Use Case Description of Delete Health Record

Use Case Name: Delete Health Record	ID: UC17	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to delete their health measurements records.		
Brief Description: This use case describes how the user deletes health records using the application.		
Trigger: The user selects the “Clear Data” option on the profile page. Type: External		
Relationships: Association: User Include: Select Record Extend: None Generalization: None		
Normal Flow of Events: 1. The user selects the “Clear Data” option on the profile page. 2. The system displays the list of all health records with a sorting button. If the user clicks the “Delete All” button, The S-1: Delete All Records is performed. If the user clicks on the sorting function, The S-2: Sort Record is performed. 3. The user selects the preferred records and clicks the “Delete” button. 4. The system prompts an alert notifying that the records will be permanetly delete and asks for confirmation. 5. The user clicks the “Delete” button.		

6. The system displays a confirmation message indicating that the health records have been successfully deleted.
SubFlows: S-1: Delete All Records 1. The user clicks the “Delete All” option. 2. The system prompts an alert notifying that the records will be permanently deleted and asks for confirmation. 3. The user clicks the “Delete” button. 4. The system displays a confirmation message indicating that the health records have been successfully deleted. S-2: Sort Record 1. The system initially displays the records sorted by “Newest”. 2. The user clicks the “Newest” label. 3. The system updates the list and sorts the records by oldest which updates the lable to “Oldest” to indicate the current sorting order.
Alternate/Exceptional Flows: None

UC18 – Logout Account

Table A.1.17 Use Case Description of Logout Account

Use Case Name: Logout Account	ID: UC18	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to log out of the application.		
Brief Description: This use case describes how the user logs out of the application.		
Trigger: The user selects the “Logout” option on the profile page. Type: External		
Relationships: Association: User Include: None Extend: None Generalization: None		

Normal Flow of Events: 1. The user selects the "Logout" option on the profile page. 2. The system displays the Logout alert and asks for user confirmation. 3. If the user clicks the "Cancel" button, The S-1: Cancel Logout is performed. 4. The user clicks the "Logout" button. 5. The system logs the user out and redirects the user to the login page.
SubFlows: S-1: Cancel Logout 1. The system closes the logout alert. 2. The user remains on the profile page.
Alternate/Exceptional Flows: None

UC19 – Consult AI Assistant

Table A.1.18 Use Case Description of Consult AI Assistant

Use Case Name: Consult AI Assistant	ID: UC19	Importance Level: High
Primary Actor: User	Use Case Type: Detail, Essential	
Stakeholders and Interests: User - wants to gain health management insights or ask questions regarding cardiac health management.		
Brief Description: This use case describes how the user interacts with the AI assistant to obtain personalised cardiac health insights based on their health scores.		
Trigger: The user selects the "Health Insights" option on top of the home page or clicks the floating heart icon at the bottom right of the home page. Type: External		
Relationships: Association: User Include: None Extend: None Generalization: None		
Normal Flow of Events:		

1. The user selects the "Health Insights" option on top of the home page or clicks the floating heart icon at the bottom right of the home page.
2. The system initialises the Gemini AI model with a system instruction to respond as a cardiac health monitoring assistant and to avoid providing any medical diagnoses or advice.
3. The system retrieves the user's chat history from the database and displays the chatbot interface.
4. The system retrieves the user's health records from the database and computes a personalized health summary.
5. The system sends the computed health summary to the Gemini AI model and displays the AI-generated greeting message summarizing the user's current cardiac health along with suggested questions.

   If the user clicks a suggested question,

   The S-1: Send Suggested Question is performed.
6. The user types a question regarding cardiac health management and clicks the send icon.
7. The system sends the user's question together with the computed health summary to the Gemini AI model via the Internet.
8. The system waits for the response from the Gemini AI model.
9. Upon receiving the response, the system displays the AI response in the chatbot interface.
10. The system saves the user's question and the AI response to the database.

    If the user clicks the delete icon at the top right,

    The S-2: Delete Chat History is performed.

SubFlows:

S-1: Send Suggested Question

1. The system sends the selected suggested question together with the computed health summary to the Gemini AI model.
2. The system waits for the response from the Gemini AI model.
3. Upon receiving the response, the system displays the AI response in the chatbot interface.
4. The system saves the suggested question and the AI response to the database.

S-2: Delete Chat History 1. The user clicks the delete icon on the top right on the page. 2. The system displays a confirmation message asking the user to confirm the deletion of the chat history. 3. The user confirms the deletion. 4. The system clears the chat history from the database and clears the chatbot interface. 5. The system reinitialises the Gemini AI model and sends the health summary to generate a new greeting message with the suggested questions.
Alternate/Exceptional Flows: 5a. If a network error occurs while sending the health summary for the greeting message, the system displays an error message indicating that the AI assistant is currently unavailable and prompts the user to try again later. 8a. If the primary Gemini AI model is unavailable due to quota limits or server overload, the system automatically retries the request using an alternative AI model. 8b. If all available AI models are exhausted and no response is received, the system displays an error message indicating that the AI assistant is currently busy and prompts the user to try again later.

