Real-Time Heart Condition Monitoring and Emergency Alert System Using Mobile and Wearable Devices

Arsalen Bidani
a.bidani@studenti.unipi.it

ABSTRACT

This project introduces RescuePulse a comprehensive continuous heart rate monitoring and emergency response system that utilizes the PPG sensor on a wearable smartwatch for heart rate monitoring, in conjunction with a companion mobile application.

The wearable device application serves as the primary data collection point, continuously monitoring heart rate and detecting anomalies. It alerts the user on the watch using sound and vibration and transmits critical data to the companion mobile application. The mobile app plays a vital role by managing emergency contacts and services and actively monitoring alerts from the wearable device application. In an emergency, the mobile app automatically initiates calls to predefined emergency services and sends messages to designated contacts. These messages include details of the detected heart anomaly and the individual's GPS location, which is also gathered by the system.

The system aims to provide an efficient, user-friendly solution for continuous heart rate monitoring and emergency alerting, particularly benefiting individuals in remote or underserved areas with limited access to clinical facilities.

1 Introduction

In today's healthcare landscape, heart rhythm abnormalities represent significant threats, often leading to cardiovascular fatalities. Continuous monitoring of heart rate is paramount, especially for individuals at high risk due to prior heart attacks. Traditional ECG-based devices, while effective, are hindered by their requirement for electrode placement and the potential discomfort associated with prolonged use.

RescuePulse addresses these challenges through an innovative approach leveraging wearable technology and a companion mobile application. The project utilizes the PPG sensor embedded in a wearable smartwatch, which serves as a non-intrusive method for continuous heart rate monitoring. This sensor, located conveniently on the user's wrist, eliminates the need for cumbersome electrode placements required by traditional ECG devices.

The main differentiator of RescuePulse compared to existing approaches lies in its seamless integration of real-time heart rate monitoring with proactive emergency response capabilities. The wearable device application not only monitors heart rate and detects anomalies but also alerts users through sound and vibration. It then transmits critical health data to the companion mobile app, which manages emergency contacts and services. In the event of an emergency, the mobile app automatically initiates calls to predefined emergency services and sends precise SMS alerts to designated contacts, including details of the detected heart anomaly and the user's current GPS location.

RescuePulse represents a significant advancement in healthcare technology, offering a user-friendly solution for continuous heart rate monitoring and immediate emergency response, particularly beneficial for individuals in remote or underserved areas lacking access to comprehensive clinical facilities.

2 System Architecture

The main objective of the RescuePulse project is to develop a comprehensive system that continuously monitors heart rate and promptly responds to emergencies.

The system leverages a wearable application that utilizes a photoplethysmography (PPG) sensor for heart rate monitoring, paired with a companion mobile application for emergency management.

The system consists of two primary components:

- **Wearable Device Application:** utilizes a PPG (Photoplethysmography) sensor for continuous heart rate monitoring and anomaly detection.
- **Mobile Device Application:** manages emergency contacts and services alerting and facilitates communication with the wearable application.

2.1 Sensors and Hardware Integration

The photoplethysmography sensor is central to the wearable device application, providing a non-invasive method to monitor heart rate. It operates by emitting light into the skin and measuring the amount of light reflected back, which varies with blood volume changes during the cardiac cycle. This continuous monitoring allows the system to track heart rate in real-time and detect anomalies effectively [1].

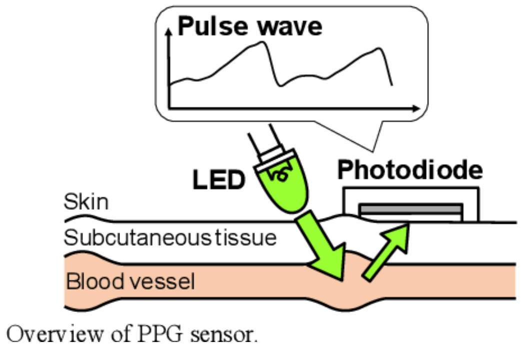

Figure 1: Overview of PPG sensor [2]

This figure illustrates the working principle of the PPG sensor, detailing the light emission, absorption, detection, and signal processing stages. The integration of the PPG sensor in the wearable device application ensures reliable and continuous heart rate monitoring, forming the backbone of the system's anomaly detection capability.

In addition to the PPG sensor, the application integrates GPS functionality for precise localization of the user. This enables the system to capture and transmit the user's geographic coordinates along with heart rate data, enhancing the context and relevance of emergency alerts and monitoring.

