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Portable ECG device with Android Mobile Application for continuous and real-time monitoring

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Abstract: Advanced patient monitoring systems are now more important than ever due to the changing healthcare landscape and the increasing requirement for prompt and effective patient care. Conventional approaches frequently fail to provide prompt reactions to significant shifts in a patient's condition. In this regard, the incorporation of Internet of Things (IoT) technology allows for ongoing, real-time data collecting from remote and wearable medical devices, providing a more responsive and dynamic healthcare setting. Machine learning techniques are used in the system to efficiently analyse large streams of health data and to identify minor trends and anomalies that could be early indicators of deterioration. A proactive healthcare approach is supported by this sophisticated anomaly detection, which enables healthcare providers to act quickly and enhance patient outcomes. Ultimately, the combination of machine learning and IoT gives healthcare professionals predictive insights that enable quicker, more intelligent, and more individualised patient treatment.

Keywords: ECG monitoring, machine learning, mobile health, real-time analysis, arrhythmia detection, wearable devices, healthcare technology

I. INTRODUCTION

The modern healthcare sector faces ongoing challenges in delivering continuous and real-time cardiac monitoring, which is vital for the early identification of potentially life-threatening conditions. This research project proposes the development of a compact, portable ECG device enhanced with artificial intelligence to enable seamless, real-time heart monitoring. The device will be designed to interpret ECG signals instantaneously, facilitating the early detection of abnormalities such as arrhythmias. Emphasizing both hardware integration and AI-based signal analysis, the system aims to ensure high precision and reliability in data acquisition and interpretation. An intuitive mobile application will serve as the user interface, providing real-time feedback on cardiac health. The app is designed for ease of use, accommodating individuals regardless of age or technical expertise. A foundational assumption of this work is that the ECG sensor will deliver clinically accurate data to support effective signal analysis. The AI models responsible for health assessment will be trained on high-quality, medically validated datasets. Ultimately, this project aspires to enable proactive heart health management and early intervention, thereby contributing to improved outcomes in preventive cardiovascular care.

II. LITERATURE SURVEY

Self Supervised Learning with Electrocardiogram Delineation for Arrhythmia Detection[1]: In order to lessen the requirement for a significant amount of labelled medical data, this study explores how self-supervised learning (SSL) can enhance the categorisation of electrocardiogram (ECG) signals for the purpose of identifying arrhythmias. To improve classification accuracy, the suggested SSL approach makes advantage of important clinical characteristics from ECG signals, such as heart rate and QRS complex intervals. The technique fared better than general-purpose SSL techniques when tested on three publicly accessible datasets. The model's performance was much improved by pre-training it using ECG-specific features, particularly when there was a shortage of labelled data. It also demonstrated good performance across a variety of datasets. Overall, by better utilising unlabelled data, the study shows how SSL might improve the efficacy and applicability of deep learning models for real-world medical diagnosis, particularly in cardiovascular care.
Applying IoT and Deep Learning for ECG Data Analysis [2]: This research proposes a mobile health system using IoT technologies and deep learning to classify three ECG rhythm types: Normal Sinus Rhythm, Congestive Heart Failure, and Atrial Fibrillation. It addresses the high cost and time constraints of traditional ECG machines by developing an

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affordable, portable device. The study also tackles noise interference in IoT devices, using Real Fast Fourier Transform and high-pass filters to improve signal quality. The deep learning approach showed better accuracy than traditional machine learning methods, although challenges remain for future work.

Research on Wearable ECG Monitoring Systems [3]: This paper explores various components involved in creating wearable ECG systems, focusing on hardware and software integration. On the hardware side, different types of electrodes are compared, including wet, dry, and non-contact capacitive sensors. Wet electrodes offer good signal stability but require conductive gel, which can dry out and cause issues. Dry electrodes are more convenient but can be sensitive to motion artifacts, while non-contact capacitive electrodes bypass direct skin contact, improving user convenience.

Hardware design of a wearable ECG-sensor[4]: This paper focuses on designing an efficient and noise-reduced ECG sensor for wearable applications. The signal conditioning process involves filtering techniques that remove various forms of noise, such as those from power lines, muscle activity, and movement. A driven-right-leg circuit is employed to minimize common-mode noise, which significantly improves the clarity of the ECG signals. To simplify the device and ensure user safety, the system uses a ground-free design and includes a protection circuit that disconnects the user from the device during charging, preventing electrical hazards. In terms of performance, clinical validation showed that the device can capture ECG signals comparable to those of more expensive, hospital-grade equipment, making it a reliable low-cost alternative for real-time heart monitoring.

III. PROPOSED METHODOLOGY

To enable real-time ECG monitoring, analysis, and health status classification, the suggested system combines hardware elements, an AI-based signal processing model, and a mobile application. From data collection to classification and mobile-based interaction, this section describes the methods used across many subsystems.

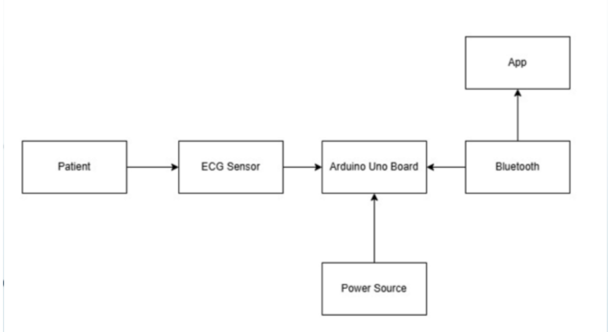

Fig 1 Architecture and flow of the project

Hardware Configuration for ECG Data Collection

The AD8232 ECG module, a small, low-power sensor made to extract, amplify, and filter the electrical activity of the heart, forms the basis of the system. An Arduino Uno microcontroller, which serves as a processing unit to handle incoming analogue signals, is interfaced with the ECG module. Before sending the data over Bluetooth for real-time processing, the Arduino digitises and preprocesses it. Real-time analysis and smooth integration are made possible by Bluetooth connectivity, which guarantees low-latency, wireless data flow between the microcontroller and the mobile application.