A.2 Activity Diagram

UC02 - Login Account

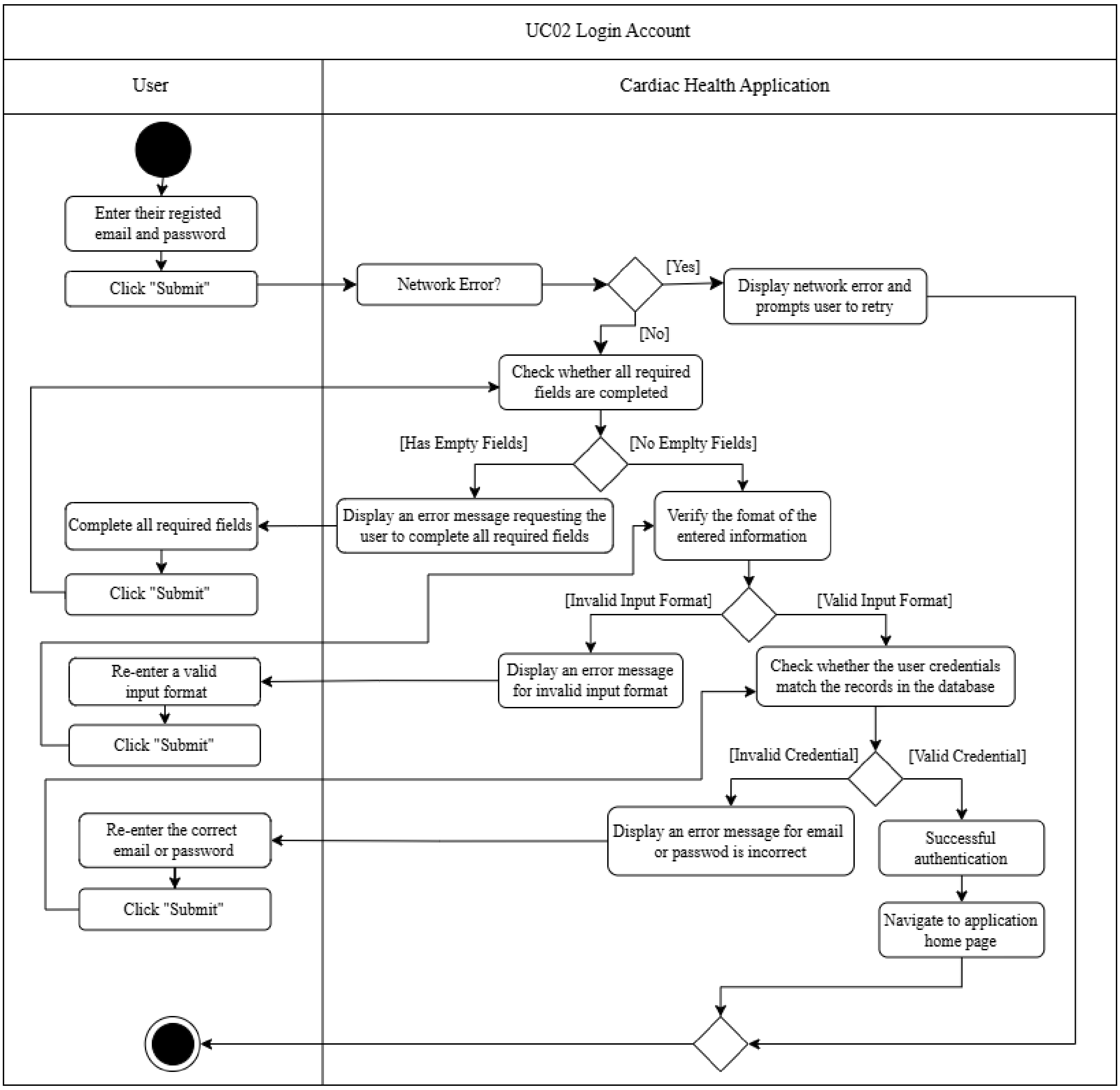


Figure A.2.1 UC02 Login Account Activity Diagram

UC03 – Login using Google Account

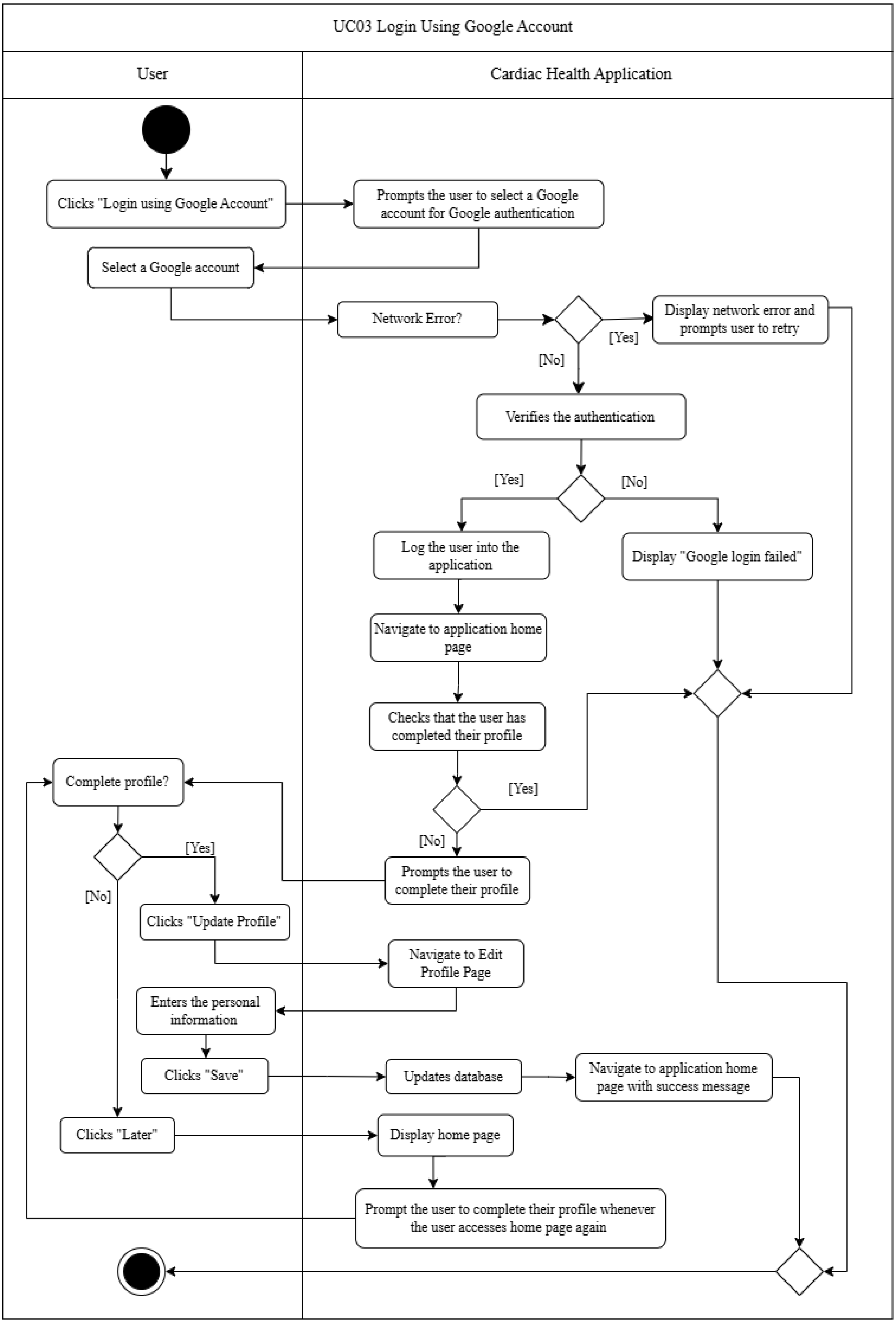


Figure A.2.2 UC03 Login using Google Account Activity Diagram

UC04 – Reset Password

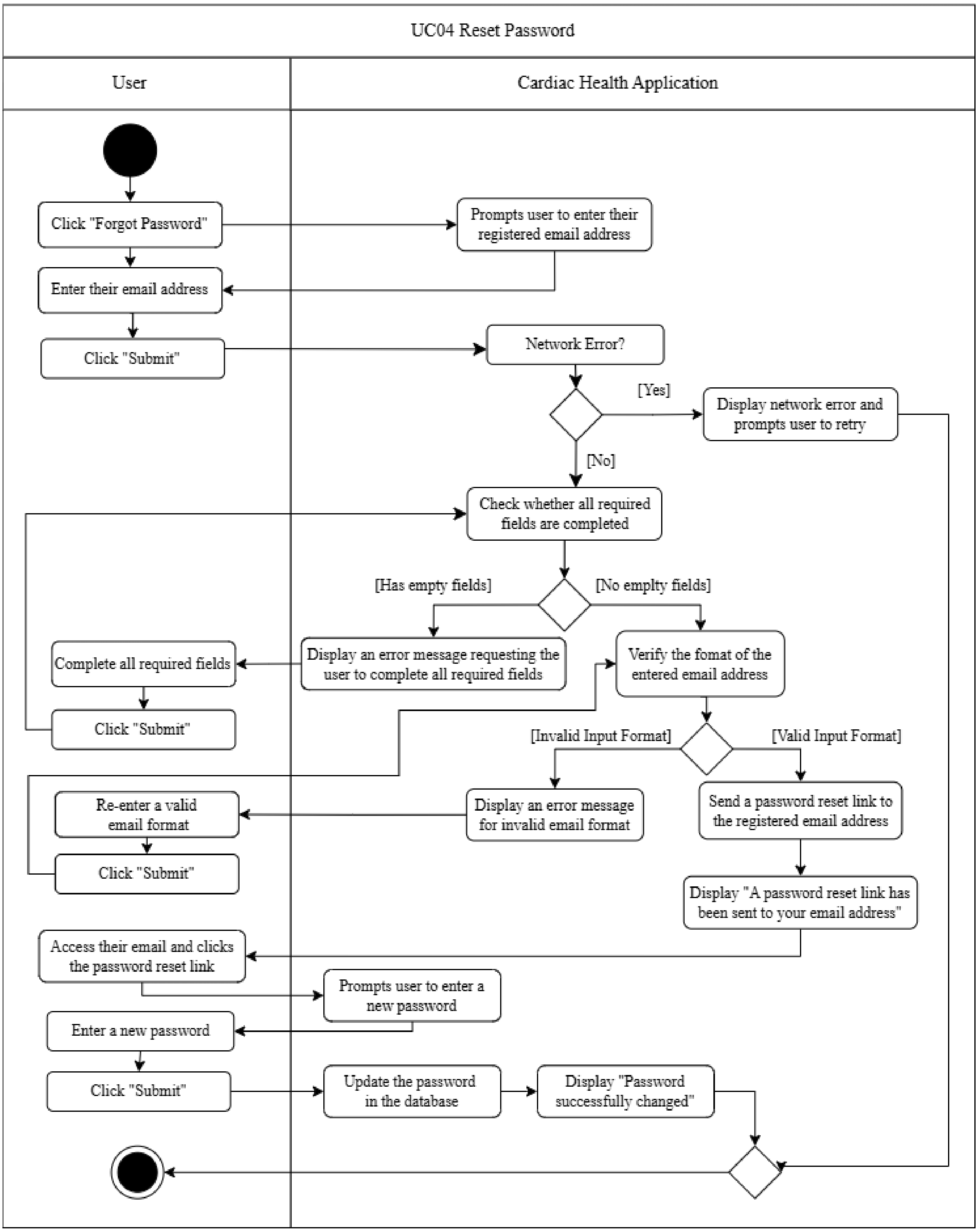


Figure A.2.3 UC04 Reset Password Activity Diagram

UC05 – Full Scan Measurement

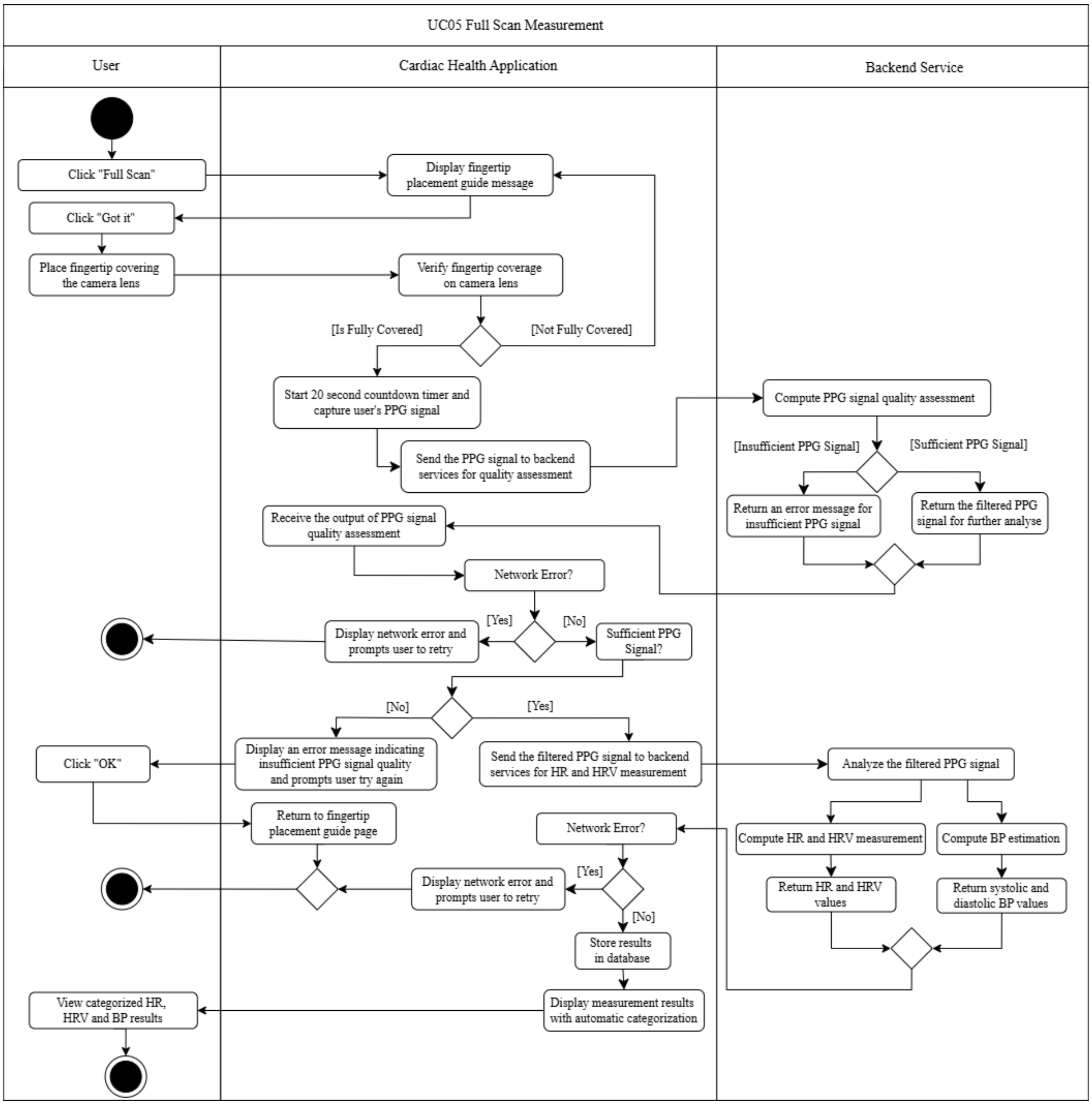


Figure A.2.4 UC05 Full Scan Measurement Activity Diagram

UC06 – Heart Rate and Heart Rate Variability Measurement

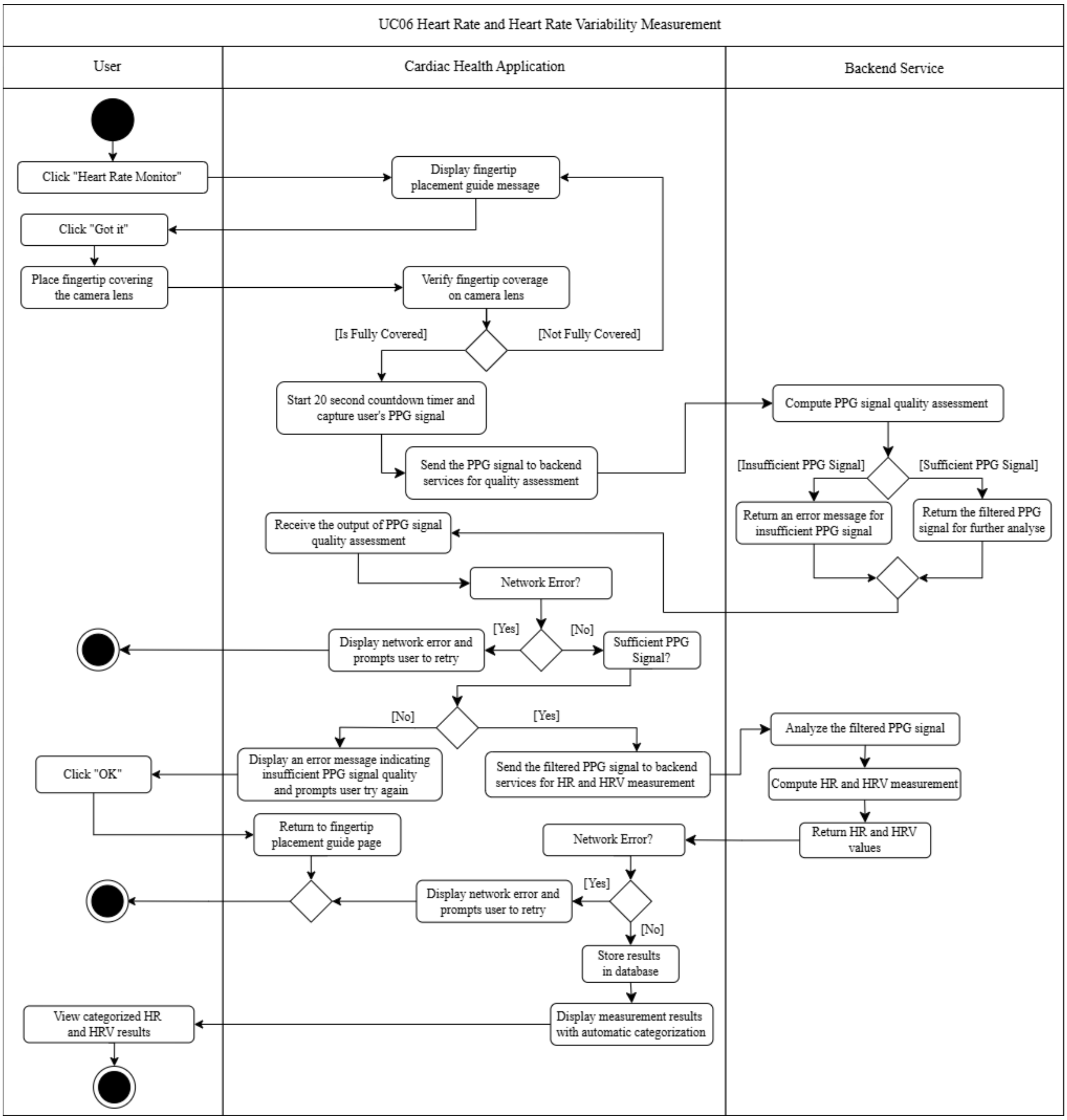


Figure A.2.5 UC06 Heart Rate and Heart Rate Variability Measurement Activity Diagram

