

# IMPLEMENTATION OF WEARABLE DEVICE FOR REALTIME ARRHYTHMIA DETECTION USING AI

SUNIL<sup>1\*</sup>, PARIMALA GANDHI G<sup>2</sup>, SANJANA C<sup>3</sup>, MITHLESH SAHANI<sup>4</sup>, PRAPTHI CR<sup>5</sup>

<sup>1</sup>Electronics and Communication Engineering, RR Institute of Technology(VTU), Karnataka, India

<sup>2</sup>Electronics and Communication Engineering, RR Institute of Technology(VTU), Karnataka, India

<sup>3</sup>Electronics and Communication Engineering, RR Institute of Technology(VTU), Karnataka, India

<sup>4</sup>Electronics and Communication Engineering, RR Institute of Technology(VTU), Karnataka, India

<sup>5</sup>Electronics and Communication Engineering, RR Institute of Technology(VTU), Karnataka, India

\*Corresponding Author Email: Sunilrshetty08@gmail.com

## Abstract

Cardiovascular diseases are a major cause of death worldwide, with arrhythmia posing serious risks such as stroke, cardiac arrest, and heart failure. Conventional monitoring methods like Holter monitors and periodic ECG tests are limited by short monitoring duration and delayed detection of irregular heart activity. To address these challenges, this project proposes the implementation of a wearable device for real-time arrhythmia detection and continuous patient monitoring. The system integrates ECG sensors into a compact wearable form, such as a wristband or chest strap, to continuously monitor cardiac activity. Collected ECG signals are processed using digital signal processing techniques to remove noise and motion artifacts. Machine learning models, including CNN and RNN algorithms trained on the MIT-BIH Arrhythmia Database, are used to classify heart rhythms into normal and abnormal categories such as atrial fibrillation, bradycardia, and tachycardia. The device performs real-time on-device analysis to reduce latency and improve data privacy. When abnormal rhythms are detected, alerts are immediately sent through vibrations, mobile notifications, or SMS to caregivers and healthcare providers. Additionally, patient data is transmitted via Bluetooth or Wi-Fi to a cloud platform for secure long-term storage and clinical analysis. This system provides a reliable, portable, and efficient solution for continuous cardiac monitoring and early arrhythmia detection.

**Keywords-** Wearable Device, Real-Time Arrhythmia Detection, Artificial Intelligence (AI), Electrocardiogram (ECG), Heart Rate Monitoring, Cardiac Monitoring, Smart Healthcare, Internet of Medical Things (IoMT), Healthcare Wearables, Biomedical Signal Processing

## 1. Introduction (Size 10)

Wearable devices for real-time arrhythmia detection represent a transformative advancement in modern cardiovascular care, enabling continuous, patient-friendly monitoring of heart rhythms outside clinical settings. Cardiovascular diseases, especially cardiac arrhythmia like atrial fibrillation, are among the leading causes of global mortality, and early, accurate detection is critical for reducing severe outcomes such as stroke, heart failure, and sudden cardiac death. Traditional monitoring methods like monitors or periodic in-hospital ECG have limitations in capturing intermittent or asymptomatic arrhythmia.

Recent developments in mobile health and wearable technologies—such as smartwatches, fitness trackers, and ECG patches now allow for ongoing, non-invasive surveillance of cardiac rhythms in daily life. These devices, often enhanced with artificial intelligence algorithms, facilitate prompt event detection and remote clinical interventions, offering both convenience and improved diagnostic accuracy for a wide population. By combining sensor innovation with advanced analytics, wearable arrhythmia detection is shifting the paradigm from reactive care to proactive, continuous health management in cardiology.

## Objectives

❑ **Develop a Wearable Monitoring System:** Create an integrated, user- friendly wearable device capable of continuously capturing and transmitting high-quality ECG and vital sign data for real- time arrhythmia detection

❑ **Validate Diagnostic Performance:** Systematically evaluate the diagnostic sensitivity, specificity, and overall clinical accuracy of the wearable-AI system against current standard-of-care practices.

❑ **Apply AI Algorithms for Detection:** Implement and optimize advanced artificial intelligence and machine learning algorithms to accurately identify various types of cardiac arrhythmia from the wearable-acquired signals.

❑ **Assess Clinical and Patient Impact:** Analyze how early detection through wearable influences clinical decision-making, management strategies, patient outcomes, and quality of life.

