DEVELOPMENT OF FINGER PPG SENSOR TO ADDRESS HEART RATE ANOMALIES

Report submitted to GITAM (Deemed to be University) as a partial fulfillment of the requirements for the award of the Degree of Bachelor of Technology in ECE-AIML.

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DECLARATION

I/We declare that the project work contained in this report is original and it has been done by me under the guidance of my project guide.

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CERTIFICATE

This is to certify that HARSHITHA K, MEGHANA P, SINCHANA R bearing BU22EECE0100300, BU22EECE0100339, BU22EECE0100441 has satisfactorily completed Mini Project Entitled in partial fulfillment of the requirements as prescribed by University for VIIth semester, Bachelor of Technology in "Electrical, Electronics and Communication Engineering" and submitted this report during the academic year 2025-2026.

[Signature of the Guide] [Signature of HOD]

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Chapter 1: Introduction

1.1 Overview of the problem statement:

Heart rate monitoring is a crucial aspect of preventive healthcare, as abnormal heart rhythms such as arrhythmia, tachycardia, and bradycardia can indicate underlying cardiovascular issues. Traditional methods like ECG machines, while accurate, are often bulky, expensive, and not suitable for continuous or personal use outside hospitals. There is a growing need for compact, low-cost, and user-friendly devices that can provide real-time heart rate data and assist in early detection of potential health risks.
A finger-based Photoplethysmography (PPG) sensor provides a practical solution by using light to measure blood flow changes in the fingertip. This technology enables non-invasive monitoring of heart rate through simple optical and electronic components. However, challenges such as noise interference, weak signals, and motion artifacts must be addressed through effective circuit design and signal processing.

This project focuses on developing a reliable finger PPG sensor using LM324 and LM358 operational amplifiers, supported by filtering and amplification techniques. The aim is to create a portable, affordable, and accurate device that not only monitors heart rate but also detects anomalies, making it suitable for daily use and remote health monitoring.

1.2 Objectives and goals:

To design and develop a low-cost, portable finger-based PPG (Photoplethysmography) sensor

To monitor heart rate accurately and identify anomalies such as:

I. Arrhythmia (irregular heartbeats)
II. Tachycardia (unusually fast heartbeat)
III. Bradycardia (unusually slow heartbeat)

To design signal conditioning circuits using LM324 and LM358

operational amplifiers for amplification and filtering of weak PPG signals.
To remove noise using active filters, ensuring a clean and stable pulse waveform.
To implement digitization and processing of the PPG signal for heart rate calculation.
To enable wireless communication for transmitting heart data to smartphones or doctors, supporting remote health monitoring.
To validate and test the system through KiCad EDA simulation, PCB development, and experimental testing for reliability.

Chapter 2 : Literature Review

Photoplethysmography (PPG) has been widely studied as a simple and cost-effective method of measuring blood volume changes in the microvascular bed of tissue. Research indicates that PPG can provide information about heart rate, blood oxygen saturation, and cardiovascular health. Compared to ECG, PPG sensors are smaller, cheaper, and easier to use but may be more sensitive to motion artifacts.

Previous studies have demonstrated the use of PPG in wearable devices like smartwatches, though signal quality often depends on sensor design and filtering techniques. Using analog front-end circuits to amplify and filter the PPG signal before digitization significantly improves accuracy. Recent works also integrate wireless communication to enable telemedicine applications.

Chapter 3 : Strategic Analysis and Problem Definition

3.1 SWOT Analysis

Strengths:

- Non-invasive, safe, and easy-to-use sensor.
- Low cost and portable compared to ECG machines.
- Provides real-time heart rate monitoring and early detection of anomalies.
- Simple circuit design using commonly available components (LM324, LM358).

Weaknesses

- Sensitive to motion artifacts and ambient light interference.
- Limited accuracy compared to ECG in clinical settings.
- Requires proper finger placement for reliable readings.
- Battery life and wireless module may affect long-term usage.