UC07 – Blood Pressure Estimation

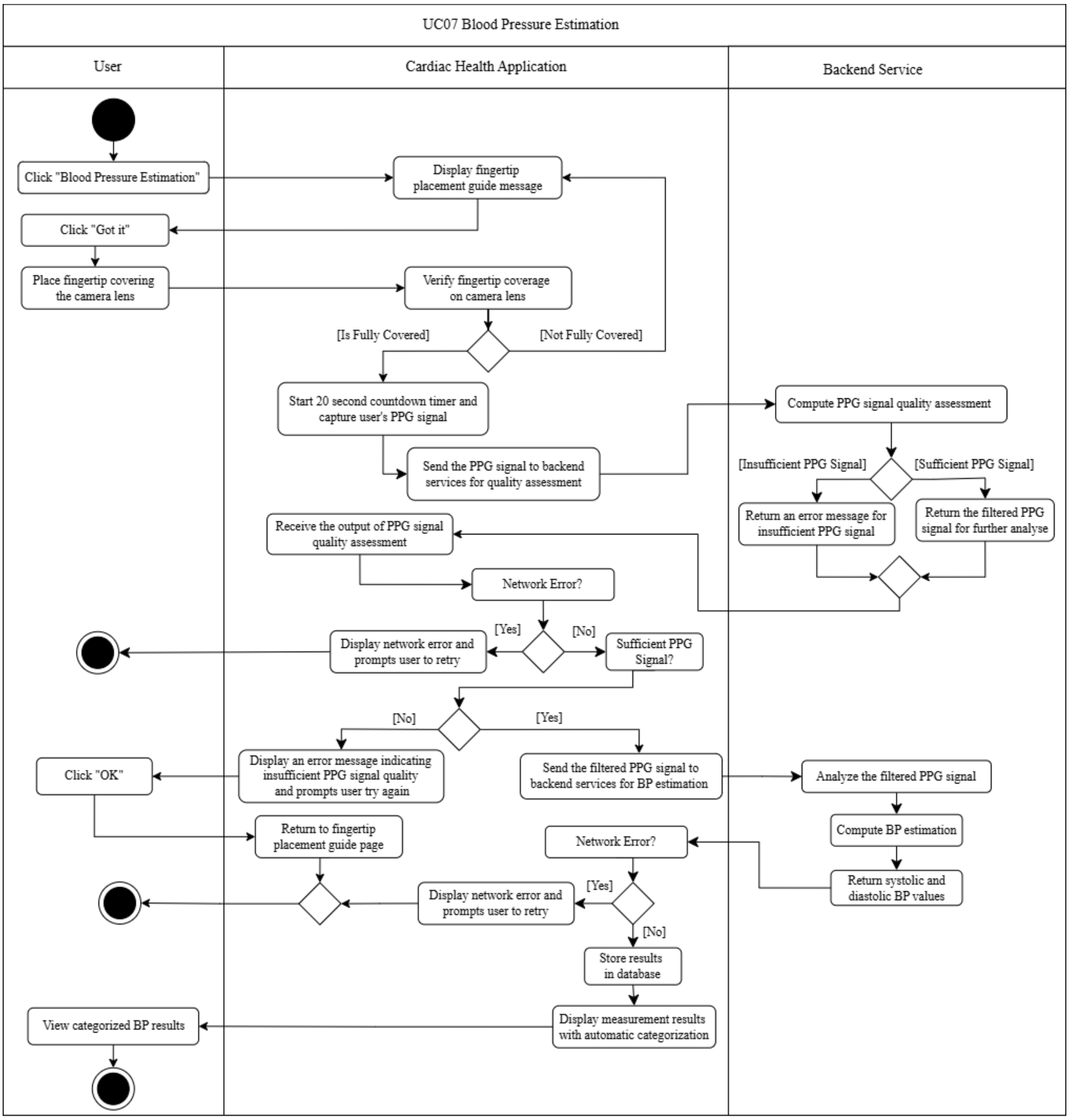


Figure A.2.6 UC07 Blood Pressure Estimation Activity Diagram

UC08 – Record Blood Pressure

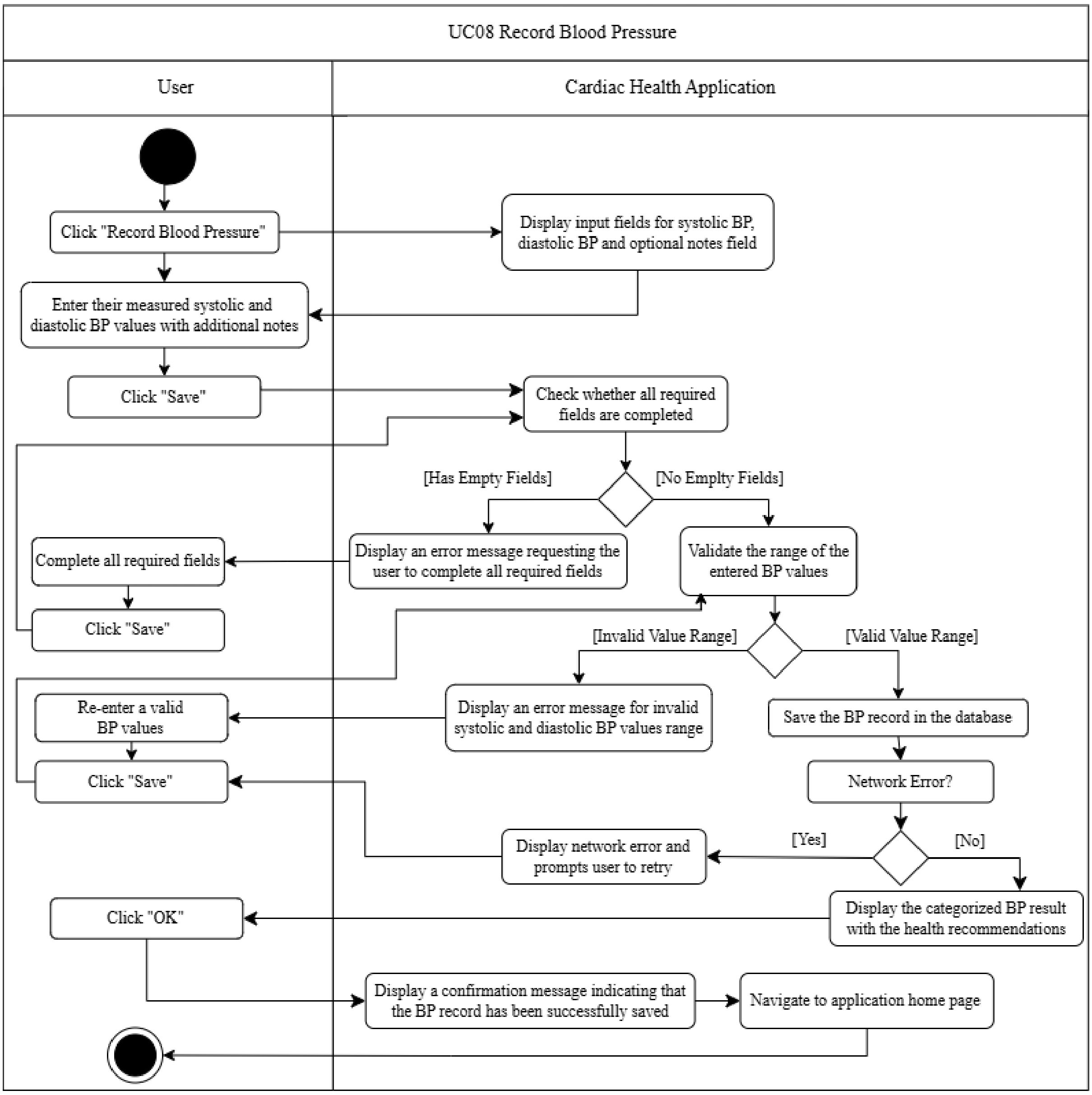


Figure A.2.7 UC08 Record Blood Pressure Activity Diagram

UC09 – View Health History

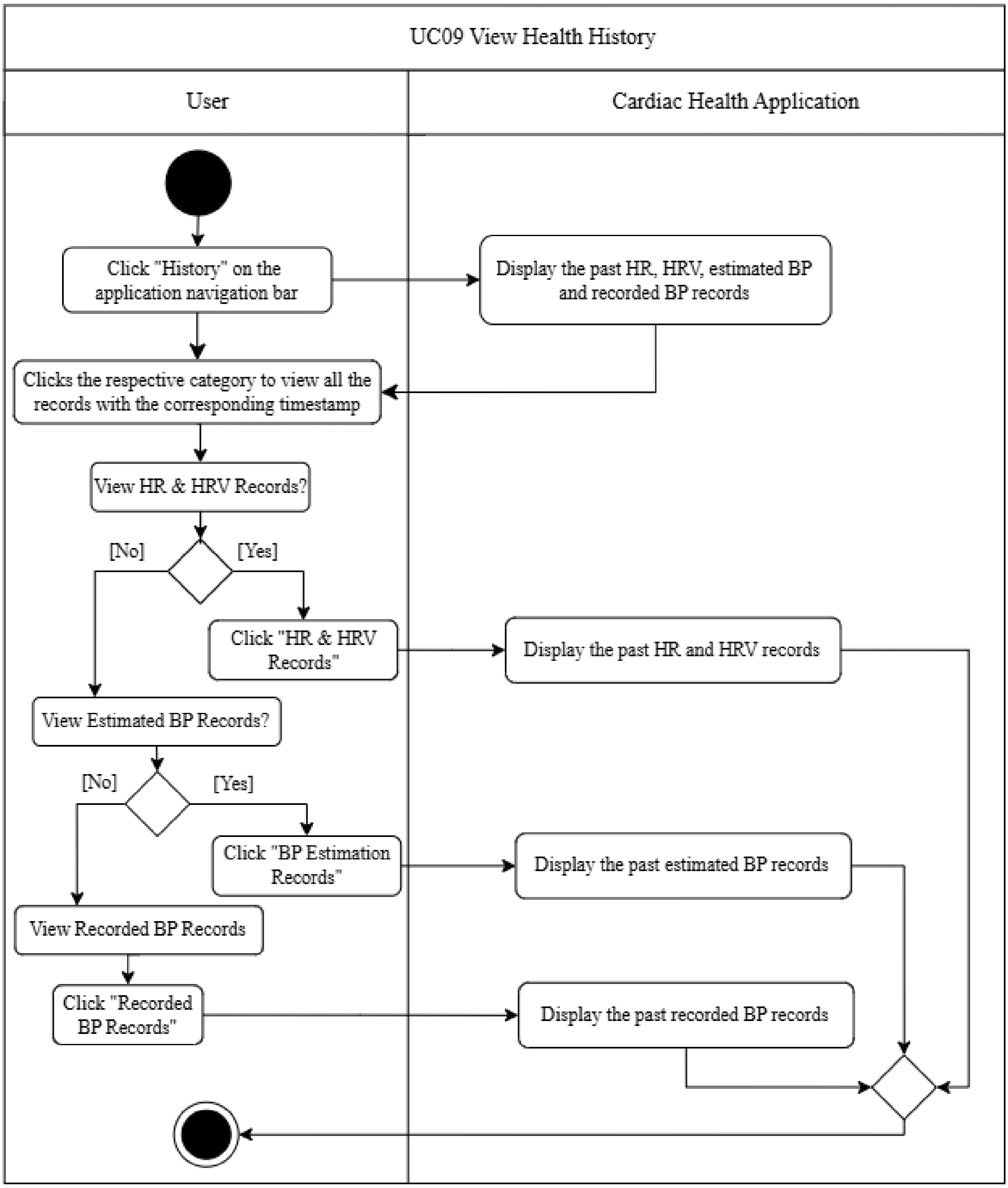


Figure A.2.8 UC09 View Health History Activity Diagram

UC10 – View Trends and Analysis

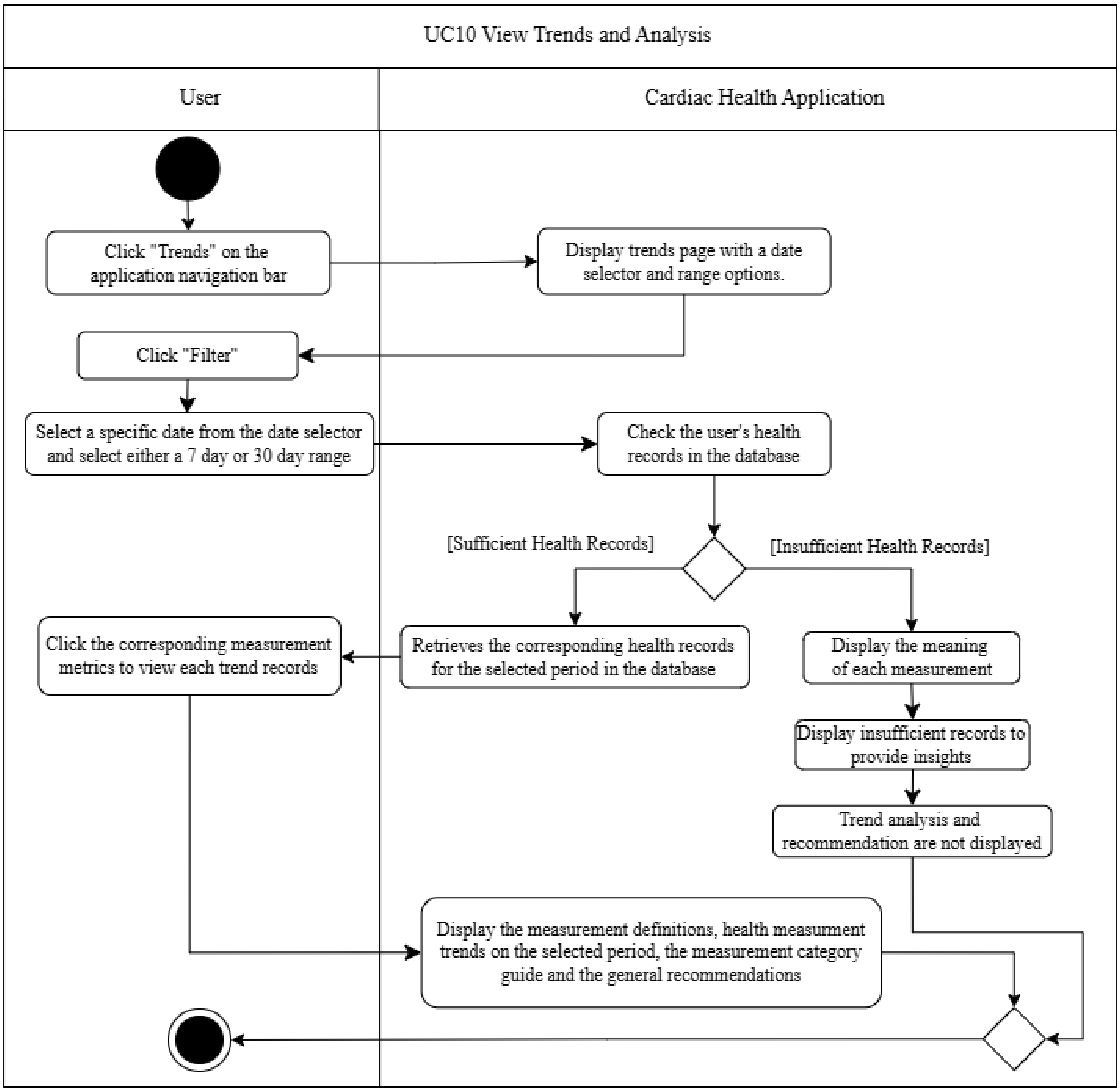


Figure A.2.9 UC10 View Trends and Analysis Activity Diagram

UC11 – Update Profile Information

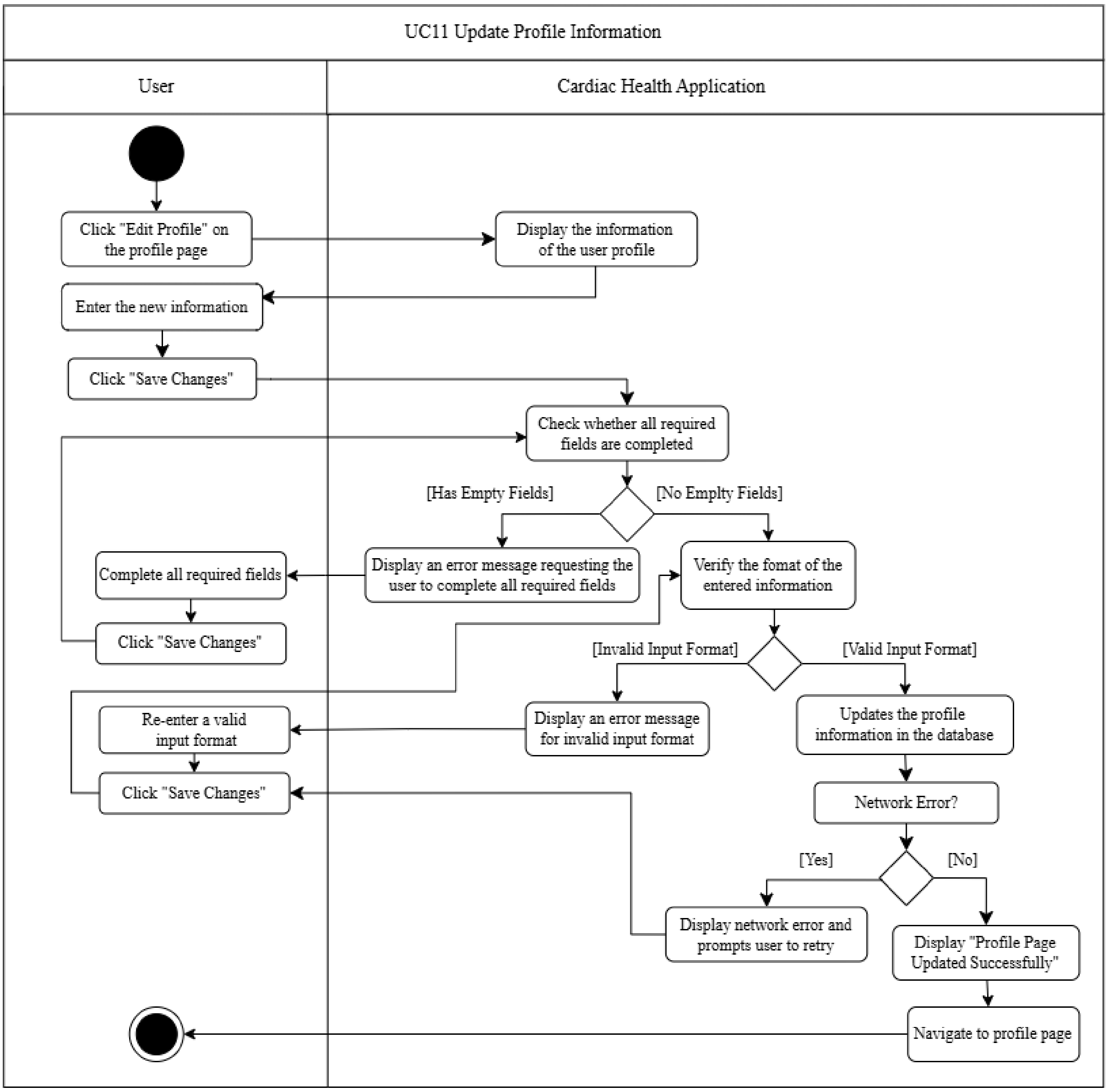


Figure A.2.10 UC11 Update Profile Information Activity Diagram

UC12 – Update Password

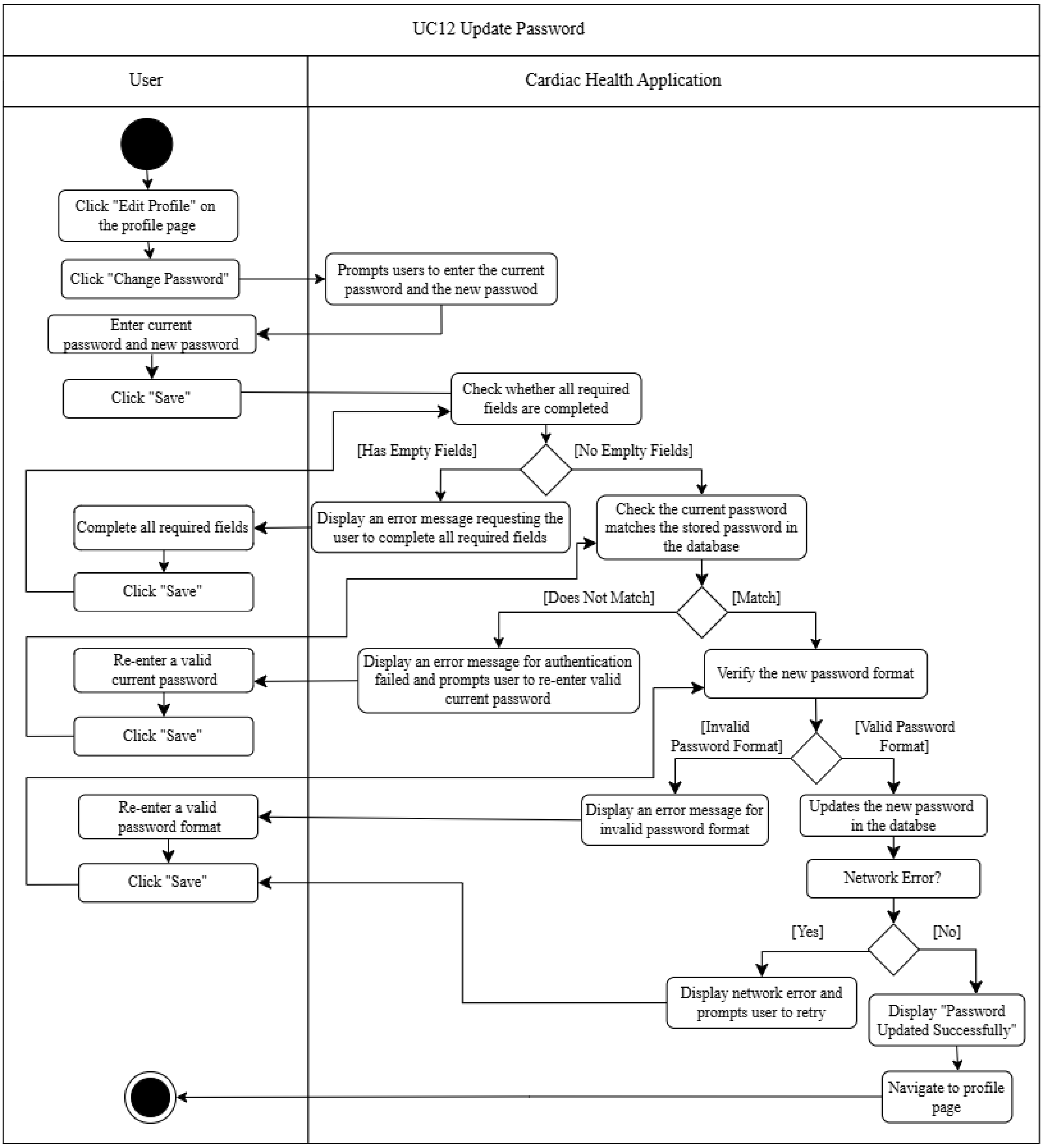


Figure A.2.11 UC12 Update Password Activity Diagram