❑ **Investigate Usability and Integration:** Examine user adherence, device usability, and barriers to adoption, as well as integration of wearable data into existing clinical workflows and electronic health records.

## 2. Related Work (Size 10)

Wu, Yankun, et al (2024) The authors propose a Hybrid deep-learning architecture named Res-BITNET, targeted at detecting arrhythmia using the Photoplethysmography (PPG) signal rather than the standard ECG. PPG signals are attractive for continuous, wearable monitoring because they are non- invasive (optical sensors) and can capture pulse-wave information[1]. The challenge is that PPG is more noisy / indirect compared to ECG The contribution is in combining spatial feature learning (via a Residual Network, i.e., ResNet) with temporal modelling (via Bi-LSTM) to extract both shape- based and sequential features from PPG segments

Bulut, Miray Gunay, et al (2025) This paper proposes a deep Convolutional neural network (CNN) model to automatically detect different cardiac rhythm disorders using PPG signals collected from wearable sensors. The authors aim to detect cardiac rhythm disorders (arrhythmia) — specifically normal sinus rhythm (NSR), atrial fibrillation (AF), and premature atrial contractions (PAC) — using

Photoplethysmography (PPG) data from wearable devices. [2] This is important because traditional diagnosis often relies on ECG or Holter monitors, which may be less convenient for continuous, long-term monitoring. A 17-layer 1D-CNN is proposed. The same CNN architecture is applied separately to ECG (two channels) and PPG signals, enabling comparison. The CNN uses convolutional layers, pooling, and activation functions; filter sizes and number of filters are designed to capture temporal patterns in the signals.

Rahman, et al (2025) The paper presents a lightweight, on-chip AI system designed for real-time arrhythmia detection in a wearable ECG device. The authors develop a full hardware–software solution that includes: A custom ECG wearable using an AD8232 analog front end, A Cortex-M4 Microcontroller to run embedded AI, A Tiny ML-based classifier for beat-by-beat arrhythmia classification.[3] To work within strict resource limits, the system extracts efficient morphological, statistical, and spectral features from ECG signals and evaluates several compact neural network models (ANN, CNN, LSTM). Through optimization, they select a small LSTM model that fits into only ~6–7 Kb of memory and performs inference in ~20 ms per heartbeat, enabling real- time detection. Using MIT - BIH data set inputs streamed to the device, the system achieves ~98% accuracy with low power consumption (~5.9 ma), demonstrating that accurate arrhythmia monitoring is feasible directly on wearable hardware without cloud processing.

Sijerčić, et al (2022) Photoplethysmography (PPG) has become the foundation of most consumer wearable devices (smartwatches, fitness bands, rings). With AF detection increasingly integrated into these devices, understanding their accuracy, limitations, and clinical implications is vital. This paper provides a comprehensive overview of how PPG - based smart devices detect AF and evaluates their clinical reliability.

Aldughayfiq, Bader, et al. Atrial fibrillation (AF) remains one of the most dangerous arrhythmia due to its association with stroke risk and silent/asymptomatic occurrence. While ECG is the gold standard for AF diagnosis, wearable devices increasingly employ PPG for long-term monitoring. However, PPG is sensitive to motion and noise. This paper leverages both ECG and PPG, taking advantage

of their complementary properties. Significance: The use of multi-modal deep learning represents an important evolution in remote cardiac monitoring and bridges the gap between clinical-grade ECG and consumer-grade PPG. Develop a deep learning model capable of classifying AF using combined ECG and PPG time-series data. Integrate multi-feature descriptors (time, frequency, and morphological features).

Pereira, Tania, et al. (2020) This paper reviews how Photoplethysmography (PPG)—the light-based heart-pulse sensor used in smartwatches and wearable devices—can be used to detect Atrial Fibrillation (AF), a common heart rhythm disorder. To analyze different methods and technologies that use PPG signals for automatic AF detection. Technology Uses PPG sensors from wearables (smartwatches, fitness trackers, phones) to capture pulse-wave patterns. Sharma, Pratyusha, et al. (2025) The paper is a review (pre print) that analyzes the current and future trends in AI-enhanced wearable devices for real-time arrhythmia detection. The authors emphasize how machine learning (ML) and deep learning can improve the diagnosis and predictive ability of wearable — for example, using AI to analyze PPG and ECG data for early detection of atrial fibrillation (AF) and other arrhythmia.