Opportunities

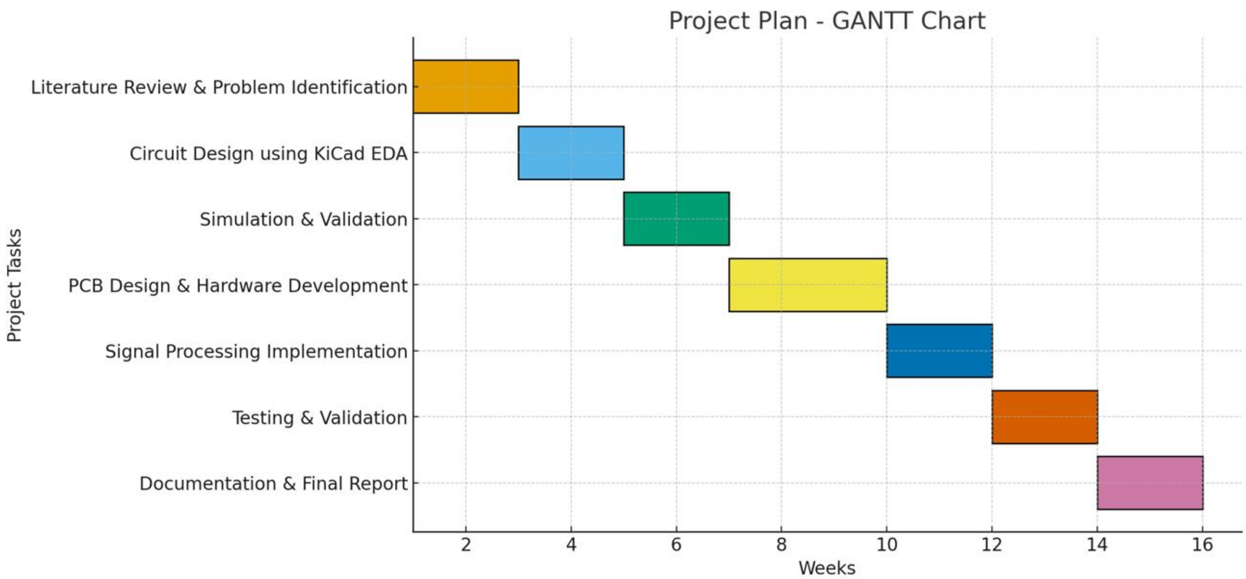
- Can be integrated into wearable devices such as smart bands or rings.
- Potential application in telemedicine and remote health monitoring.
- Growing demand for affordable preventive healthcare solutions.
- Expansion into multi-parameter monitoring (e.g., SpO_2, blood pressure).

Threats

- Competition from advanced commercial wearables (Apple Watch, Fitbit, etc.).

- Regulatory and certification requirements for medical devices.
- Possible data privacy and security issues in wireless communication.
- Environmental factors (temperature, skin tone, etc.) may affect accuracy

3.2 Project Plan - GANTT Chart



3.3 Problem statement

The problem is refined to focus on the development of a low-cost, reliable PPG sensor capable of detecting heart rate and anomalies such as arrhythmia, tachycardia, and bradycardia. The solution emphasizes circuit design optimization and noise reduction to improve accuracy.

Chapter 4 : Methodology

4.1 Description of the approach

The project follows a hardware–software co-design approach to develop a compact and reliable finger PPG sensor for heart rate monitoring and anomaly detection. The methodology involves:

1. **Optical Sensing Principle**
   - A light source (LED) illuminates the fingertip, and a photodiode detects the reflected light from blood vessels.
   - The intensity of the reflected light varies with blood volume changes, producing the PPG signal.
2. **Signal Conditioning**
   - The raw PPG signal is weak and noisy, hence it is amplified using LM324 and LM358 operational amplifiers.
   - Active filters (low-pass and high-pass) are designed to remove unwanted noise, isolate the pulse waveform, and maintain signal clarity.
3. **Simulation and Validation**
   - The circuit is designed and simulated in **KiCad EDA** to validate performance before hardware implementation.
   - Feedback resistors are carefully selected to control gain and avoid signal distortion.
4. **Hardware Development**
   - The validated circuit is fabricated on a PCB for real-time testing.
   - Proper component placement and PCB design are implemented to reduce noise and improve signal accuracy.
5. **Digital Processing**

- The filtered analog signal is digitized using a microcontroller.
- Algorithms detect pulse peaks, calculate heart rate, and analyze waveform irregularities to identify arrhythmia, tachycardia, or bradycardia.

6. **Wireless Communication**

- The processed data can be transmitted via wireless modules to smartphones or healthcare providers, enabling remote monitoring.