UC13 – Set Reminder

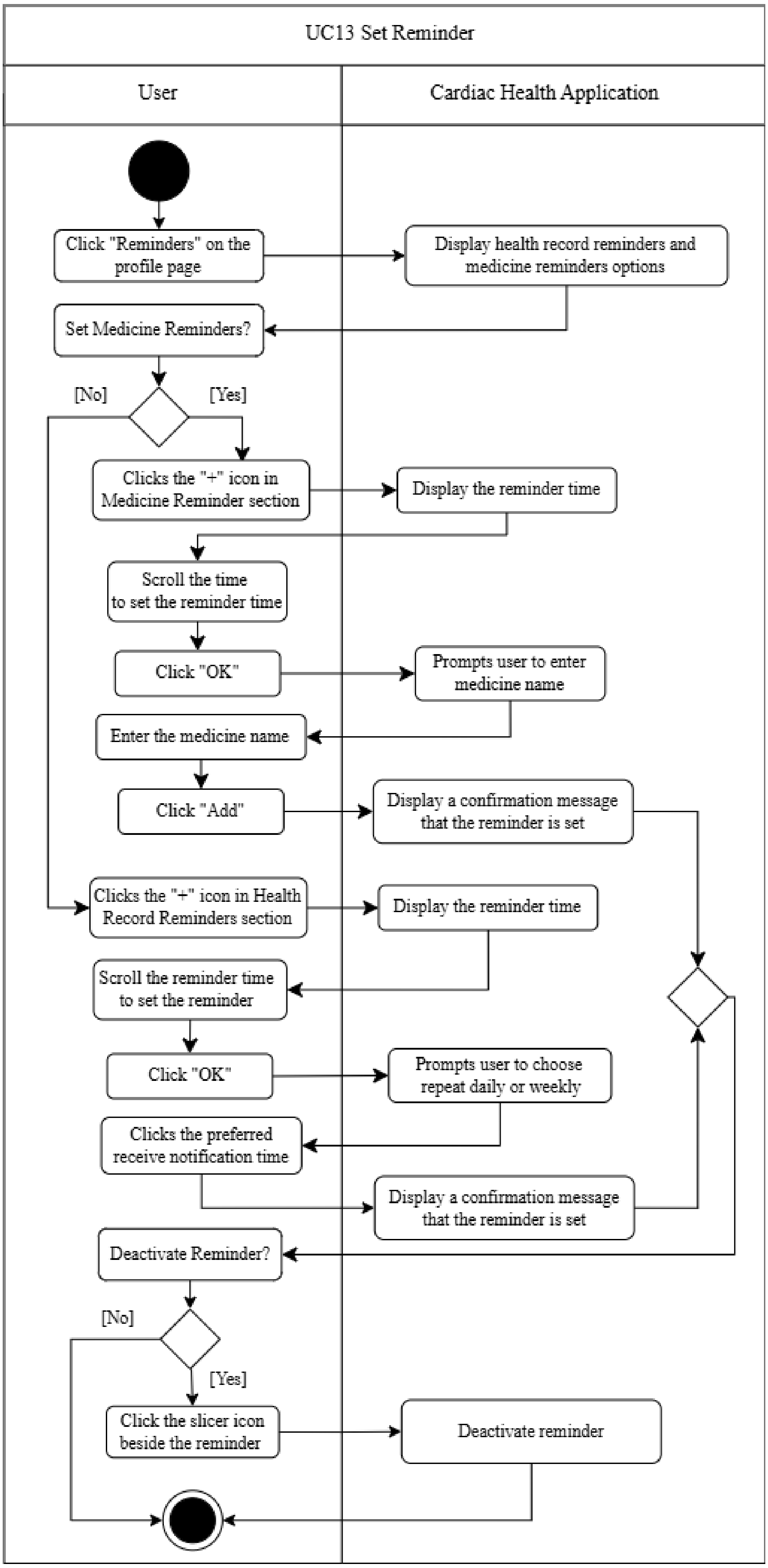


Figure A.2.12 UC13 Set Reminder Activity Diagram

UC14 – Edit Reminder

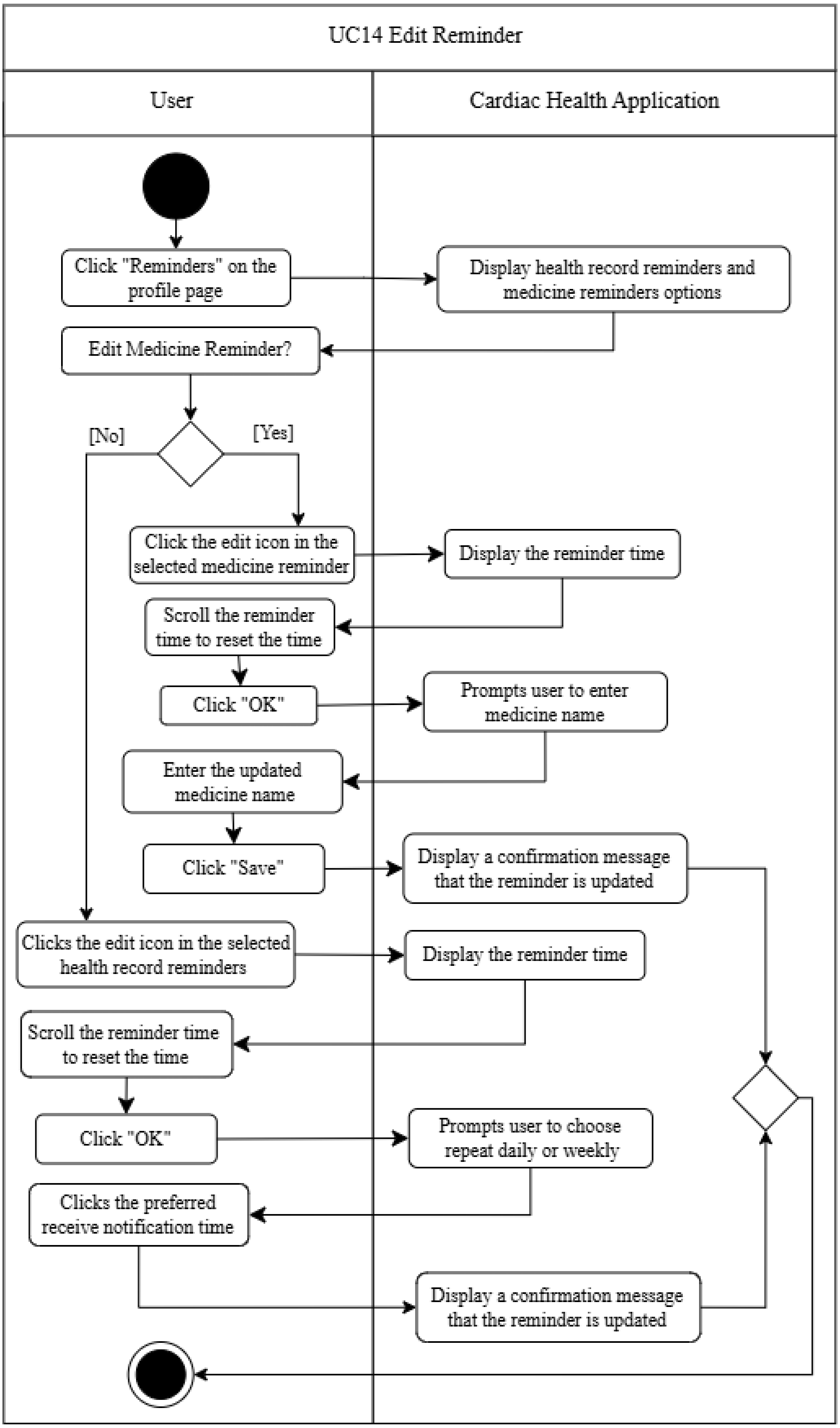


Figure A.2.13 UC14 Edit Reminder Activity Diagram

UC15 – Delete Reminder

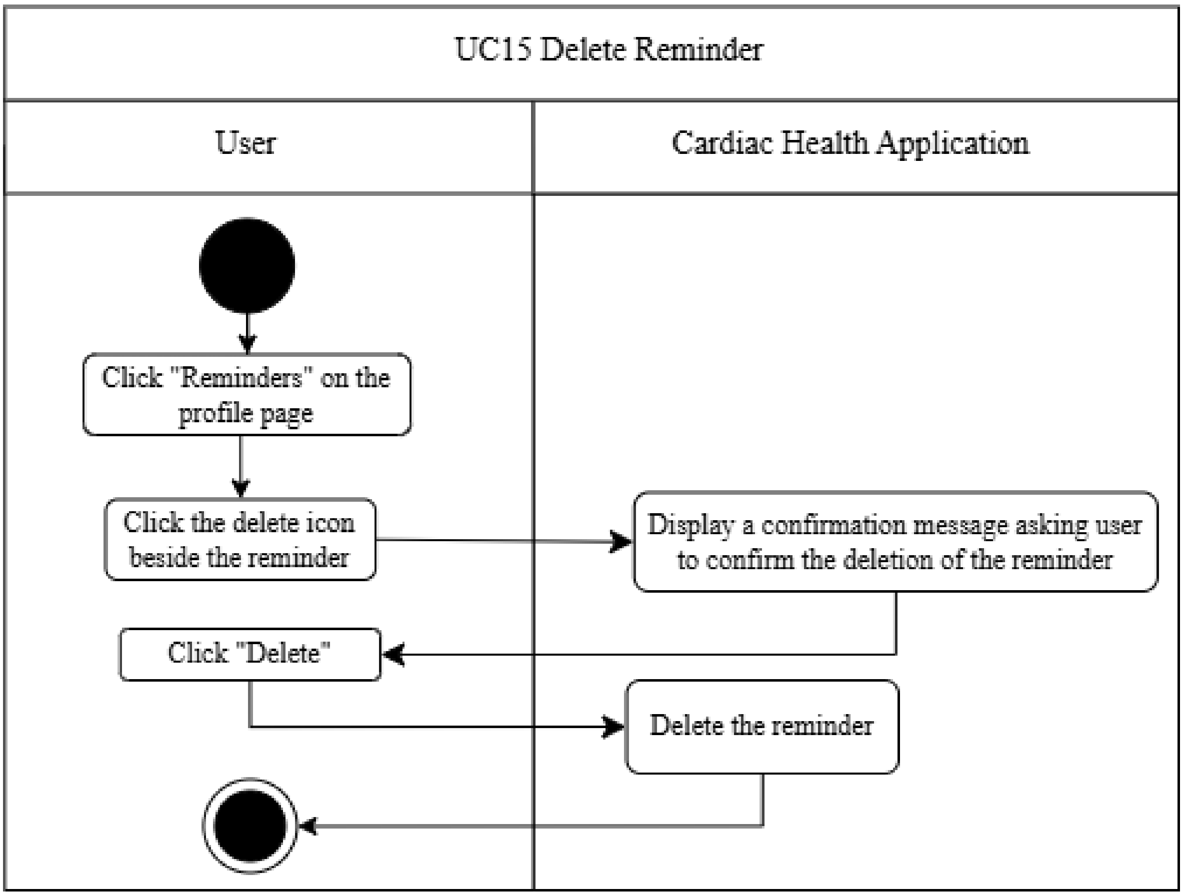


Figure A.2.14 UC15 Delete Reminder Activity Diagram

UC16 – Export Health Record

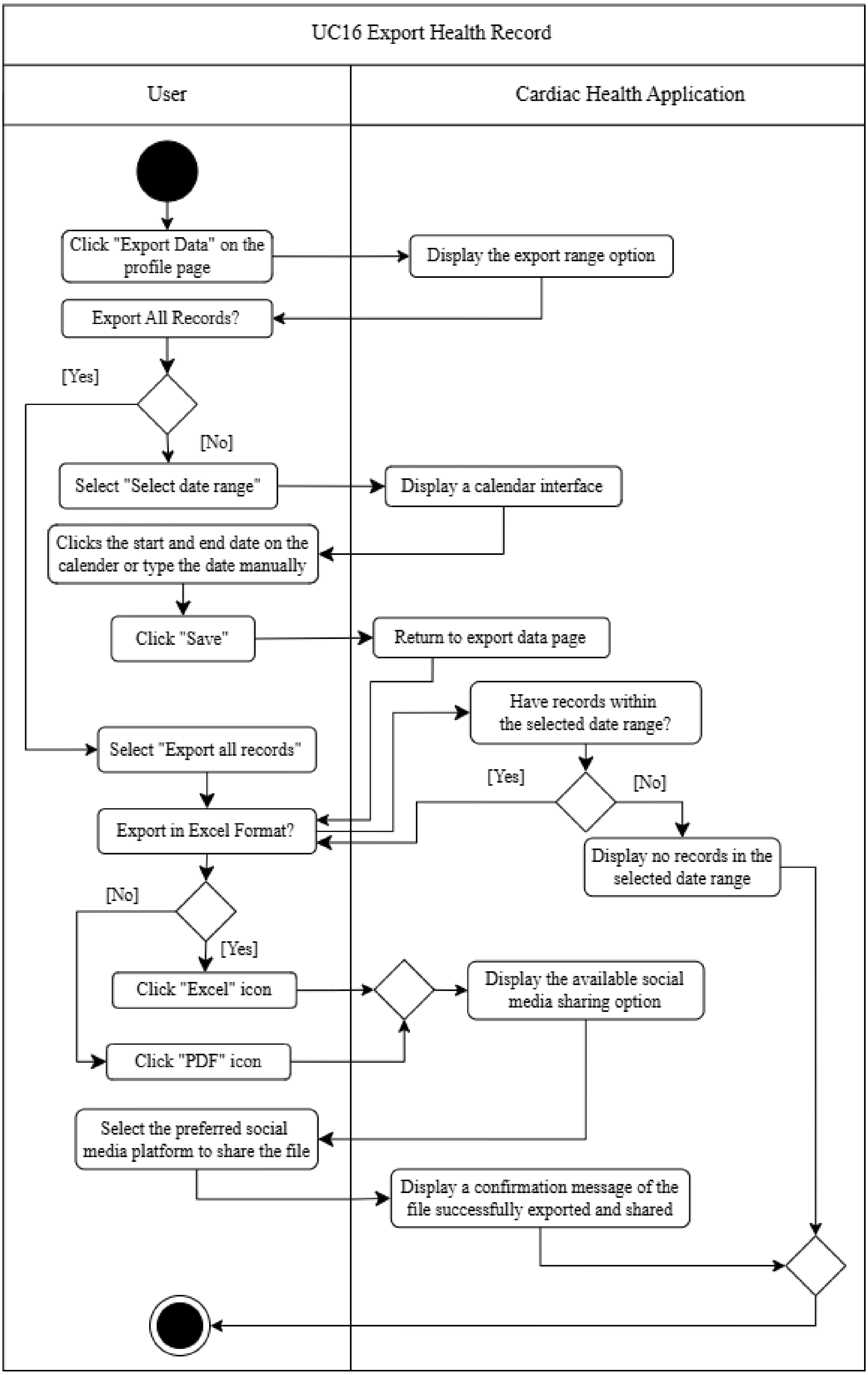


Figure A.2.15 UC16 Export Health Record Activity Diagram

UC17 – Delete Health Record

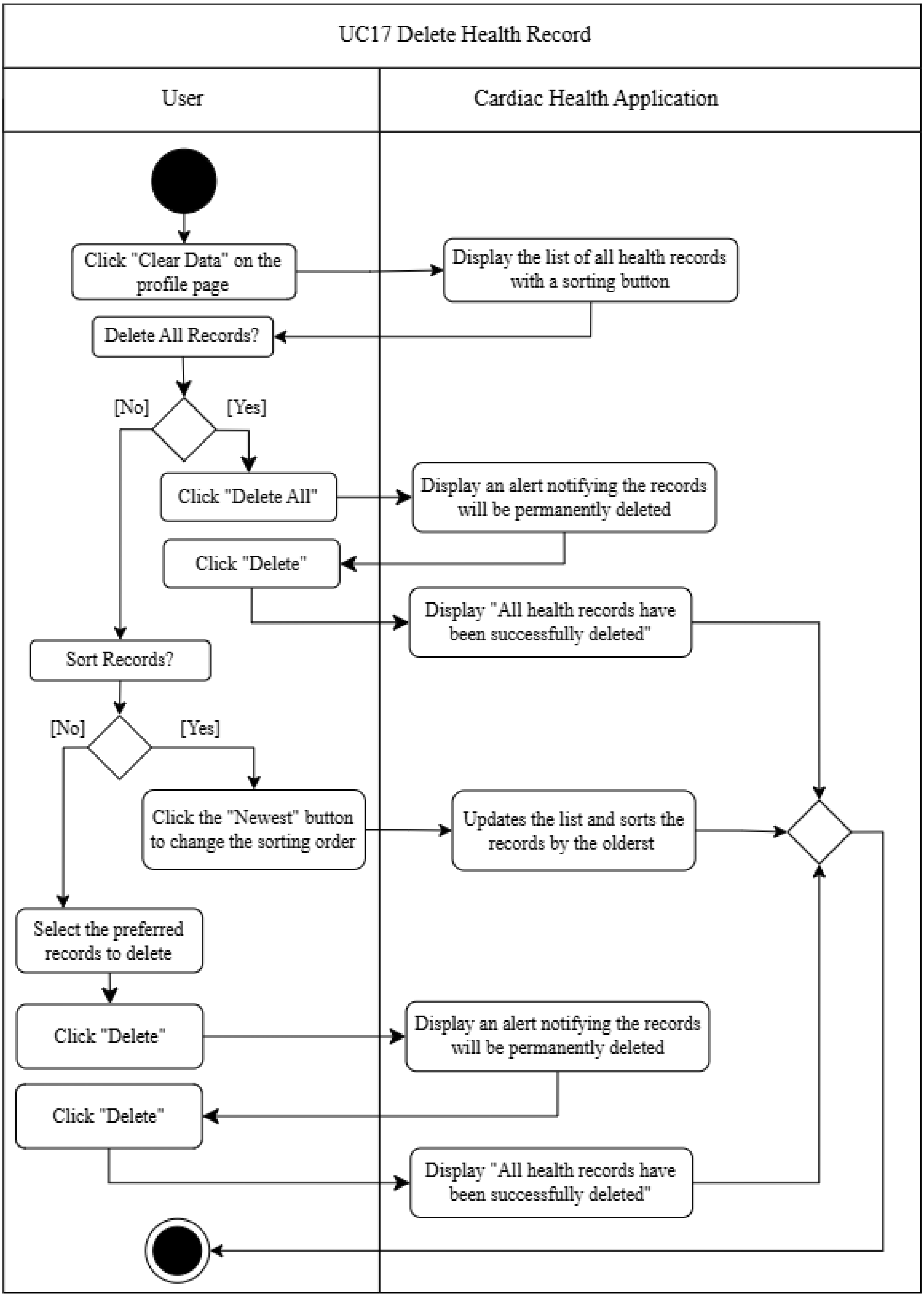


Figure A.2.16 UC17 Delete Health Record Activity Diagram

UC18 – Logout Account

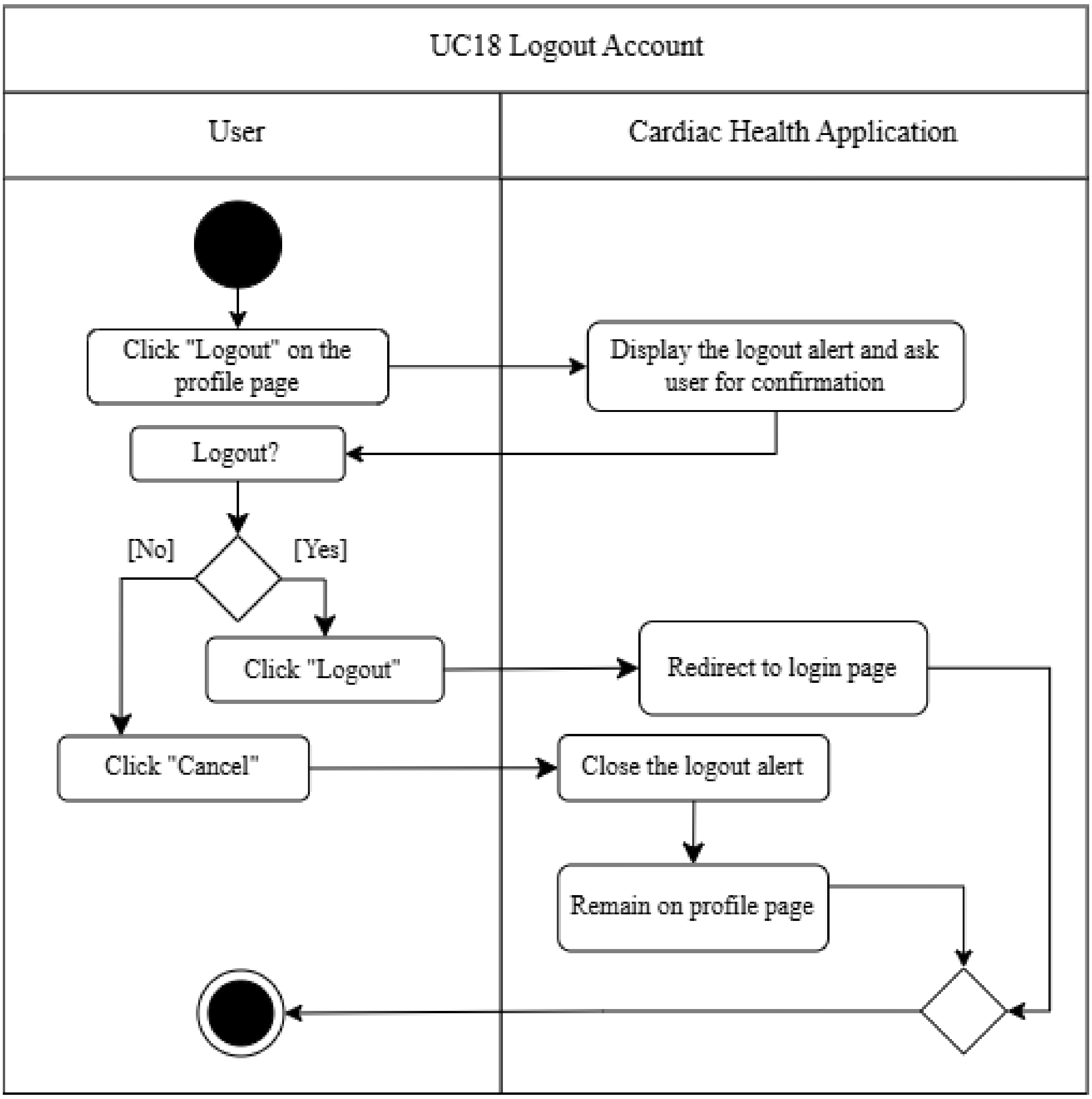


Figure A.2.17 UC18 Logout Account Activity Diagram

UC19 – Consult AI Assistant