Kwon, S et al (2020) Atrial fibrillation (AF) prevalence is rising globally, and continuous detection via wearable devices offers major potential for early intervention. While many studies focus on wrist-based PPG, this paper investigates ring-type PPG, which typically exhibits fewer motion artifacts due to less hand/wrist movement. The study also leverages deep learning, reflecting a shift from traditional feature-engineered approaches toward end-to-end signal classification. Strength is Addresses two emerging trends—alternative wearable form factors and deep learning-based AF detection. Limitations are the deep learning model's architecture details, while presented, may be too brief for full comprehensibility. The study appears to be conducted in controlled conditions rather than long-term free-living environments. Dataset size may be limited for training a deep neural model.

Kudo, et al Atrial fibrillation (AF) detection using PPG signals is a growing research area fueled by the rapid expansion of wearable devices. However, PPG based AF classification is challenging due to Motion

artifacts ,Physiological variability, Inconsistent data quality across subjects and devices, The need for scalable and adaptable training pipelines. This paper addresses a major gap: how to construct a robust, generalize training pipeline for AF detection from PPG, rather than merely proposing a single model.

### 3. Methodology

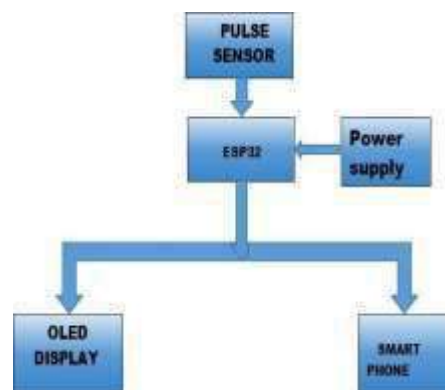


Fig 1: Block Diagram

#### Signal Acquisition:

Collect ECG signals continuously using wearable sensors. Ensure comfort, stability, and long-term usability for patients.

#### Pre processing of Signals:

Apply band pass filters(0.5–50 Hz) to remove baseline wander, motion artifacts, and high-frequency noise. Use adaptive filtering techniques to handle motion and environmental disturbances.

#### Feature Extraction:

Detect QRS complexes and heart rate variability using algorithms like Pan-Tompkins. Extract waveform features(P, QRS, T morphology) and rhythm patterns.

#### Arrhythmia Classification:

Employ deep learning models(CNN,RNN,LSTM,CNN-BiGRU-Attention hybrids). Train and validate using benchmark datasets such as MIT-BIH Arrhythmia Database and Physio Net.

#### Real-Time Processing & Alerts:

Implement on-device processing to detect arrhythmia in real time. Generate immediate alerts

(vibration, sound, or visual notifications) Forward abnormal event data to mobile app and physician dashboard.

### Wireless Communication:

Use Bluetooth Low Energy (BLE) to transmit data to smartphones. Use Wi-Fi for cloud integration and remote monitoring.

### Mobile Application & Data Management:

Provide real-time visualization of ECG and alerts on a companion app. Enable secure storage of ECG data in the cloud for physician access.

### Pulse Sensor Reads PPG Signals:

PPG (Photoplethysmography) is a non-invasive optical technique used to detect blood volume changes in the micro vascular bed of tissue. The pulse sensor uses light (typically infrared or green LED) and a photo detector to measure these changes, which correlate with heartbeats.

### Signal Filtering:

Raw PPG signals often contain noise from motion artifacts, ambient light, and electrical interference. Filtering techniques (e.g., low-pass, high-pass, or band-pass filters) are applied to isolate the heart rate frequency.

### Threshold Classification:

The filtered signal is analyzed to calculate Beats Per Minute (BPM). Based on BPM, the system classifies the heart rate into:

Normal: 60–100 BPM — typical resting heart rate for adults.

❑ Tachycardia: >100 BPM — may indicate stress, fever, or cardiac issues.

❑ Bradycardia: <60 BPM — common in athletes or may signal heart function.

### Action Based on Classification :

If normal: BPM and status are displayed on an OLED screen, providing real-time feedback to the user. No further action is taken unless the reading changes. If Tachycardia or Bradycardia: Data is transmitted via

Bluetooth Low Energy (BLE) to a connected mobile app. BLE ensures low power consumption and continuous monitoring. If the condition is deemed abnormal (based on preset thresholds or user profile), an alert notification is triggered — potentially via app push notification, sound, or vibration.