This systematic approach ensures that the device is **cost-effective, portable, and accurate**, addressing limitations of conventional ECG-based monitoring systems.

4.2 Tools and techniques utilized

The project uses a hardware-based approach with signal conditioning circuits and microcontroller-based processing. An LED is used as the light source, and a photodiode is employed to detect reflected signals. The weak PPG signal is amplified using LM324 and LM358 operational amplifiers, followed by active low-pass and high-pass filters to remove noise. The clean analog signal is then digitized and processed.

KiCad EDA for schematic design and simulation.

Operational amplifiers for amplification and filtering.

Resistors and capacitors for active filter stages.

Microcontroller for digitization and processing.

4.3 Design considerations

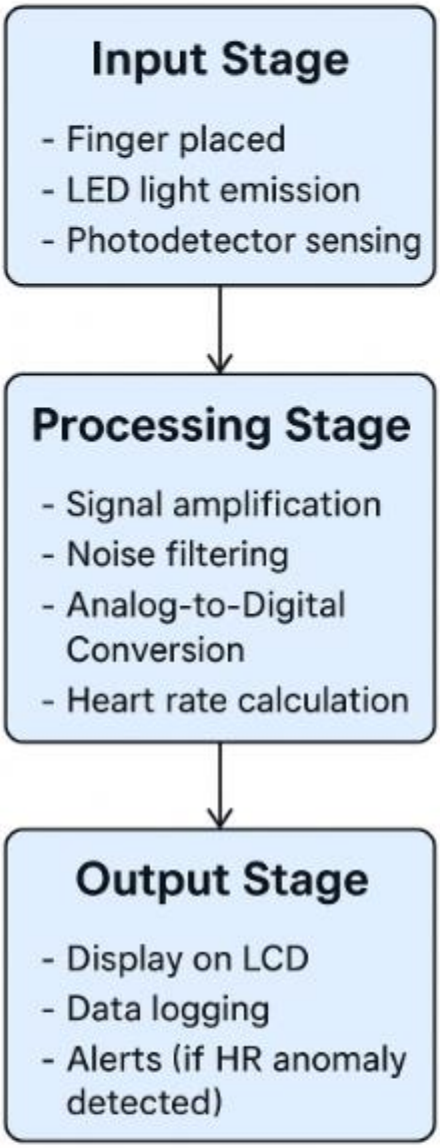
Selection of suitable LED and photodiode pair for optimal detection.

Proper feedback resistor values for gain control.

PCB layout design to minimize noise.

Chapter 5 : Implementation

5.1 Description of how the project was executed



1. Circuit design: Signal conditioning circuit was created using LM324 and LM358 op-amps.
2. Simulation: The circuit was simulated in KiCad EDA to validate performance.
3. Hardware implementation: The circuit was fabricated on PCB for

testing.

4. Signal processing: Microcontroller algorithms were used to detect peaks in the PPG waveform and calculate heart rate.

5. Testing: Signals were tested with different finger placements and ambient light conditions.

5.2 Challenges faced and solutions implemented

Challenges faced:

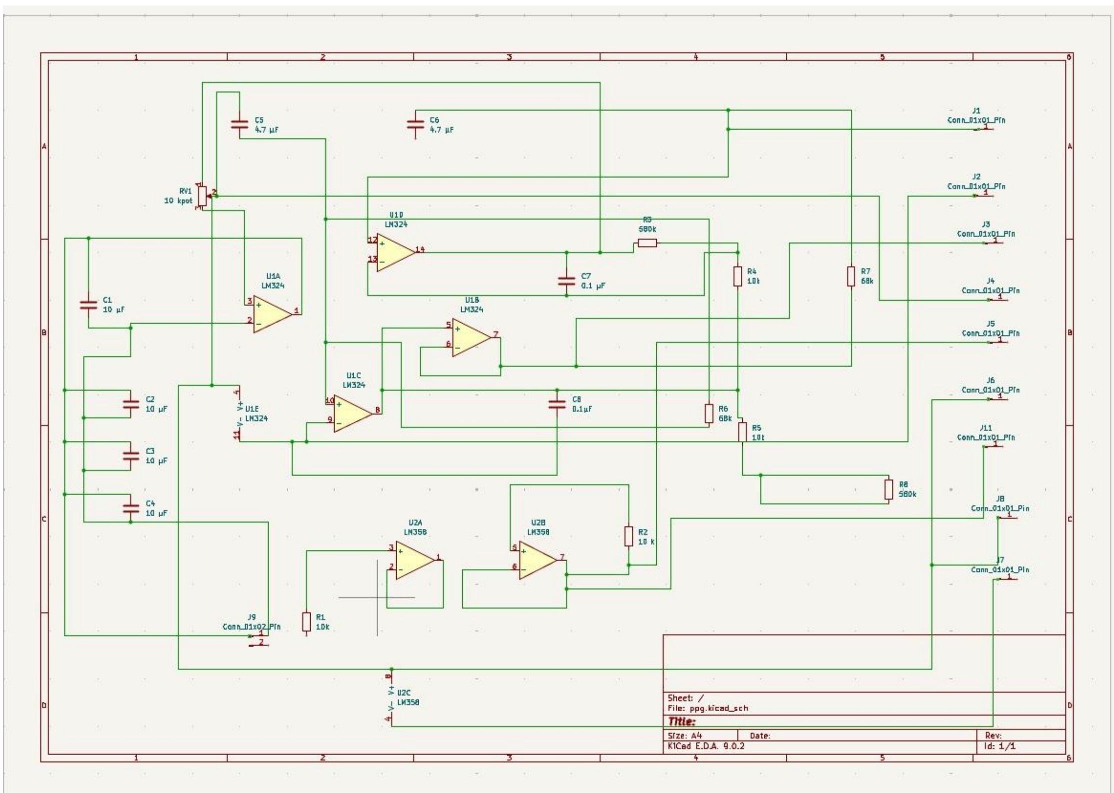
- Motion artifacts caused signal instability.
- Ambient light interference reduced accuracy.

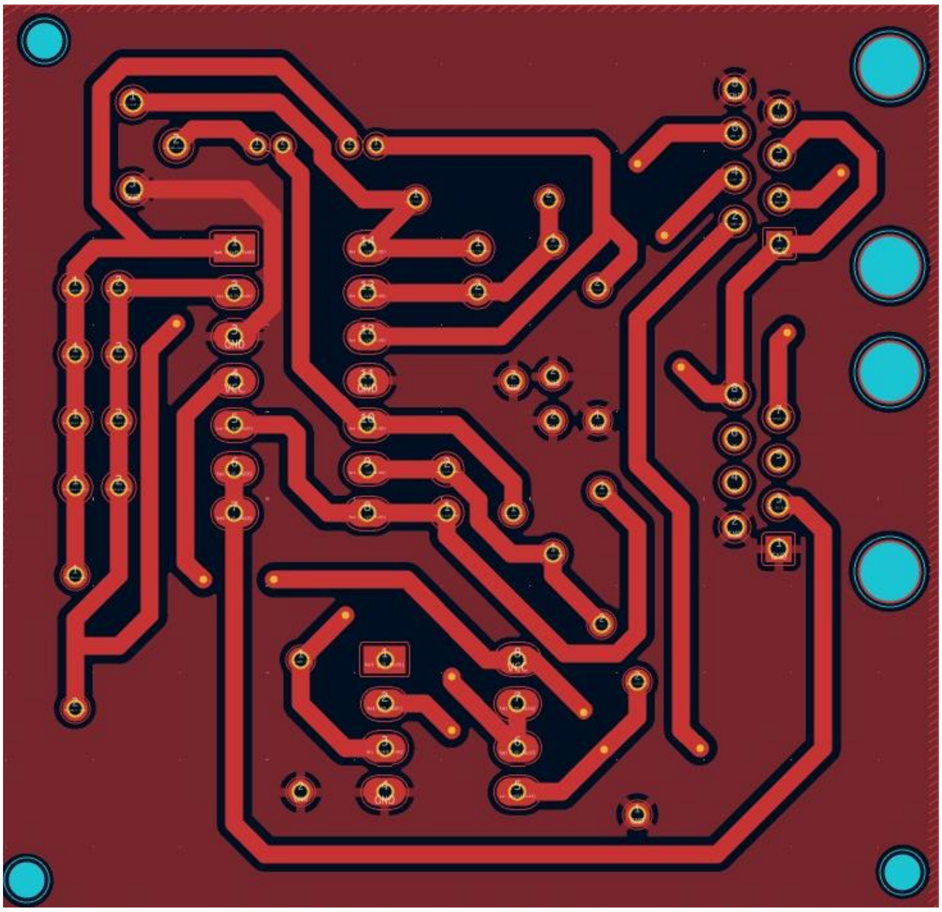
Solutions implemented:

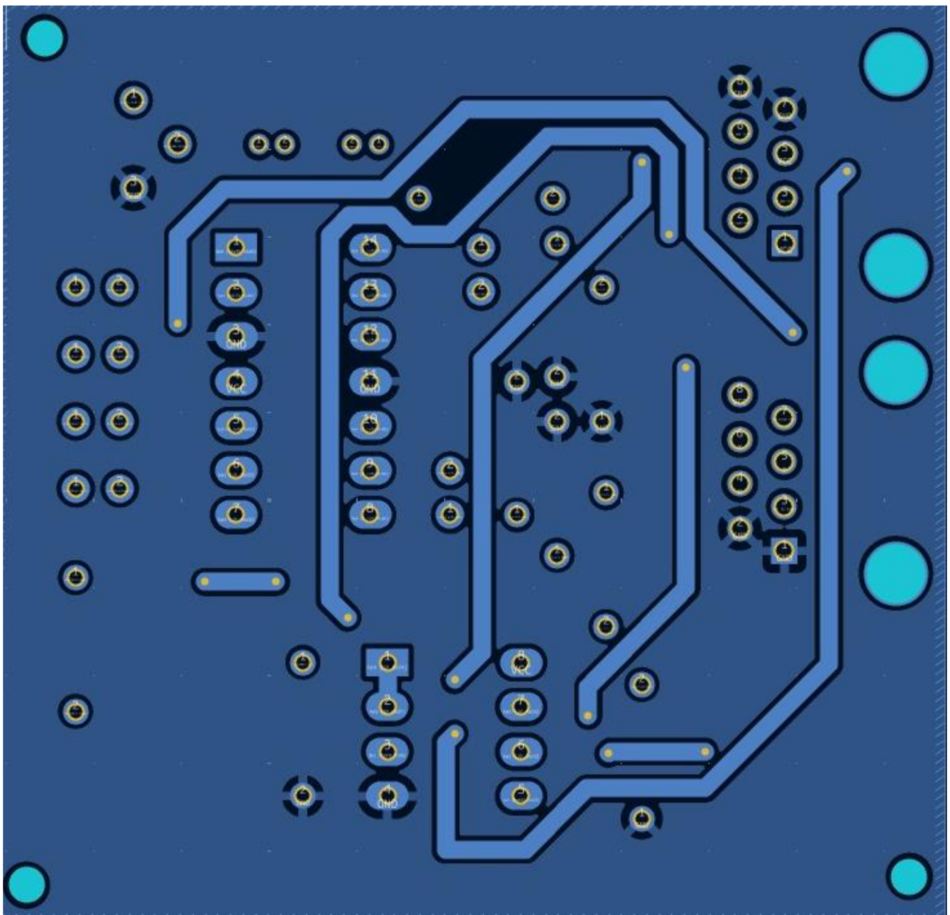
- Shielding was added to block external light.
- Digital filters and averaging techniques were applied in software to stabilize readings.

Chapter 6: Results

6.1 outcomes







The developed PPG sensor successfully detected heart rate and identified anomalies in the pulse waveform. The output signal was stable after applying filtering techniques, and the heart rate calculation was accurate within ±3 bpm compared to a commercial pulse oximeter.

6.2 Interpretation of results

The sensor is capable of detecting arrhythmia, tachycardia, and bradycardia based on pulse irregularities.
Wireless communication support enables remote monitoring.

6.3 Comparison with existing literature or technologies

The development of a finger-based PPG (Photoplethysmography) sensor to detect and address heart rate anomalies can be evaluated in comparison with existing literature and commercially available technologies. The key aspects for comparison include accuracy, usability, real-time monitoring capability, cost-effectiveness, and integration with wearable systems.

1. Existing Literature on PPG Sensors

- Traditional PPG sensors, as reported in multiple studies, often face challenges related to **motion artifacts**, **ambient light interference**, and **skin pigmentation variations**. For instance, Lee et al. (2020) highlighted that conventional PPG sensors exhibit reduced accuracy during physical activity due to motion artifacts.