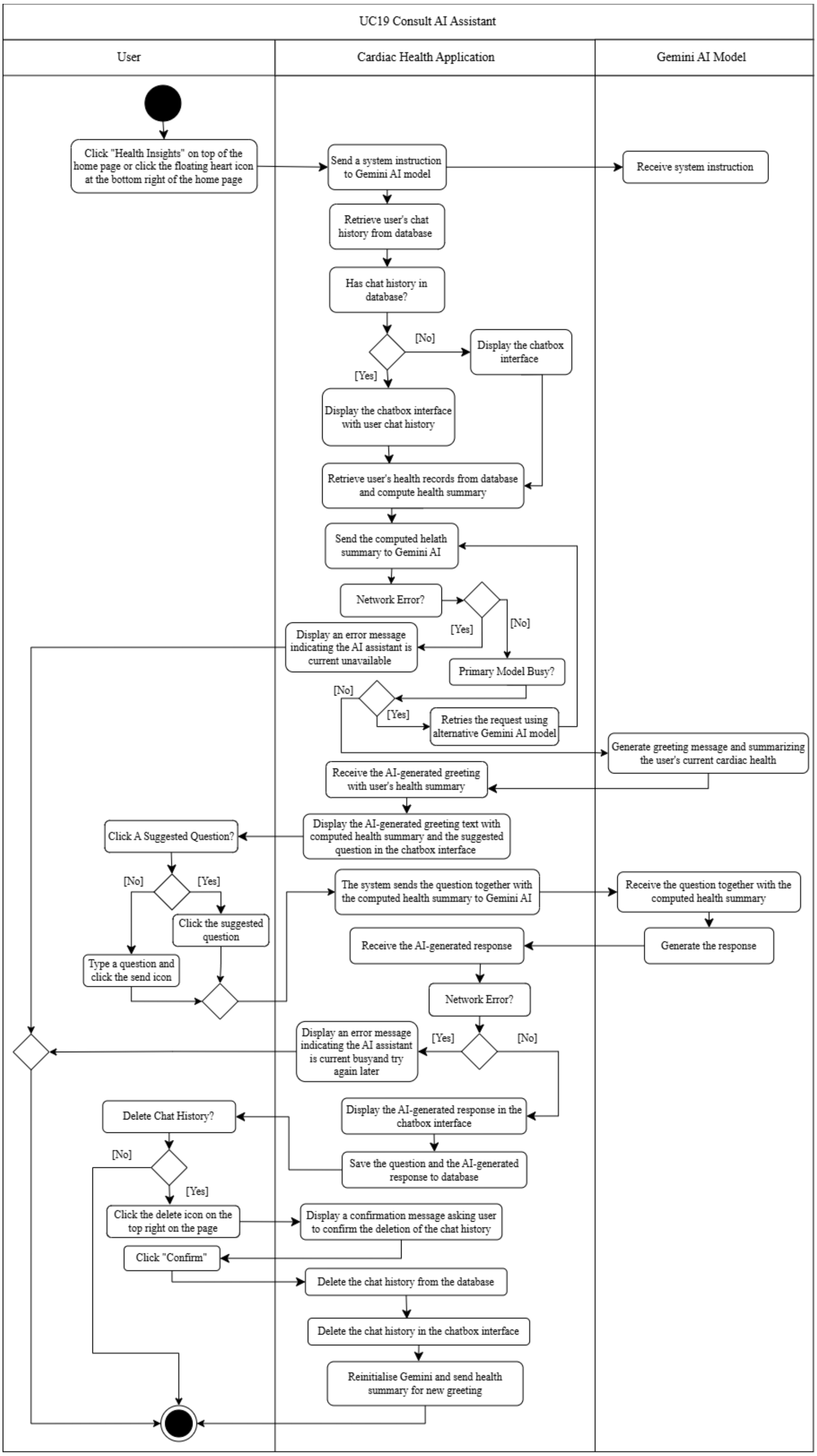


Figure A.2.18 UC19 Consult AI Assistant Activity Diagram

A.3 Application Interface Design

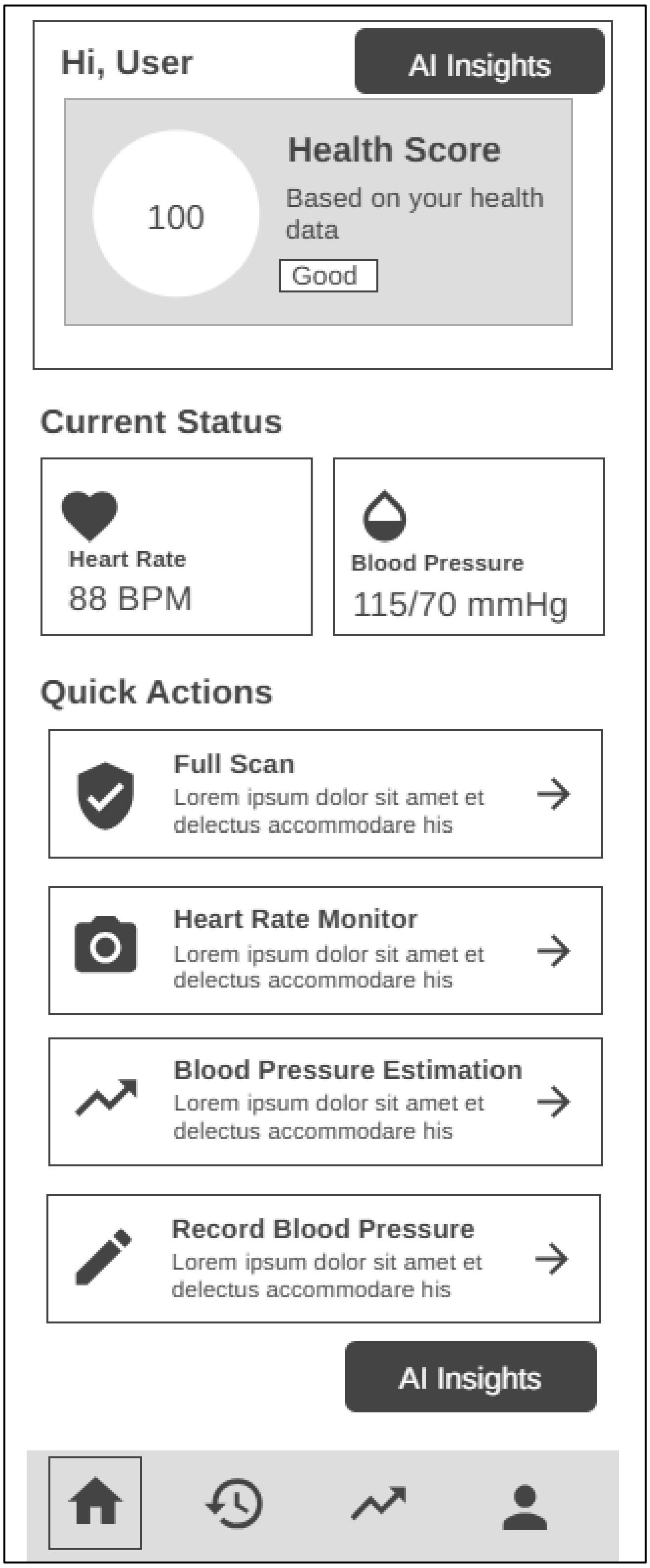


Figure A.3.1 Home Page Prototype

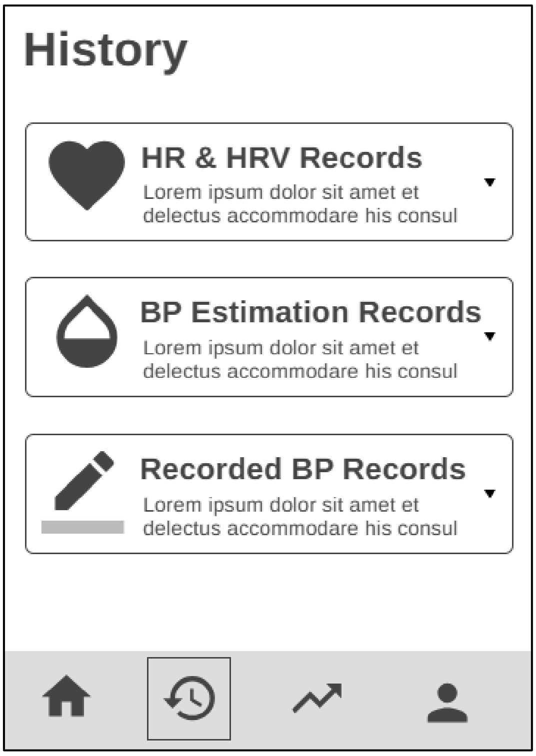


Figure A.3.2 History Page Prototype

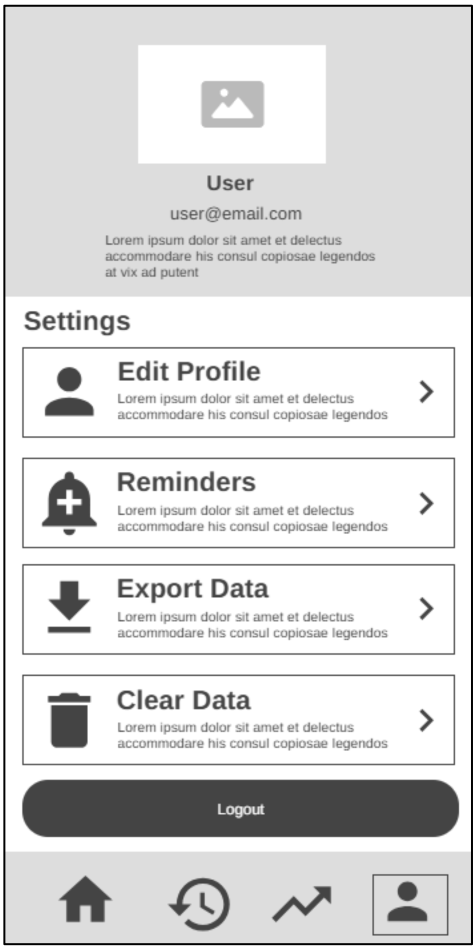


Figure A.3.3 Profile Page Prototype

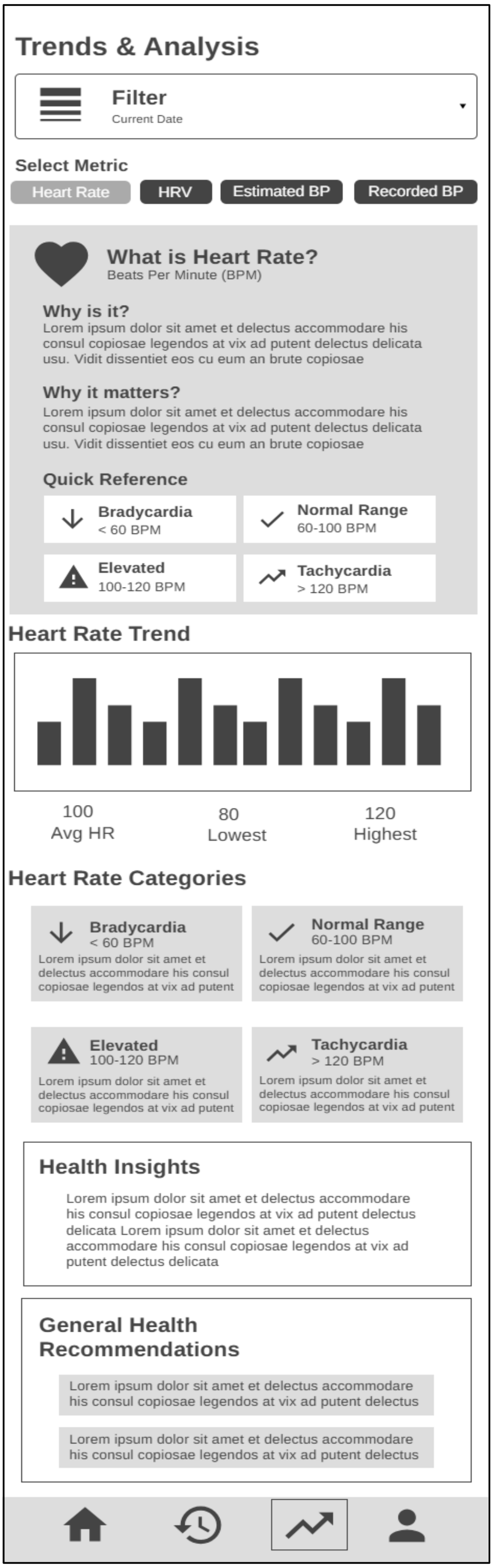


Figure A.3.4 Trends Page Prototype

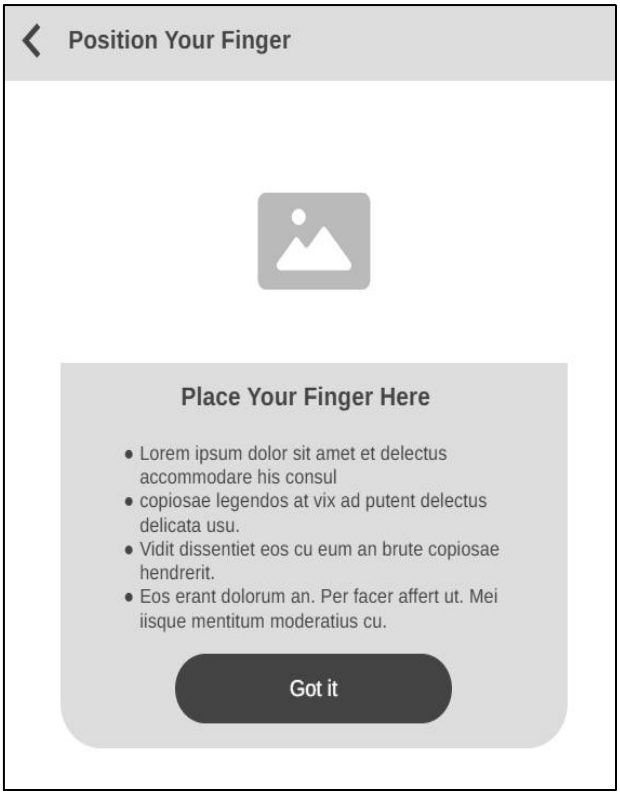


Figure A.3.5 Fingertip Positioning Guidance Prototype

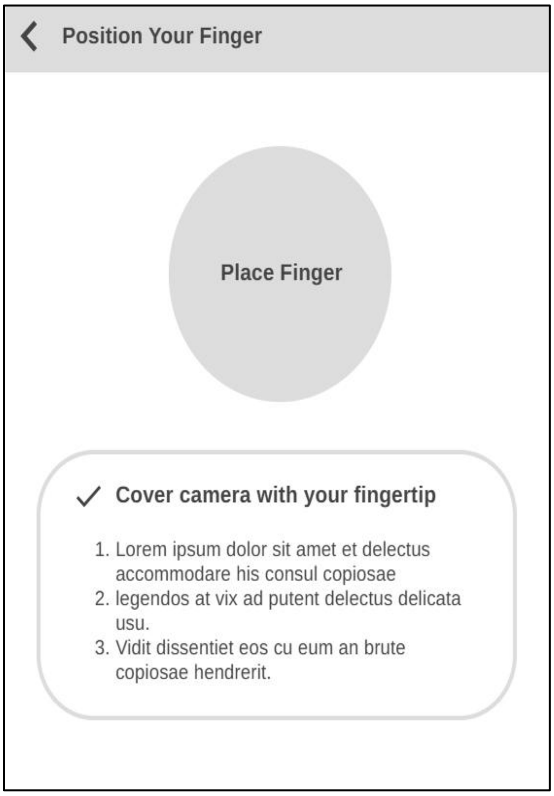
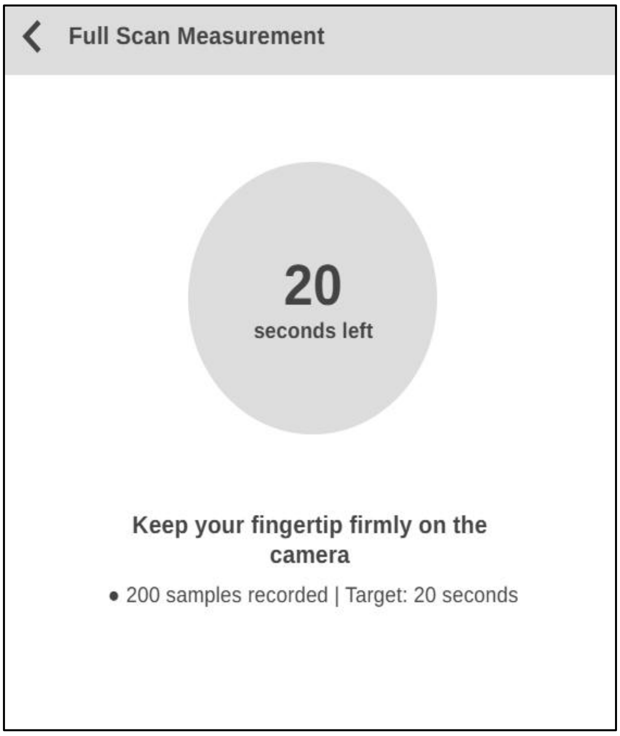
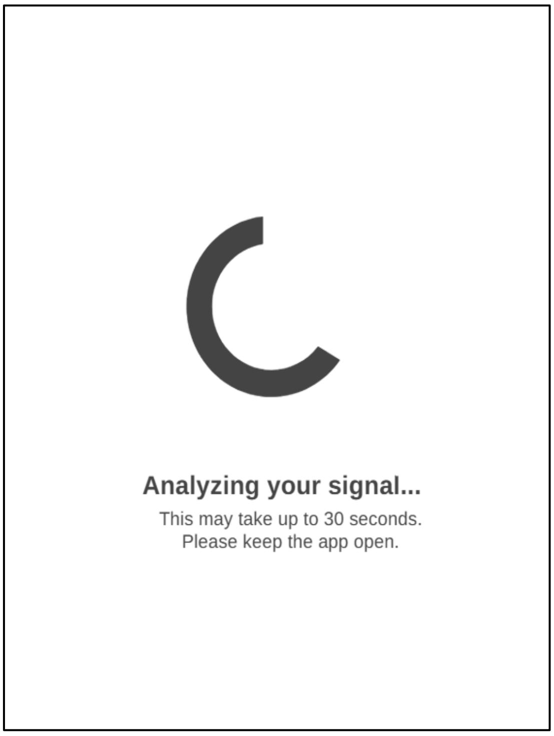


Figure A.3.6 Fingertip Positioning Page Prototype

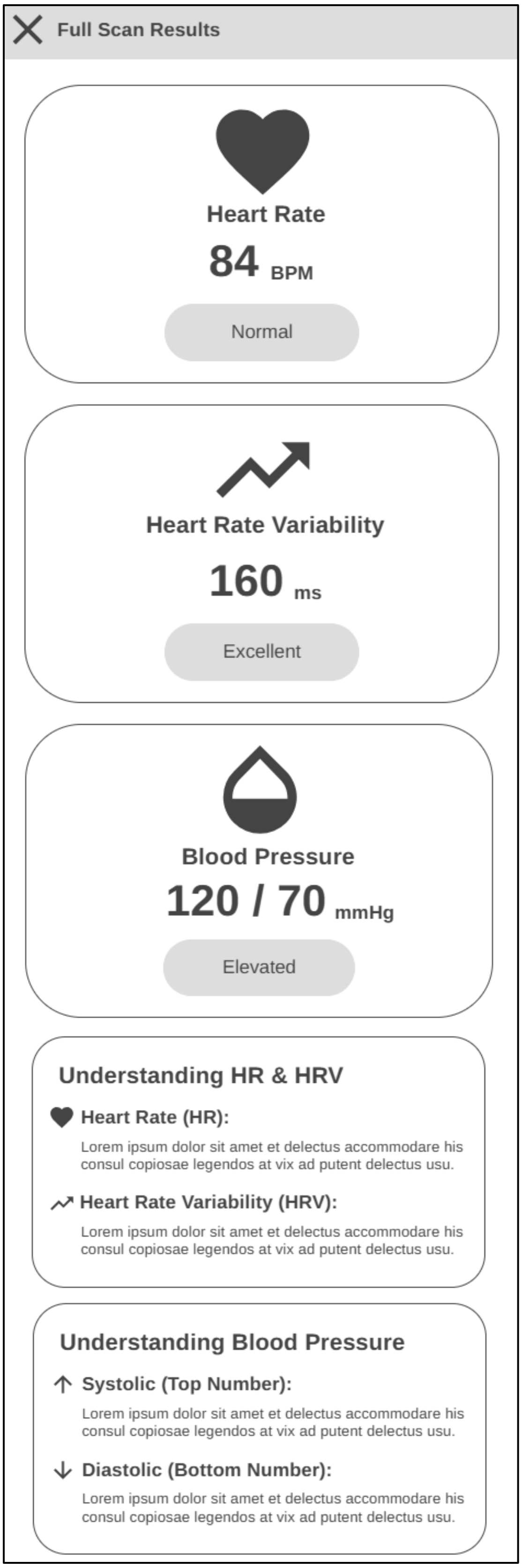


(a)