## I. PROTOTYPE OF PROPOSED SYSTEM

The proposed system measures heart activity using a pulse sensor based on Photoplethysmography (PPG) technology. The user places a finger on the pulse sensor, which detects changes in blood volume through variations in light absorption. Each heartbeat creates a small fluctuation in the reflected light intensity, generating a PPG waveform. The analog PPG signal is then provided to the ADC pin of the ESP32 microcontroller, which continuously samples the signal in real time for further processing.

- To improve signal quality, noise and unwanted disturbances are removed using smoothing and filtering techniques.

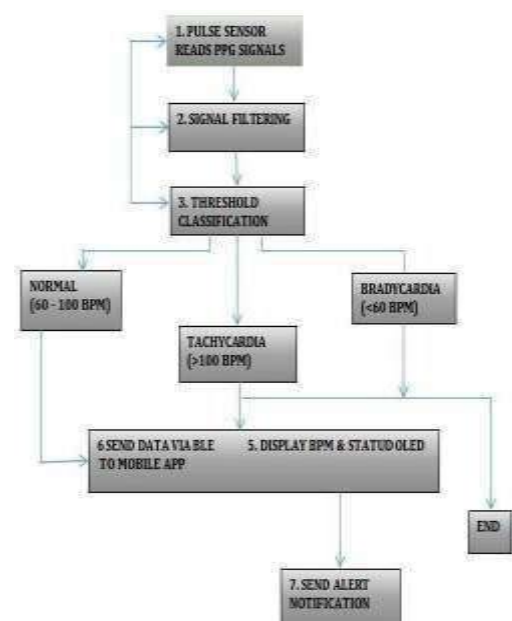


Fig 2: Flowchart of proposed system.

The ESP32 then performs peak detection on the filtered PPG waveform, where each detected peak corresponds to one heartbeat. Using the time interval between consecutive peaks, the system calculates the heart rate in terms of Beats Per Minute (BPM) and can also estimate heart rate variability if required.

- For arrhythmia classification, the ESP32 compares the calculated BPM values with predefined medical thresholds. A BPM below 60 is classified as bradycardia, a BPM between 60 and 100 is considered normal, and a BPM above 100 is identified as tachycardia. Sudden variations in BPM are treated as irregular heart rhythms. The processed information is displayed on an OLED screen, which shows the live BPM value, optional heartbeat waveform, and the detected heart condition such as Normal, Tachycardia, or Bradycardia.

- Additionally, the ESP32 uses Bluetooth Low Energy (BLE) to transmit BPM data and arrhythmia status to a companion mobile application. If abnormal heart conditions are detected, alert notifications can be generated and sent to the user or caregivers for immediate attention.

- The developed wearable heart rate monitoring system successfully measures the user's pulse using an optical pulse sensor and displays the processed heart rate values on an OLED display. Simultaneously, the measured heart rate data is transmitted wireless via Bluetooth Low Energy (BLE) using the standard Heart Rate Service and Heart Rate Measurement Characteristic.

- The BLE notifications confirm real-time data transmission, ensuring continuous monitoring on a mobile application. The OLED display provides instant visual feedback, including heart rate value (in BPM) and health status classification.

#### 4. Results and Discussion (Size 10)

The developed wearable heart rate monitoring system successfully measured heart rate using a pulse sensor based on Photoplethysmography (PPG) technology. The system achieved an average accuracy of approximately 90–95% under stable and low-motion conditions. Real-time BPM values were processed by the ESP32 microcontroller and displayed correctly on the OLED screen. The implemented signal filtering and peak detection techniques effectively reduced noise and enabled reliable heartbeat detection from the PPG waveform.

The system also demonstrated successful arrhythmia classification based on predefined BPM thresholds. Heart rates below 60 BPM were identified as bradycardia and displayed as "LOW," values between

60–100 BPM were classified as "NORMAL," and heart rates above 100 BPM were recognized as tachycardia and displayed as "HIGH." Sudden fluctuations in BPM were flagged as irregular rhythm conditions. The OLED display updated BPM values every second and clearly showed the corresponding heart condition, providing immediate visual feedback to the user.