The integration further extends to additional hardware components such as the vibrator and audio manager. Upon detecting anomalies in heart rate, the system triggers alerts using these components. The vibrator provides tactile feedback to the user, ensuring alerts are noticed even in noisy or silent environments. Simultaneously, the audio manager controls sound notifications, enhancing the user's awareness of critical events.

This integrated approach ensures comprehensive monitoring and timely alerts, leveraging both physiological data from the PPG sensor and contextual information from GPS localization.

2.2 Data Collection and Transmission

On the wearable application the heart rate data is collected and stored locally using SharedPreferences, a mechanism in Android that stores key-value pairs of primitive data types such as Booleans, floats, Ints, longs, and strings. This data is stored in an XML file in the app's private storage, ensuring it is only accessible to the app itself. This lightweight storage mechanism is utilized to persistently store pairs of heart rate measurements and timestamps. These pairs are crucial for the anomaly detection system to assess the heart rate status over time, ensuring continuous monitoring and enabling timely alerts in case of anomalies.

On the mobile application side, the data model consists of emergency contact details, emergency service numbers, and personal information about the user (name, surname, date of birth, and weight). This information is essential for personalizing the emergency response and ensuring that accurate and relevant details are available during critical situations.

In order to facilitate to Data transmission to and from the companion mobile application, we opted for its management using MessageClient API.

The MessageClient API facilitates remote procedure calls (RPC), it is suitable for one-way requests or a request-response communication model. If the handheld and wearable are connected, the system queues the message for delivery and returns a successful result code. If the devices aren't connected, an error is returned. A successful result code doesn't indicate that the message was delivered successfully, as the devices might disconnect after receiving the result code.

2.3 Foreground Services

Foreground services are employed in both the wearable and mobile applications to ensure continuous operation, even when the apps are running in the background.
These services are crucial for tracking heart rate status, sending and receiving emergency alerts, and initiating phone calls and SMS messages. Given the critical nature of heart rate monitoring and the need for immediate emergency response, foreground services were chosen over alternatives like WorkManager.

Reasons for Choosing Foreground Services:

1. **Real-time Data Processing:** Foreground services are better suited for continuous, real-time data monitoring. This ensures an immediate response to critical heart rate conditions, which is essential for timely medical intervention.

2. **Immediate UI Updates and Notifications:** Foreground services can directly update the user interface and trigger alarms without any latency. This capability is vital for promptly alerting the user and initiating emergency protocols.

3. **User Awareness and Reliability:** Running as a foreground service ensures that the user is constantly aware of the monitoring activity. Additionally, the system is less likely to terminate a foreground service, providing greater reliability for critical health monitoring tasks.

Foreground services allow the wearable application to continuously monitor heart rate data, assess the status, and transmit emergency alerts to the companion mobile application. Similarly, the mobile app, running a foreground service, listens for these alerts and can immediately initiate emergency calls and send SMS messages to predefined contacts and services. This setup guarantees a robust and reliable system for emergency response and heart rate monitoring.

2.4 System Workflow and Opeation

The system workflow and operation ensure reliable heart rate monitoring and prompt emergency response. The sequence diagram in Figure 2 illustrates the initiation and communication processes between the wearable and mobile applications.

The process begins when the user initiates monitoring through the mobile application. An initiation flag, along with the user's age, is sent to the wearable application. Upon receiving this flag, the wearable device responds with an acknowledgment. This two-way communication confirms the start of heart rate monitoring and provides feedback to the user about the connection status, enhancing the system's reliability and ensuring the user is aware of the monitoring status.

The sequence diagram in Figure 2 visually represents these initial interactions, while the rest of the workflow, including continuous monitoring, anomaly detection, and emergency response, is also detailed in the figure.