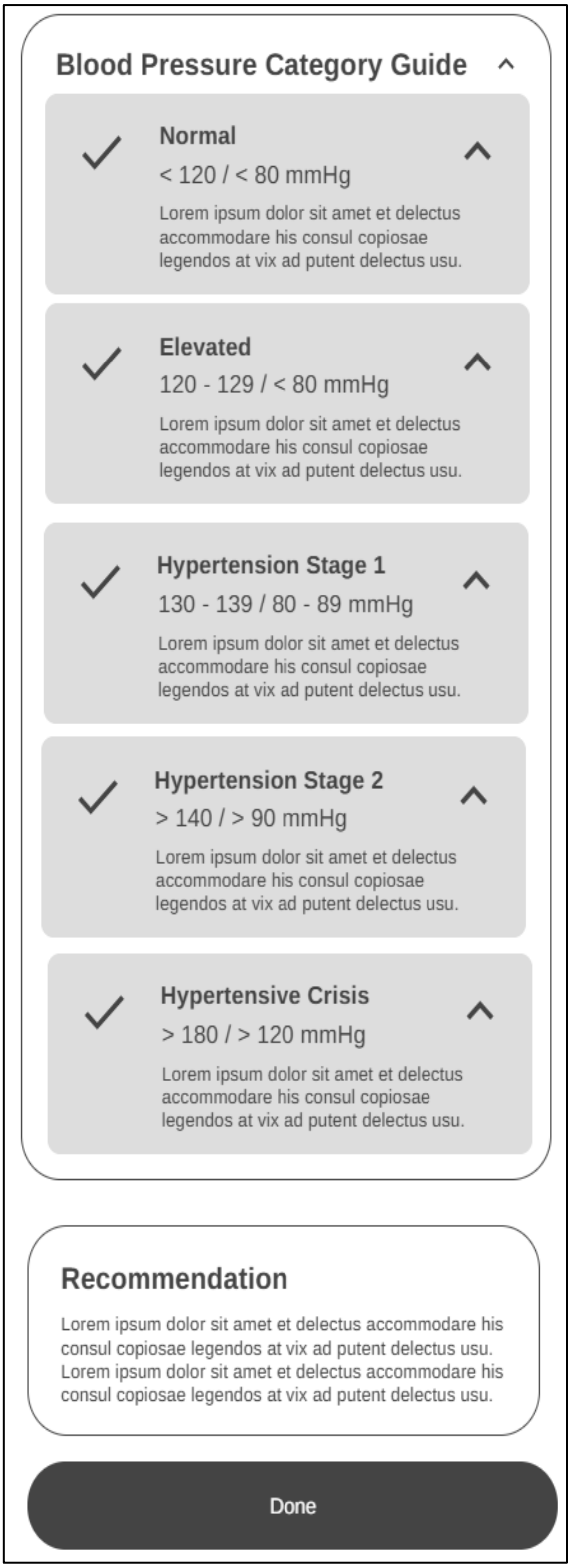


(b)

Figure A.3.7 Full Scan Measurement Page Prototype (a)Start Measurement; (b)Computing Result



(a)



(b)

Figure A.3.8 Full Scan Measurement Result Page Prototype (a) Result Page; (b) Continuation of the Result Page (a)

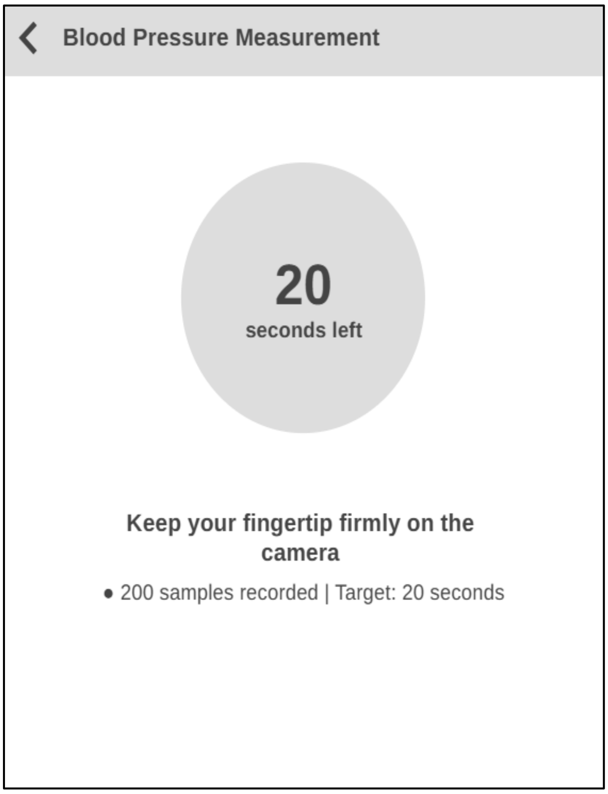


Figure A.3.9 Blood Pressure Measurement Page Prototype

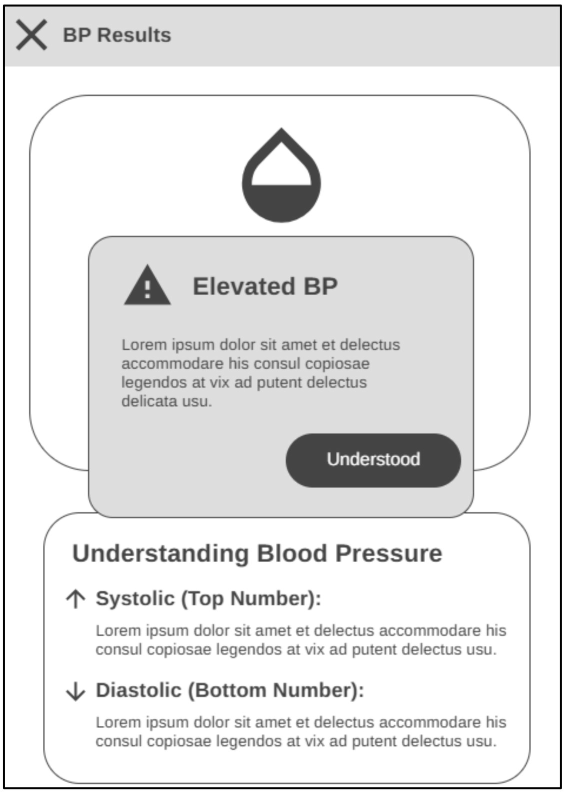


Figure A.3.10 Blood Pressure Classification Alert Prototype

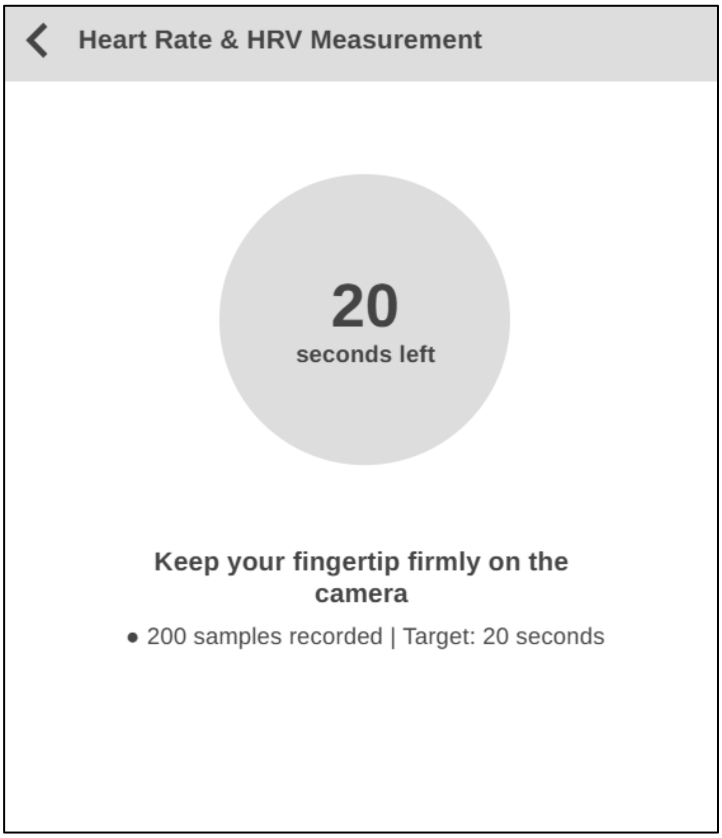


Figure A.3.11 Heart Rate and Heart Rate Variability Measurement Page Prototype

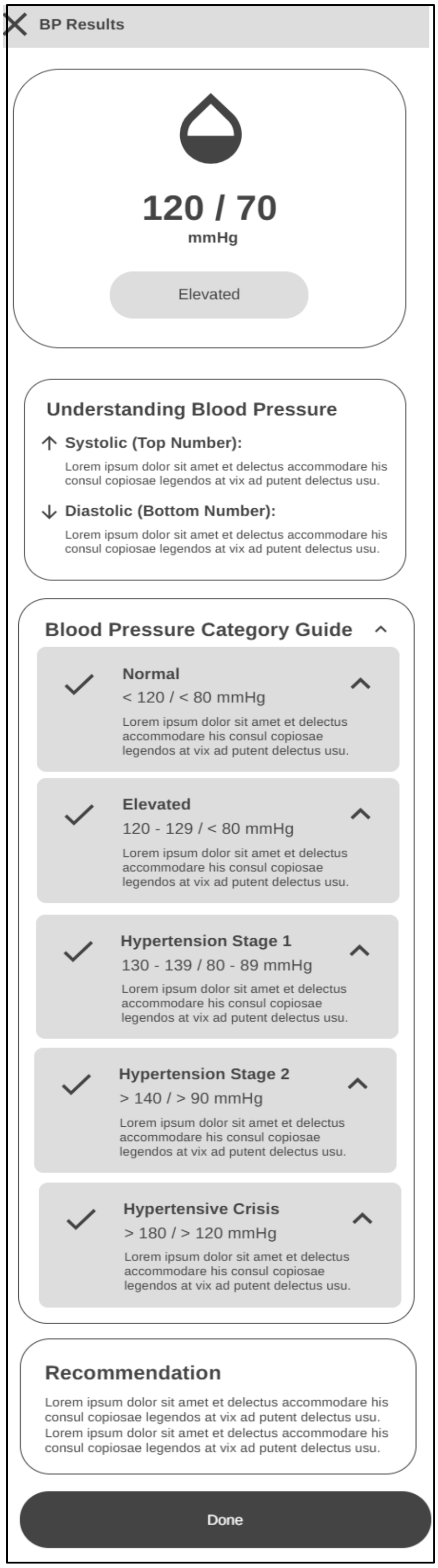


Figure A.3.12 Blood Pressure Measurement Result Page Prototype

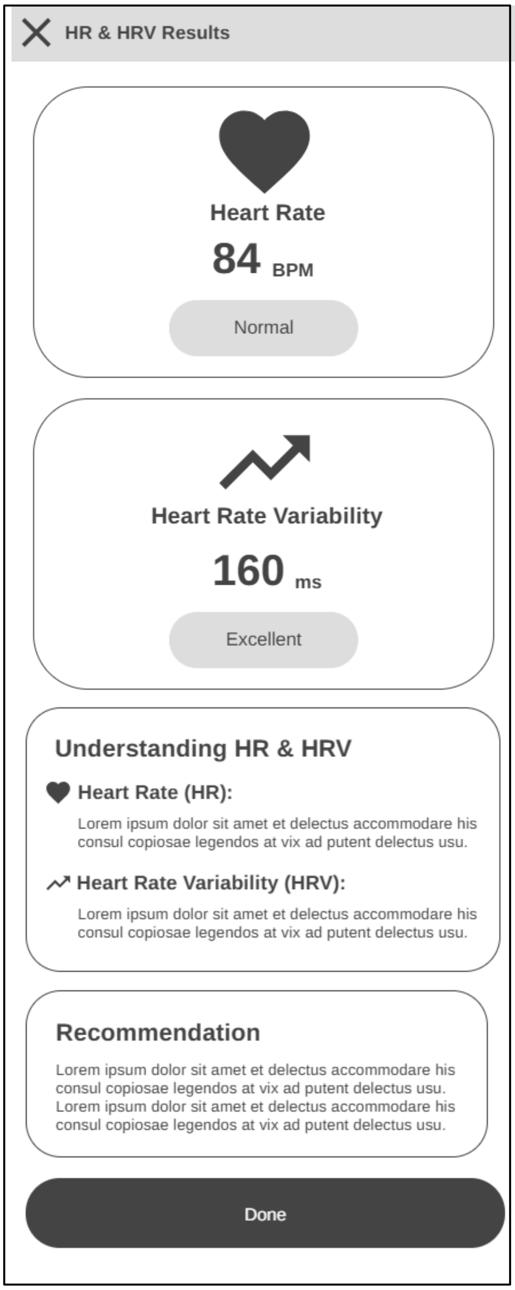


Figure A.3.13 Heart Rate and Heart Rate Variability Measurement Result Page Prototype