Fig 6: OLED display showing Low heart rate condition (48 BPM) with BLE heart rate notification

| Heart Rate Range (BPM) | Classification | Display Output |
|------------------------|----------------|----------------|
| Below 60               | Low            | LOW            |
| 60 – 100               | Normal         | NORMAL         |
| Above 100              | High           | HIGH           |

Wireless communication using Bluetooth Low Energy (BLE) was successfully implemented through the ESP32. The measured heart rate data was transmitted to a mobile application using the standard Heart Rate Service (UUID: 0x180D) and Heart Rate Measurement Characteristic (UUID: 0x2A37). BLE notifications confirmed real-time wireless data transfer with minimal delay, ensuring continuous remote monitoring capability. The system outputs validated the reliability of the sensor, signal processing, and communication modules.

Experimental observations showed three major heart rate conditions. In the first case, a heart rate of 136 BPM was recorded and classified as "HIGH." The system successfully detected the elevated heart rate and generated the appropriate OLED display and BLE notifications. This condition may occur due to stress, physical activity, or cardiac irregularities, demonstrating the effectiveness of the threshold-based classification method. In the second case, a heart rate of 65 BPM was observed and correctly

categorized as “NORMAL,” validating the accuracy and stability of the monitoring system for regular health monitoring applications. In the third case, a heart rate of 48 BPM was measured and classified as “LOW,” indicating possible bradycardia.

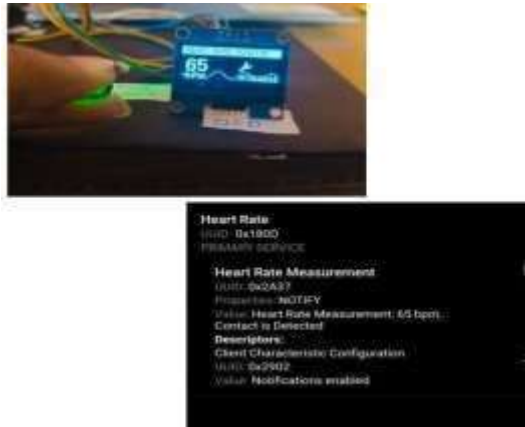


Fig 5 : OLED display showing Normal heart rate condition (65 BPM) with BLE heart rate measurement



Fig 6: OLED display showing Low heart rate condition (48 BPM) with BLE heart rate notification

The OLED display significantly improved the usability and portability of the system by providing clear and real-time monitoring information. Stable power supply through USB ensured uninterrupted system operation without voltage fluctuations. Overall, the developed system demonstrated good potential for wearable healthcare and fitness monitoring applications by providing low-cost, portable, and real-time heart rate monitoring with basic arrhythmia detection capability.

#### 4. Conclusion and Future Scope

This project successfully demonstrates a low-cost, real-time arrhythmia detection system using a pulse

sensor, ESP32 microcontroller, and machine-learning algorithms trained on the MIT - BIH Arrhythmia Database. The developed system efficiently acquires PPG/ECG data, performs signal preprocessing, extracts relevant features, and classifies cardiac conditions such as normal rhythm, tachycardia, bradycardia, and other abnormalities. The implemented wearable prototype proves that accurate physiological monitoring can be achieved with minimal hardware and power consumption. By integrating Bluetooth Low Energy (BLE), the system ensures seamless transmission of health data to mobile devices, enabling remote monitoring and timely alerts for abnormal cardiac events. The results show that AI-based analysis significantly improves the detection accuracy compared to traditional threshold methods.

The proposed system offers a reliable and scalable platform for early detection of cardiac irregularities. With further enhancements such as multi-sensor integration, cloud connectivity, and clinical validation, the system can play a significant role in future smart healthcare and tele medicine solutions. Overall, the project highlights the potential of combining embedded systems, biomedical sensors, and machine-learning techniques to develop affordable and portable health-monitoring solutions. With further enhancements such as multi-lead signal support, improved noise reduction, and cloud-based analytics the system can evolve into a robust tool for preventive healthcare and continuous cardiac monitoring.

#### FUTURE WORK

Future improvements to the proposed wearable arrhythmia detection system include integrating ECG sensors for more accurate detection of complex heart abnormalities and implementing advanced AI-based algorithms for improved classification accuracy. Motion artifact reduction techniques and low-power optimization can enhance wearable performance during daily activities. Additional sensors such as SpO<sub>2</sub> and temperature sensors may also be added for complete health monitoring. Furthermore, cloud and IoT integration with a mobile application can support remote patient monitoring,

emergency alerts, and long-term healthcare analysis.

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