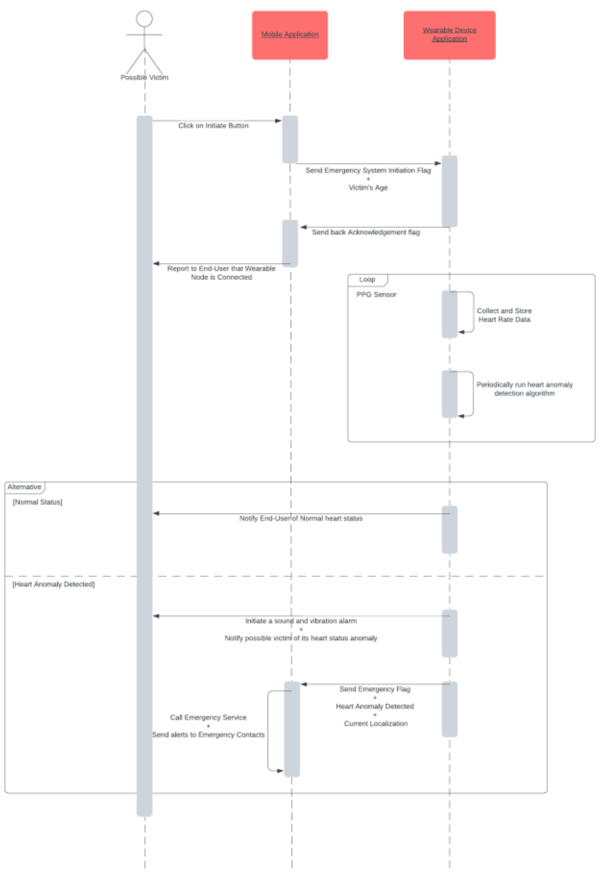

Figure 2: Sequence Diagram of System Workflow

This initial establishment of two-way communication is crucial for ensuring that the system functions smoothly, providing a foundation for continuous heart rate monitoring and timely emergency alerts.

3 Anomaly Detection and Alerting System

The anomaly detection and alerting system in the RescuePulse application is designed to monitor heart rate continuously and provide timely alerts in case of abnormalities.
The system utilizes the Gellish formula to calculate the Maximum Heart Rate (MHR), which adjusts for age-related variability in heart rate. This variability reflects individual differences in observed HRmax, and studies indicate that age alone can account for anywhere from 35% to 80% of MHR variation [3].
Via incorporating age into the MHR calculation, the system ensures accurate and personalized heart rate thresholds for anomaly detection.

3.1 Maximum Heart Rate (MHR) Calculation

The Gellish formula, which factors in age, allows RescuePulse to determine an individual's MHR as it was deemed highly statistically significant compared to the various formulas present:

$$\mathbf{MHR = 207 - (0.7 \times age)}\ \textbf{[4]}$$

This calculated MHR serves as a baseline against which heart rate measurements are compared to detect anomalies.

3.2 Anomaly Detection Criteria

RescuePulse monitors heart rate in real-time to detect anomalies over a continuous 10-minute period. The system identifies two primary anomalies:

- **Bradycardia:** Defined as a heart rate persistently lower than 50 (depending on health condition and age) beats per minute (bpm) over 10 minutes. The system alerts the user or caregiver when bradycardia is detected, indicating a potential health concern such as poor blood circulation or heart disease.

- **Tachycardia:** Characterized by a heart rate persistently exceeding the calculated MHR for the individual's age over 10 minutes. This condition triggers immediate alerts to ensure prompt medical attention, as it may signal underlying cardiac issues or acute stress.

The anomaly detection algorithm continuously monitors heart rate data against predefined thresholds, ensuring rapid detection and notification of abnormal heart rhythms.

4 Conclusion

RescuePulse system provides a comprehensive solution for continuous heart rate monitoring and emergency response, utilizing a wearable smartwatch and a companion mobile application. The system's use of the PPG sensor for real-time heart rate data collection, combined with a robust anomaly detection algorithm based on the Gellish formula, ensures accurate and personalized monitoring for high-risk patients.

Future improvements to the proposed system could include enhanced data analytics, incorporating machine learning algorithms to analyze historical heart rate data and predict potential anomalies before they occur, improving preventative care. Additionally, integrating additional sensors to monitor other vital signs, such as oxygen saturation and blood pressure, could provide a more comprehensive health overview. Improving the user interface for both the wearable and mobile applications to make the system more intuitive and user-friendly is another area for potential enhancement.

REFERENCES

[1] Tamura, Toshiyo, et al. "Wearable photoplethysmographic sensors—past and present." Electronics, vol. 3, no. 2, 2014, pp. 282–302. doi:10.3390/electronics3020282.

[2] Sasai, Kana et al. "A Low-Power Photoplethysmography Sensor using Correlated Double Sampling and Reference Readout Circuit." 2019 IEEE SENSORS (2019): 1-4.

[3] Engels, H-J., W. Zhu, and R. J. Moffatt. An empirical evaluation of the prediction of maximal heart rate. Res. Q. Exerc. Sport 69:94-98, 1998.

[4] GELLISH, RONALD L.; GOSLIN, BRIAN R.; OLSON, RONALD E.; McDONALD, AUDRY; RUSSI, GARY D.; MOUDGIL, VIRINDER K.. Longitudinal Modeling of the Relationship between Age and Maximal Heart Rate. Medicine & Science in Sports & Exercise 39(5):p 822-829, May 2007. | DOI: 10.1097/mss.0b013e31803349c6