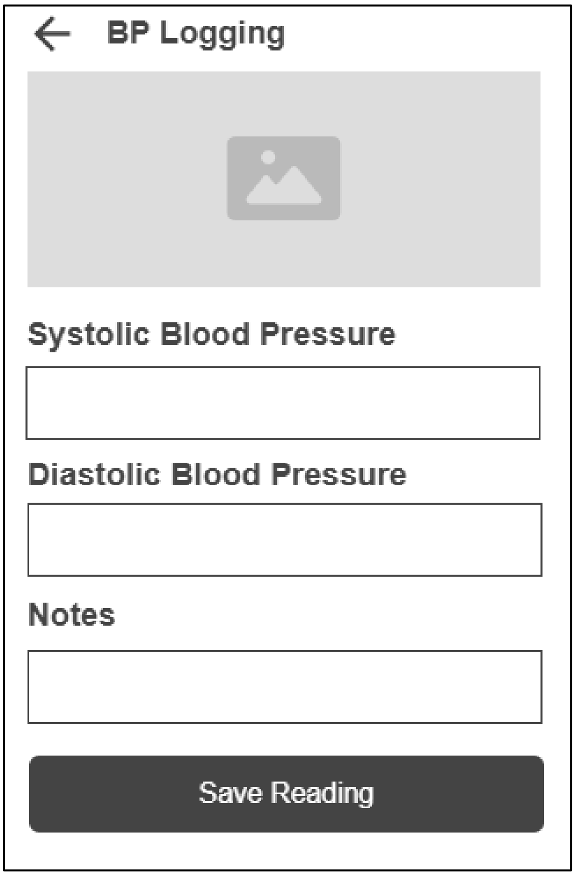


Figure A.3.14 Blood Pressure Recording Page Prototype

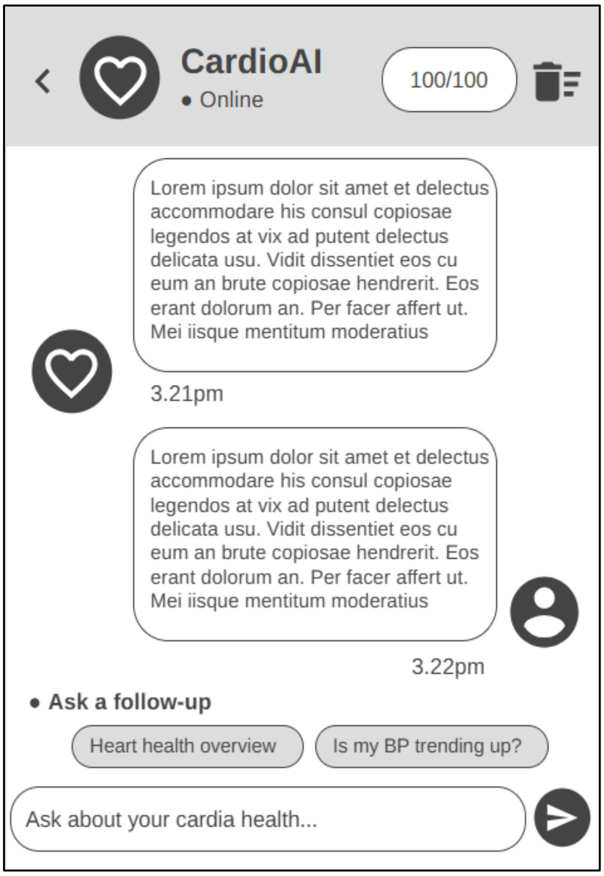


Figure A.3.15 AI Cardio Assistant Page Prototype

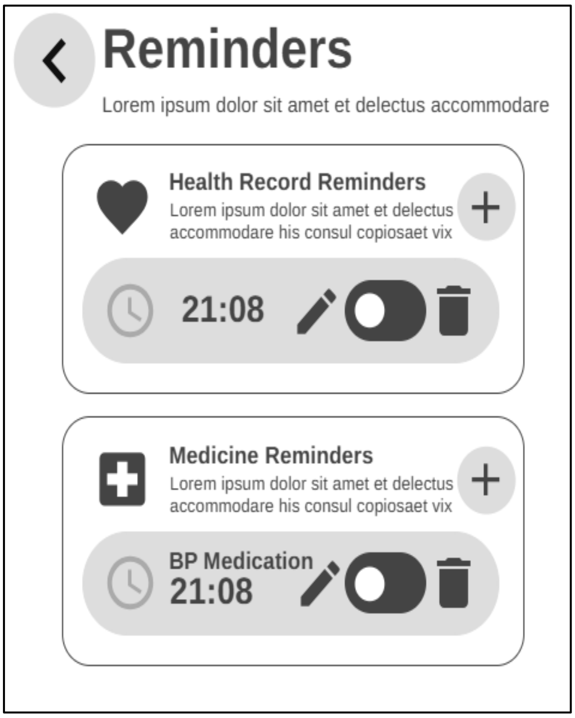


Figure A.3.16 Mange Reminders Page Prototype

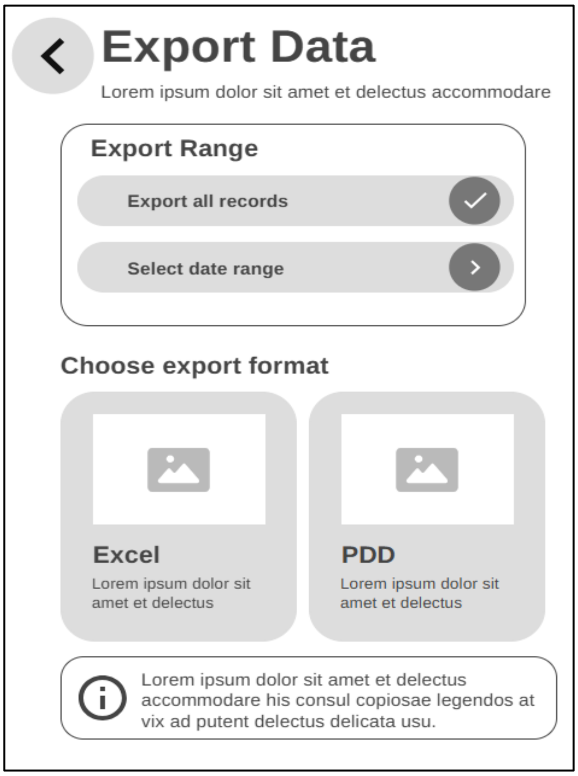


Figure A.3.17 Export Data Page Prototype

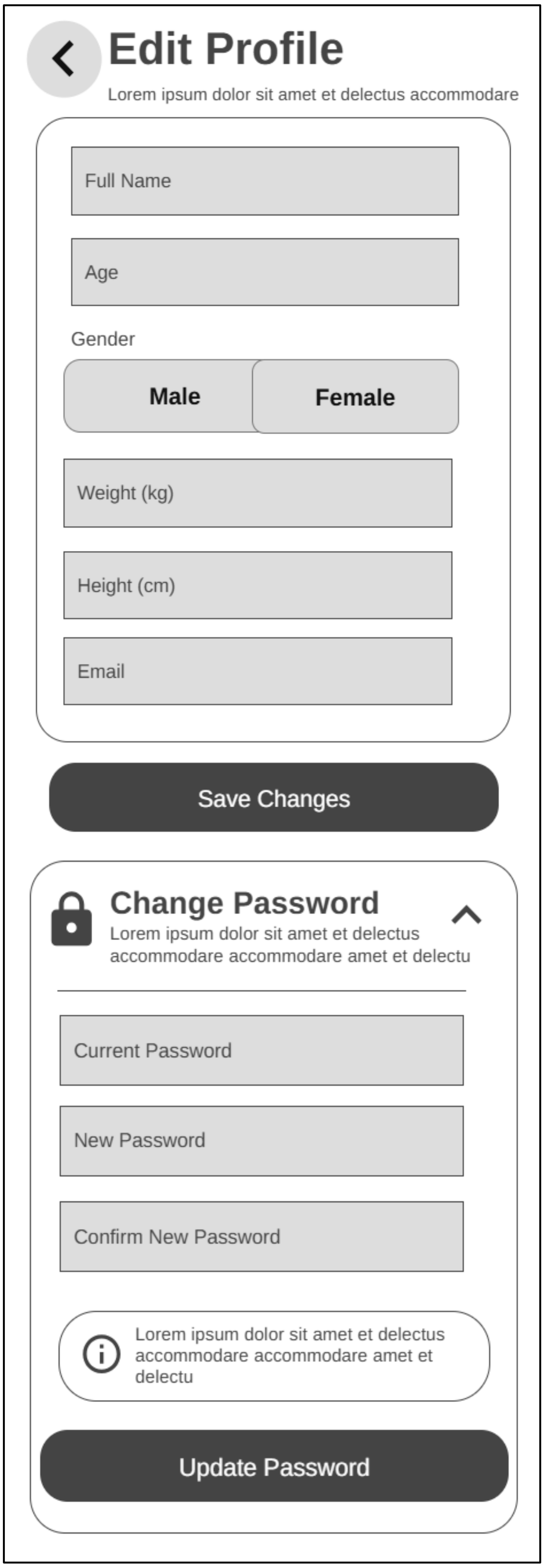


Figure A.3.18 Edit Profile Page Prototype

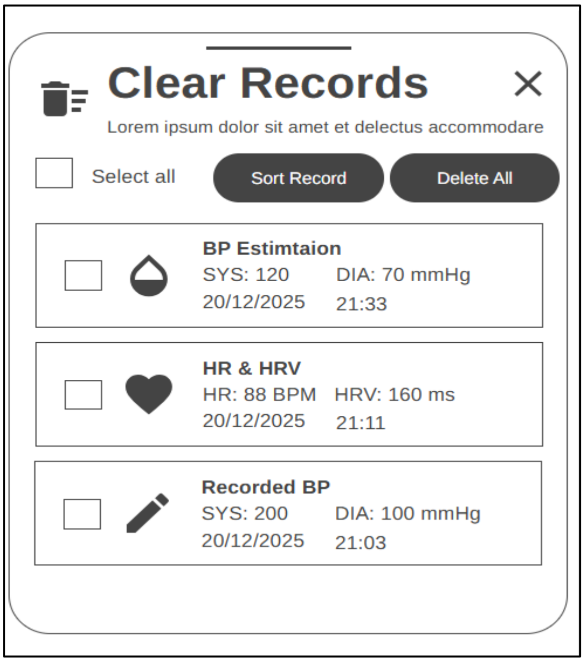


Figure A.3.19 Clear Records Page Prototype

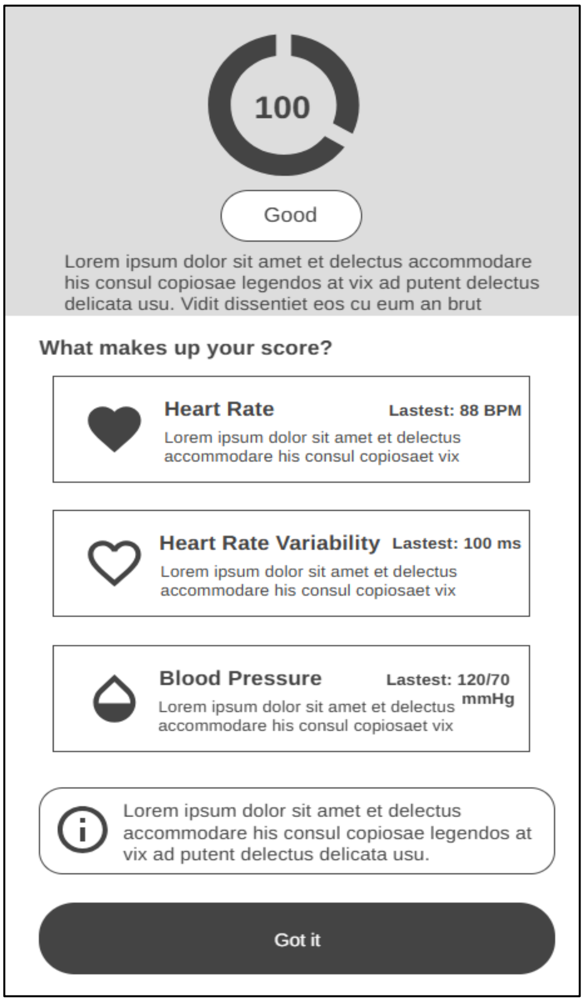


Figure A.3.20 View Health Score Page Prototype

A.4 Functional Testing of Proposed Application Modules

Login Module

Table A.4.1 Functional Test Cases for Login Module

Activity: Login				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User does not enter the email address or password and clicks the "Sign In" button.	Prompt the user to enter their email address and password.	The error message "Please enter your email and password." is displayed.	Pass
TC02	User enters an invalid email address and clicks the "Sign In" button.	Prompt the user to enter a valid email address.	The error message "Please enter a valid email address." is displayed.	Pass
TC03	User entered an invalid password with less than 6 characters and clicks the "Sign In" button.	Prompt the user to enter a valid password.	The error message "Password must be at least 6 characters." is displayed.	Pass
TC04	User enters a valid email address and password without registering an account and clicks the "Sign In" button.	Prompt the user to register first before logging in.	The error message "The supplied credential is incorrect. Please register an account before login." is displayed.	Pass
TC05	User enters a registered email address and clicks the "Sign Up" button.	Display the account is already registered.	The error message "The account already exists for that email." is displayed.	Pass
TC06	User clicks the eye icons in the password fields.	Display the password in visible form or hidden form.	The passwords are shown or hidden.	Pass
TC07	No internet connection during the sign-in process.	Prompt the user to log in using a stable Internet connection.	The error message "No internet connection. Please	Pass

			check your network and try again." is displayed.	
TC08	User clicks the "Forget Password?" button.	Display the Reset Password Page.	The Reset Password Page is displayed.	Pass
TC09	User clicks the "Sign up" button.	Display the Sign Up Page.	The Sign Up Page is displayed.	Pass

Login Using Google Account Module

Table A.4.2 Functional Test Cases for Login Using Google Account Module

Activity: Login Using Google Account Module				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the "Sign in with Google" button.	Display a dialog box to prompt the user to select an existing Google Account to continue. An account will be automatically created for a non-existent account.	The dialog box is displayed.	Pass
TC02	User clicks the "Sign in with Google" button without an Internet connection.	Prompt the user to log in using a stable Internet connection.	The error message "No internet connection. Please check your network and try again." is displayed.	Pass
TC03	User signed in using a Google account without completing their profile.	Display a dialog box to prompt the user to complete the profile.	The dialog box is displayed.	Pass
TC04	User clicks the "Update Profile" button.	Display the Edit Profile Page.	The Edit Profile Page is displayed.	Pass
TC05	User clicks the "Later" button.	Display the Home Page.	The Home Page is displayed.	Pass
TC06	User clicks the Home Page button in the	Display a dialog box to prompt the user to complete the profile.	The dialog box is displayed.	Pass

	navigation bar without completing their profile.			

Reset Password Module

Table A.4.3 Functional Test Cases for Reset Password Module

Activity: Reset Password				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User does not enter the email address and clicks the "Send Reset Link" button.	Prompt the user to enter their email address.	The error message "Please enter your email address." is displayed.	Pass
TC02	User enters an invalid email address and clicks the "Send Reset Link" button.	Prompt the user to enter a valid email address.	The error message "Please enter a valid email address." is displayed.	Pass
TC03	User enters a valid email address and clicks the "Send Reset Link" button.	Display a successful message.	The successful message "Password reset link sent to your email! Check your inbox!" is displayed.	Pass
TC04	No internet connection during the password reset process.	Prompt the user to reset their password using a stable Internet connection.	The error message "No internet connection. Please check your network and try again." is displayed.	Pass
TC05	User enters a new password and clicks the "Save" button.	Display a success message indicating that the password has been changed.	The success message "Password changed. You can now sign in with your new password" is displayed.	Pass

Register Account Module

Table A.4.4 Functional Test Cases for Register Account Module

Activity: Register Account				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User does not fill in all fields and clicks the "Sign Up" button.	Prompt the user to fill in all fields.	The error message "Please fill all fields." is displayed.	Pass
TC02	User enters an invalid email address and clicks the "Sign Up" button.	Prompt the user to enter a valid email address.	The error message "Please enter a valid email address." is displayed.	Pass
TC03	User enters special characters or digits in the Full Name field and clicks the Sign Up" button.	Prompt the user to enter a Full Name that contains only letters and spaces.	The error message "Full Name must contain only letters and spaces." is displayed.	Pass
TC04	User enters an invalid age and clicks the Sign Up" button.	Prompt the user to enter a valid age.	The error message "Please enter a realistic age between 5 and 100." is displayed.	Pass
TC05	User enters an invalid weight and clicks the Sign Up" button.	Prompt the user to enter a valid weight.	The error message "Please enter a realistic weight between 50 and 200kg." is displayed.	Pass
TC06	User enters an invalid height and clicks the Sign Up" button.	Prompt the user to enter a valid height.	The error message "Please enter a realistic height between 50 and 200 cm." is displayed.	Pass
TC07	User enters a password with less than 6 characters and clicks the "Sign Up" button.	Prompt the user to enter a valid password.	The error message "The password provided is too weak. Password must be at least 6 characters." is displayed.	Pass

TC08	User enters a password and a confirmation password that do not match and clicks the Sign Up” button.	Prompt the user to enter the matching password.	The error message “Passwords do not match!” is displayed.	Pass
TC09	User clicks the eye icons in the password fields.	Display the password in visible form or hidden form.	The passwords are shown or hidden.	Pass
TC10	User enters a registered email address and clicks the “Sign Up” button.	Display the account is already registered.	The error message “The account already exists for that email.” is displayed.	Pass
TC11	No internet connection during the sign up process.	Prompt the user to sign up using a stable Internet connection.	The error message “No internet connection. Please check your network and try again.“ is displayed.	Pass

Home Page Module

Table A.4.5 Functional Test Cases for Home Page Module

Activity: Home Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the “Home” icon button in the navigation bar.	Display the Home Page.	The Home Page is displayed.	Pass
TC02	User clicks the “Health Score” button.	Display a dialog box containing the current health scores, latest measurement records and the “Got it” button.	The dialog box is displayed.	Pass
TC03	User clicks the “Got it” button.	Redirect the user to the Home Page.	The Home Page is displayed.	Pass
TC04	User clicks the “AI Insights” button at the top right of the Home Page or	Display the AI Cardio Assistant Page with a welcome message, chat history, a delete button,	The AI Cardio Assistant Page is displayed.	Pass

	the floating button at the bottom right.	suggested questions, an input field and a send button.		
TC05	User clicks the “Full Scan” button in the Quick Actions section.	Display the Full Scan Measurement Page.	The Full Scan Measurement Page is displayed.	Pass
TC06	User clicks the “Heart Rate Monitor” button in the Quick Actions section.	Display the Heart Rate Monitor Page.	The Heart Rate Monitor Page is displayed.	Pass
TC07	User clicks the “Blood Pressure Estimation” button in the Quick Actions section.	Display the Blood Pressure Estimation Page.	The Blood Pressure Estimation Page is displayed.	Pass
TC08	User clicks the “Record Blood Pressure” button in the Quick Actions section.	Display the Record Blood Pressure Page.	The Record Blood Pressure Page is displayed.	Pass

AI Cardio Assistant Module

Table A.4.6 Functional Test Cases for AI Cardio Assistant Module

Activity: AI Cardio Assistant Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the delete button at the top right of the AI Cardio Assistant Page.	Display a confirmation message asking whether to clear the chat.	The confirmation dialog box is displayed.	Pass
TC02	User clicks the “Clear” button in the confirmation message for deleting the chat history.	Clear the chat history and refresh the AI Cardio Assistant Page.	The chat history is deleted, and the page displays a welcome message, a delete button, suggested questions, an input field and a send button.	Pass

TC03	User clicks the “Cancel” button in the confirmation message for deleting the chat history.	Redirect the user to the AI Cardio Assistant Page.	The AI Cardio Assistant Page with the previous chat history is displayed.	Pass
TC04	User clicks a suggested question.	Send the suggested question to the chat.	The suggested question is sent to the chat.	Pass
TC05	User enters the cardio-related question in the input field and clicks the send button.	The AI assistant provides the answer with the user’s health measurement summary.	The AI assistant's response is displayed.	Pass
TC06	No internet connection during the AI assistant consultation process.	Prompt the user to use a stable Internet connection.	The error message “A network error occurred. Please try again with a stable network connection.” is displayed.	Pass

Full Scan Measurement Module

Table A.4.7 Functional Test Cases for Full Scan Measurement Module

Activity: Full Scan Measurement Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the “Full Scan” button in the Quick Actions section of the Home Page.	Display a dialog guiding the user on where to place their finger to cover the camera lens.	The guidance dialog box is displayed.	Pass
TC02	User clicks the “Got it” button.	Display the Fingertip Positioning Page.	The Fingertip Positioning Page is displayed.	Pass
TC03	User places the fingertip over the camera lens.	Display the three states of the fingertip positioning and navigate to the Full Scan Measurement Page.	The three fingertip positioning states are displayed. The Full Scan Measurement Page is also displayed.	Pass

TC04	User places their fingertip over the camera lens and holds still for 20 seconds.	Display a loading page indicating that the captured signals are being processed.	The loading page is displayed.	Pass
TC05	User places their fingertip over the camera lens but removes it during the measurement.	Display an error message indicating that the finger was removed and redirect the user to the Fingertip Positioning Page.	The error message "Finger removed. Please place finger again." is displayed and the user is redirected to the Fingertip Positioning Page.	Pass
TC06	User has a sufficient PPG signal.	Display the Full Scan results page.	The Full Scan results page is displayed.	Pass
TC07	User has an insufficient PPG signal.	Display an alert dialog indicating that the captured signal is insufficient for measurement.	The alert dialog "Poor Fingertip Signal Quality. Tips: keep finger flat and still, avoid pressing too hard." is displayed.	Pass
TC08	A connection error or server error occurs during the signal processing.	Display an alert dialog indicating that an error occurred while communicating with the server.	The alert dialog "Connection Timeout, Server response timeout. Please try again." is displayed.	Pass

Heart Rate and Heart Rate Variability Measurement Module

Table A.4.8 Functional Test Cases for Heart Rate and Heart Rate Variability Measurement Module

Activity: Heart Rate Monitor Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the "Heart Rate Monitor" button in the Quick Actions section of the Home Page.	Display a dialog guiding the user on where to place their finger to cover the camera lens.	The guidance dialog box is displayed.	Pass

TC02	User clicks the "Got it" button.	Display the Fingertip Positioning Page.	The Fingertip Positioning Page is displayed.	Pass
TC03	User places the fingertip over the camera lens.	Display the three states of the fingertip positioning and navigate to the Heart Rate Monitor Page.	The three fingertip positioning states are displayed. The Heart Rate Monitor Page is also displayed.	Pass
TC04	User places their fingertip over the camera lens and holds still for 20 seconds.	Display a loading page indicating that the captured signals are being processed.	The loading page is displayed.	Pass
TC05	User places their fingertip over the camera lens but removes it during the measurement.	Display an error message indicating that the finger was removed and redirect the user to the Fingertip Positioning Page.	The error message "Finger removed. Please place finger again." is displayed and the user is redirected to the Fingertip Positioning Page.	Pass
TC06	User has a sufficient PPG signal.	Display the Heart Rate Monitor results page.	The Heart Rate Monitor results page is displayed.	Pass
TC07	User has an insufficient PPG signal.	Display an alert dialog indicating that the captured signal is insufficient for measurement.	The alert dialog "Poor Fingertip Signal Quality. Tips: keep finger flat and still, avoid pressing too hard." is displayed.	Pass
TC08	A connection error or server error occurs during the signal processing.	Display an alert dialog indicating that an error occurred while communicating with the server.	The alert dialog "Connection Timeout, Server response timeout. Please try again." is displayed.	Pass