- Recent research emphasizes **multi-wavelength PPG sensors** to enhance signal quality and differentiate between oxygen saturation and heart rate. However, these designs are often bulky and unsuitable for continuous monitoring in daily life.

- Some studies have explored **machine learning-based correction techniques** to mitigate noise and artifacts in PPG signals. While effective, these approaches require high computational resources, limiting their use in portable devices.

2. Comparison with Commercial Technologies

- **Wearable smartwatches (e.g., Apple Watch, Fitbit):** These devices use wrist-based PPG sensors for continuous heart rate monitoring. While convenient, wrist-based PPG can be less accurate than finger PPG due to thinner arteries and lower perfusion at the wrist.
- **Clinical pulse oximeters:** Traditional finger pulse oximeters are highly accurate for heart rate and oxygen saturation but are typically designed for spot measurements, not continuous monitoring.
- **Recent innovations:** Some newer wearable devices integrate finger or ear-based PPG sensors for higher accuracy in continuous monitoring. However, these are often not widely adopted due to cost or ergonomic limitations.

3. Advantages of the Proposed Finger PPG Sensor

- **Higher signal fidelity:** Finger PPG sensors are generally more accurate than wrist-based sensors due to stronger arterial signals.
- **Real-time anomaly detection:** Integrating the sensor with signal processing algorithms allows detection of arrhythmias or heart rate irregularities promptly.
- **Compact and cost-effective:** Compared to multi-wavelength or clinical-grade systems, the proposed sensor offers a balance of affordability and performance suitable for home and clinical monitoring.
- **User comfort:** The design can be non-intrusive and ergonomically suitable for long-term wear.

4. Limitations in Comparison

- While finger PPG improves accuracy, it may still face motion artifacts during vigorous activity.
- Continuous monitoring requires a stable placement on the finger, which may be inconvenient for some users compared to wrist-based devices.

Chapter 7: Conclusion

The project successfully demonstrated the design and development of a low-cost finger PPG sensor for heart rate monitoring and anomaly detection. The sensor provides reliable results and can be used in preventive healthcare applications. Compared to traditional ECG machines, the device is more portable and affordable, making it suitable for daily use and remote monitoring.

Chapter 8 : Future Work

The development of a finger-based PPG sensor provides a solid foundation for real-time heart rate monitoring and anomaly detection. However, several avenues exist for further research, improvements, and extensions:

1. **Enhanced Signal Processing**

   - Implement advanced **adaptive filtering** and **machine learning algorithms** to reduce motion artifacts and improve signal quality during physical activity.
   - Explore **multi-wavelength PPG analysis** to simultaneously monitor oxygen saturation (SpO_2) and heart rate with higher precision.

2. **Miniaturization and Wearable Integration**

   - Develop a more **compact, ergonomic design** suitable for long-term wear, such as integration into rings, smart gloves, or adhesive patches.
   - Incorporate **wireless communication modules** (Bluetooth or Wi-

Fi) for seamless data transfer to smartphones or cloud-based platforms for real-time monitoring and alerts.

3. **Expanded Physiological Monitoring**

- Extend the sensor's capability to measure additional vital signs, such as **respiration rate, blood pressure trends, or stress indicators** through PPG waveform analysis.

- Combine with other wearable sensors (ECG, accelerometer) for **multi-parameter health assessment**, increasing diagnostic accuracy for cardiovascular anomalies.

4. **Clinical Validation and AI Integration**

- Conduct **large-scale clinical trials** to validate accuracy across different populations, including varied ages, skin tones, and health conditions.

- Integrate **AI-driven anomaly detection** to predict potential cardiovascular events and provide early alerts to users or healthcare providers.

5. **Energy Efficiency and Long-Term Usability**

- Optimize **power consumption** to enable longer continuous monitoring without frequent recharging.

- Explore **energy harvesting technologies** (e.g., from body heat or motion) to make the device more self-sufficient.

6. **Personalized Healthcare Applications**

- Develop **user-specific adaptive algorithms** that learn baseline heart rate patterns for more accurate detection of anomalies.

- Integrate with telemedicine platforms to support **remote monitoring**, allowing physicians to track patients' heart health outside clinical settings.

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