Blood Pressure Estimation Module

Table A.4.9 Functional Test Cases for Blood Pressure Estimation Module

Activity: Blood Pressure Estimation Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the "Blood Pressure Estimation" button in the Quick Actions section of the Home Page.	Display a dialog guiding the user on where to place their finger to cover the camera lens.	The guidance dialog box is displayed.	Pass
TC02	User clicks the "Got it" button.	Display the Fingertip Positioning Page.	The Fingertip Positioning Page is displayed.	Pass
TC03	User places the fingertip over the camera lens.	Display the three states of the fingertip positioning and navigate to the Blood Pressure Estimation Page.	The three fingertip positioning states are displayed. The Blood Pressure Estimation Page is also displayed.	Pass
TC04	User places their fingertip over the camera lens and holds still for 20 seconds.	Display a loading page indicating that the captured signals are being processed.	The loading page is displayed.	Pass
TC05	User places their fingertip over the camera lens but removes it during the measurement.	Display an error message indicating that the finger was removed and redirect the user to the Fingertip Positioning Page.	The error message "Finger removed. Please place finger again." is displayed and the user is redirected to the Fingertip Positioning Page.	Pass
TC06	User has a sufficient PPG signal.	Display the Blood Pressure Estimation results page.	The Blood Pressure Estimation results page is displayed.	Pass
TC07	User has an insufficient PPG signal.	Display an alert dialog indicating that the	The alert dialog "Poor Fingertip Signal Quality.	Pass

		captured signal is insufficient for measurement.	Tips: keep finger flat and still, avoid pressing too hard." is displayed.	
TC08	A connection error or server error occurs during the signal processing.	Display an alert dialog indicating that an error occurred while communicating with the server.	The alert dialog "Connection Timeout, Server response timeout. Please try again." is displayed.	Pass

Record Blood Pressure Module

Table A.4.10 Functional Test Cases for Record Blood Pressure Module

Activity: Record Blood Pressure Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the "Save Reading" button.	Prompt the user to enter both systolic and diastolic values.	The error message "Please enter both systolic and diastolic values." is displayed.	Pass
TC02	User enters invalid systolic or diastolic values and clicks the "Save Reading" button.	Prompt the user to enter a valid systolic and diastolic value.	The error message "Readings out of range. Systolic must be 60-250 mmHg, Diastolic 30-150 mmHg, and Diastolic must be lower than Systolic." is displayed.	Pass
TC03	User enters valid systolic and diastolic values with additional notes and clicks the "Save Reading" button.	Display a dialog box notifying the user of automatic classification based on the input values, along with general recommendations.	The dialog box is displayed.	Pass
TC04	User clicks the "Got it" button on the dialog box.	Redirect the user to the Home Page with a	The Home Page is displayed with a success	Pass

		success message indicating that the blood pressure has been recorded.	message "Blood Pressure is recorded successfully.".	

History Page Module

Table A.4.11 Functional Test Cases for History Page Module

Activity: History Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the "History" icon button in the navigation bar.	Display the History Page.	The History Page is displayed.	Pass
TC02	User clicks the "HR & HRV Records" button.	Display past HR and HRV records with a timestamp.	The HR and HRV records are displayed.	Pass
TC03	User clicks the "HR & HRV Records" button when records are already expanded.	Hide the HR and HRV records.	The HR and HRV records are hidden.	Pass
TC04	User clicks the "BP Estimation Records" button.	Display past estimated BP records with a timestamp.	The BP estimation records are displayed.	Pass
TC05	User clicks the "BP Estimation Records" button when records are already expanded.	Hide the estimated BP records.	The BP estimation records are hidden.	Pass
TC06	User clicks the "Recorded BP Records" button.	Display past recorded BP records with a timestamp.	The recorded BP records are displayed.	Pass
TC07	User clicks the "Recorded BP Records" button when records are already expanded.	Hide the recorded BP records.	The recorded BP records are hidden.	Pass

Trends and Analysis Page Module

Table A.4.12 Functional Test Cases for Trends and Analysis Page Module

Activity: Trends and Analysis Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the "Trends" icon button in the navigation bar.	Display the Trends and Analysis Page.	The Trends and Analysis Page is displayed.	Pass
TC02	User clicks the "Filter" button.	Expand the filter panel shows the current month and year, 7 day date range and both "7 days" and "30 days" buttons.	Filter panel displays the current date, month, and year correctly with 7 day range selected.	Pass
TC03	User clicks the "Filter" button when it is already expanded.	Hide the filter panel.	The filter panel is hidden.	Pass
TC04	User clicks the calendar icon or the current month and year button in the Filter section.	Display the month and year selection interface.	The month and year selection interface is displayed.	Pass
TC05	User clicks the "+" or "-" icon in the year section.	Increase or decrease the year value accordingly.	The year is updated correctly based on user action.	Pass
TC06	User selects a month in the month section.	Highlight the selected month.	The selected month is highlighted correctly.	Pass
TC07	User clicks the "Apply" button.	Redirect the user to the filter panel and update the selected month and year.	The date is updated correctly based on selected values.	Pass
TC08	User clicks the ">" or "<" navigation arrows above the 7 day date range.	Update the 7 day date range forward or backward accordingly.	The date range updates correctly.	Pass

TC09	User clicks the "7 days" or "30 days" button.	Display the updated trends and analysis based on the selected time range.	The trends and analysis is updated based on the selected date range.	Pass
TC10	User clicks the "Heart Rate" button on the Select Metric Section.	Display the HR analysis including the definition, HR trend chart, HR categories, insights and recommendations.	The HR trends and analysis are displayed.	Pass
TC11	User clicks the "HRV" button on the Select Metric Section.	Display the HRV analysis including the definition, HRV trend chart, HRV categories, insights and recommendations.	The HRV trends and analysis are displayed.	Pass
TC12	User clicks the "Estimated BP" button on the Select Metric Section.	Display the estimated BP analysis including the definition, estimated BP trend chart, BP categories, insights and recommendations.	The estimated BP trends and analysis are displayed.	Pass
TC13	User clicks the "Recorded BP" button on the Select Metric Section.	Display the recorded BP analysis including the definition, recorded BP trend chart, BP categories, insights and recommendations.	The recorded BP trends and analysis are displayed.	Pass

Profile Page Module

Table A.4.13 Functional Test Cases for Profile Page Module

Activity: Profile Page Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the "Profile" icon button in the navigation bar.	Display the Profile Page.	The Profile Page is displayed.	Pass

TC02	User clicks the "Edit Profile" button.	Display the Edit Profile Page.	The Edit Profile Page is displayed.	Pass
TC03	User clicks the "Reminders" button.	Display the Reminders Page.	The Reminders Page is displayed.	Pass
TC04	User clicks the "Export Data" button.	Display the Export Data Page.	The Export Data Page is displayed.	Pass
TC05	User clicks the "Clear Data" button.	Display the Clear Data Page.	The Clear Data Page is displayed.	Pass
TC06	User clicks the "Logout" button.	Display the logout confirmation dialog box.	The logout confirmation dialog box is displayed.	Pass

Edit Profile Page Module

Table A.4.14 Functional Test Cases for Edit Profile Page Module

Activity: Edit Profile Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User enters an empty name and clicks the "Save Changes" button.	Prompt the user to enter a name.	The error message "Name is required." is displayed.	Pass
TC02	User enters an invalid full name containing special characters or digits and clicks the "Save Changes" button.	Prompt the user to enter a valid name that contains only letters and spaces.	The error message "Name can only contain letters and spaces." is displayed.	Pass
TC03	User enters an invalid full name with less than 2 characters and clicks the "Save Changes" button.	Prompt the user to enter a valid name with at least 2 characters.	The error message "Name must be at least 2 characters." is displayed.	Pass
TC04	User enters an empty age and clicks the "Save Changes" button.	Prompt the user to enter an age.	The error message "Age is required." is displayed.	Pass

TC05	User enters an invalid age and clicks the "Save Changes" button.	Prompt the user to enter a valid age.	The error message "Enter a valid age (1-100)" is displayed.	Pass
TC06	User clicks the "Male" or "Female" button.	Highlight the selected gender button.	The selected gender button is highlighted based on user selection.	Pass
TC07	User enters an empty weight and clicks the "Save Changes" button.	Prompt the user to enter a weight.	The error message "Weight is required." is displayed.	Pass
TC08	User enters an invalid weight and clicks the "Save Changes" button.	Prompt the user to enter a valid weight.	The error message "Enter a valid weight (50-250kg)" is displayed.	Pass
TC09	User enters an empty height and clicks the "Save Changes" button.	Prompt the user to enter a height.	The error message "Height is required." is displayed.	Pass
TC10	User enters an invalid height and clicks the "Save Changes" button.	Prompt the user to enter a valid height.	The error message "Enter a valid height (50-250cm)" is displayed.	Pass
TC11	User clicks the "Save Changes" button.	Display a success message indicating that the profile has been updated.	The success message "Profile updated successfully!" is displayed	Pass
TC12	User clicks the "Change Password" button.	Expand the change password panel, display the current password, new password and confirm new password fields.	The change password panel is expanded.	Pass
TC13	User clicks the "Change Password" button when it is already expanded.	Hide the change password panel.	The change password panel is hidden.	Pass

TC14	User does not fill in all fields and clicks the "Update Password" button	Prompt the user to fill in all fields.	The error message "Current password, new password and confirm your new password is required." is displayed.	Pass
TC15	User enters a new password with less than 8 characters and clicks the "Update Password" button.	Prompt the user to enter a password containing at least 8 characters.	The error message "Password must be at least 8 characters and include an uppercase character and a digit." is displayed.	Pass
TC16	User enters a new password without an uppercase character and clicks the "Update Password" button.	Prompt the user to include at least 1 uppercase character.	The error message "Include at least one uppercase character" is displayed.	Pass
TC17	User enters a new password without a digit and clicks the "Update Password" button.	Prompt the user to include at least 1 digit.	The error message "Include at least one digit" is displayed.	Pass
TC18	User enters a password and a confirmation password that do not match and clicks the "Update Password" button.	Prompt the user to enter the matching password.	The error message "Passwords do not match!" is displayed.	Pass
TC19	User enters the current password the same as the new password and the confirmation password and clicks the "Update Password" button.	Prompt the user to enter a different new password.	The error message "New password must differ from the current" is displayed.	Pass

TC20	User enters an invalid current password with a valid new password and confirmation password and clicks the "Update Password" button.	Prompt the user to enter the correct current password.	The error message "The supplied auth credential is incorrect, malformed or has expired." is displayed.	Pass
TC21	User clicks the "<" button at the top left of the Edit Profile Page.	Redirect the user to the Profile Page.	The Profile Page is displayed.	Pass

Reminders Page Module

Table A.4.15 Functional Test Cases for Reminders Page Module

Activity: Reminders Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the "+" icon in the Health Record Reminders or Medicine Reminders section.	Display reminder time interface.	The reminder time interface is displayed.	Pass
TC02	User scrolls the reminder time interface to set the hour and minutes.	Increase or decrease the reminder time accordingly.	The reminder time is updated based on user selection.	Pass
TC03	User clicks "OK" after selecting the reminder time in the Health Record Reminders section.	Prompt the user to select a repeat frequency with the "Daily" and "Weekly" buttons.	The repeating frequency including the "Daily" and "Weekly" buttons is displayed.	Pass
TC04	User clicks the "Daily" button to set a daily health record reminder.	Display a success message indicating the reminder is set.	The success message "Health reminder set for the selected time" is displayed.	Pass
TC05	User clicks the "Weekly" button to set a weekly health record reminder.	Prompt the user to select the day to receive the reminder.	The list of days is displayed.	Pass

TC06	User selects the preferred days in the day selection section.	Display a success message indicating the reminder is set.	The success message “Health reminder set for the selected time” is displayed.	Pass
TC07	User clicks “OK” after selecting the reminder time in the Medicine Reminders section.	Prompt the user to enter the medicine name.	The medicine name input field is displayed.	Pass
TC08	User enters a medicine name and clicks “Add”.	Display a success message indicating the reminder is set.	The success message “Medicine Reminder set for the selected time” is displayed.	Pass
TC09	User clicks “Cancel” in the medicine name input.	Redirect the user to the Reminders Page.	The Reminders Page is displayed.	Pass
TC10	After the user sets a reminder.	Display the reminder notification at the scheduled time.	The reminder notification is displayed at the scheduled time.	Pass
TC11	User clicks the toggle icon in a health record reminder or medicine reminder.	Activate or deactivate the reminder.	The reminder is activated or deactivated.	Pass
TC12	User clicks the edit icon in a health record reminder or medicine reminder.	Update the reminder by repeating the reminder creation steps.	The reminder is updated.	Pass
TC13	After the user successfully updates the reminder.	Display a success message indicating the reminder is updated.	The success message “Health reminder updated to the selected time” or “Medicine reminder updated to the selected time” is displayed.	Pass
TC14	User clicks the delete icon in a health record reminder or medicine reminder.	Display a confirmation message asking the user to confirm deletion.	The confirmation message is displayed.	Pass

TC15	User clicks the “Delete” button in the confirmation message.	Delete the reminder from the Reminders Page.	The reminder is deleted from the Reminder Page.	Pass
TC16	User clicks the “Cancel” button in the confirmation message.	Redirect the user to the Reminder Page.	The Reminders Page is displayed.	Pass
TC17	User clicks the “<” button at the top left of the Reminders Page.	Redirect the user to the Profile Page.	The Profile Page is displayed.	Pass

Export Data Page Module

Table A.4.16 Functional Test Cases for Export Data Page Module

Activity: Export Data Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the “Select date range” button.	Prompt the user to select or enter the date on the calendar interface.	The calendar interface is displayed.	Pass
TC02	User scrolls the calendar interface.	Update the calendar based on user interaction.	The calendar is updated accordingly.	Pass
TC03	User selects the start date and end date on the calendar interface.	Highlight the selected date range in the calendar interface.	The selected date range is highlighted.	Pass
TC04	User selects a date range and clicks “Save”.	Redirect the user to the Export Date Page and display a statement indicating the total number of records found or that no records were found within the selected range.	The statement is displayed.	Pass
TC05	User clicks the edit icon in the calendar interface.	Prompt the user to manually enter the start and end dates.	The input fields are displayed.	Pass

TC06	User enters an invalid start or end date and clicks “OK”.	Display an error message indicating an invalid date format.	The error message “Invalid format” is displayed.	Pass
TC07	User enters a valid start or end date and clicks “OK”.	Redirect the user to the Export Date Page and display a statement indicating the total number of records found or that no records were found in the range.	The statement is displayed.	Pass
TC08	User clicks the calendar icon above the input field.	Redirect the user to the calendar interface.	The calendar interface is displayed.	Pass
TC09	User clicks the “Cancel” button when entering the start and end dates.	Redirect the user to the Export Data Page.	The Export Data Page is displayed.	Pass
TC10	User selects a date range with no records and clicks the “Excel” or “PDF” button.	Display an error message indicating no records are available for export.	The error message “No records found in the selected date range.” is displayed.	Pass
TC11	User selects a date range with records and clicks the “Excel” or “PDF” button.	Display the file sharing interface.	The file sharing interface is displayed.	Pass
TC12	User clicks the “Export all records” button and clicks the “Excel” or “PDF” button.	Display the file sharing interface.	The file sharing interface is displayed.	Pass
TC13	User selects a sharing option and shares the file.	Redirect the user to the Export Data Page and display a success message indicating the file has been exported.	The success message “Exported and shared as EXCEL.” or “Exported and shared as PDF” is displayed.	Pass
TC14	User does not select a sharing option in the file	Redirect the user to the Export Data Page and display	The success message “Exported and shared	Pass

	sharing interface and clicks elsewhere in the application.	an error message indicating the file has not been exported.	as EXCEL." or "Exported and shared as PDF" is displayed.	
TC15	User clicks the "<" button at the top left of the Export Data Page.	Redirect the user to the Profile Page.	The Profile Page is displayed.	Pass

Clear Data Module

Table A.4.17 Functional Test Cases for Clear Data Module

Activity: Clear Data				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User selects the record from the record list by ticking the checkbox beside it.	Tick the selected record and display the "Delete selected record" button.	The selected record is ticked and the "Delete selected record" button is displayed.	Pass
TC02	User clicks the "Delete selected record" button.	Display a confirmation message asking the user to confirm the deletion.	The confirmation message is displayed.	Pass
TC03	User clicks the "Delete" button.	Delete the selected record from the record lists.	The record is deleted from the record lists.	Pass
TC04	User clicks the "Cancel" button.	Redirect the user to the record lists.	The record list is displayed.	Pass
TC05	User clicks the "Select all" button.	Tick all records in the record list.	All records in the record list are ticked.	Pass
TC06	User clicks the "Deselect all" button.	Untick all records in the record list.	All records in the record lists are unticked.	Pass
TC07	User clicks the "Newest" button.	Sort the record list from newest to oldest and update the button label to "Oldest".	The record list is sorted in descending order and the "Oldest" button is displayed.	Pass

TC08	User clicks the "Oldest" button.	Sort the record list from oldest to newest and updates the button label to "Newest".	The record list is sorted in ascending order and the "Newest" button is displayed.	Pass
TC09	User clicks the "Delete All" button.	Display a confirmation message asking the user to confirm the deletion of all records.	A confirmation message is displayed.	Pass
TC10	User clicks the "X" button at the top right of the Clear Data Page.	Redirect the user to the Profile Page.	The Profile Page is displayed.	Pass

Logout Module

Table A.4.18 Functional Test Cases for Logout Module

Activity: Logout Page				
ID	**Test Case**	**Expected Results**	**Actual Results**	**Status**
TC01	User clicks the "Logout" button on the confirmation dialog box.	Redirect the user to the Login Page.	The Login Page is displayed.	Pass
TC02	User clicks the "Cancel" button on the confirmation dialog box.	Redirect the user to the Profile Page.	The Profile Page is displayed.	Pass

APPENDIX B

Poster