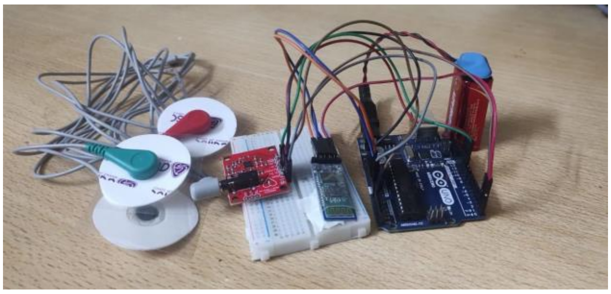

Fig 2 Hardware setup for real-time ECG collection

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Signal Processing and Heart Rate Variability (HRV) Analysis

Once received, the raw ECG signal undergoes a series of preprocessing steps to improve signal quality and prepare the data for analysis. The signal is first detrended to remove baseline wander and linear drifts. A 4th-order low-pass Butterworth filter is then applied to eliminate high-frequency noise. To further enhance signal clarity, a smoothing operation is conducted, reducing residual fluctuations without distorting key features of the waveform.

R-peak detection is supported by a multi-algorithm approach, combining the Biosppy's R-peak detection, Christov, Hamilton and Engzee algorithms and is performed utilising a threshold-based methodology. An important measure of cardiovascular health and autonomic nervous system function is heart rate variability (HRV). To evaluate possible arrhythmias and overall cardiac rhythm stability, important time-domain metrics, such as pNN50 (percentage of successive RR intervals that deviate by more than 50ms), RMSSD (root mean square of successive differences), and SDNN (standard deviation of NN intervals) are computed based on the RRintervals

An AI Model for Classifying ECG Data

The MIT-BIH Arrhythmia Database[5] is used to train a neural network model that can differentiate between arrhythmic and normal cardiac rhythms. Accuracy, precision, recall, and confusion matrix measures are used to assess the model in order to guarantee effective categorisation. The model is used to categorise user-provided real-time ECG data after it has been validated. This promotes proactive health monitoring and allows for the early detection of heart problems.

Real-time monitoring mobile application

Developed with Flutter and Dart, the mobile application serves as the user's front-end interface. It receives ECG signals in real time and establishes a Bluetooth connection to the Arduino. The app shows the heart rhythm status classification, computed HRV metrics, and the live ECG waveform. Users are provided with instant visual feedback regarding their cardiovascular health. To guarantee data protection and grant access to only authorised patients and healthcare professionals, a dual-login technique utilising email and password authentication is implemented.

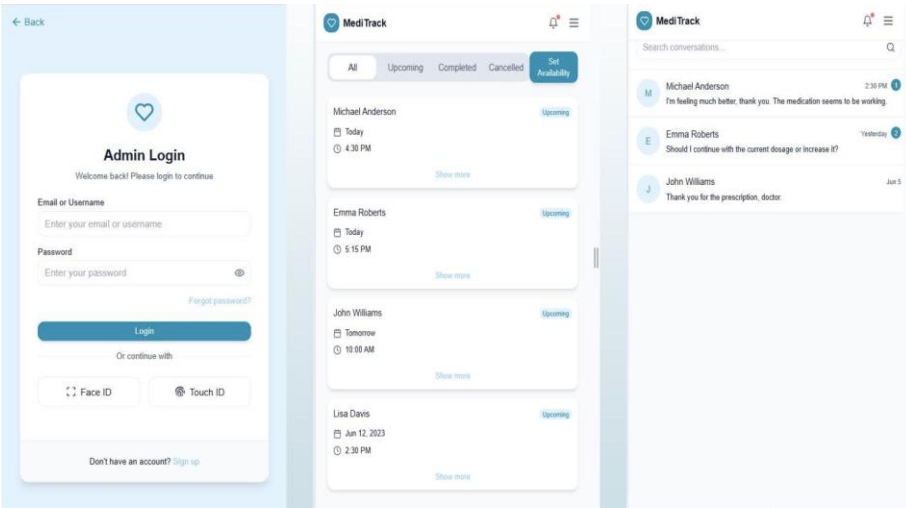

Fig 3 Screen design of the mobile application

Integration with the Cloud and Alerts

The Firebase cloud platform securely stores all ECG and HRV data to provide long-term monitoring and accessibility. In addition, Firebase provides real-time synchronisation between the device and the cloud and handles user authentication. In order to facilitate prompt action and better patient outcomes, the app also has an integrated warning system that alerts users when anomalous or possibly harmful cardiac rhythms are identified.

Mobile notifications for doctors and emergency contacts

To enhance the responsiveness and safety of the real-time ECG monitoring system, a notification feature has been integrated into the mobile application. This functionality is designed to detect unexpected or abnormal changes in the patient's ECG readings, such as arrhythmias, tachycardia, bradycardia, or other irregular patterns that may indicate a potential health risk. Upon detecting such anomalies through predefined thresholds or machine learning models, the system automatically triggers alerts. These alerts are immediately sent to the patient's assigned doctor and pre-registered emergency contacts via push notifications/SMS

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IV. EXPERIMENTAL RESULTS

This research's implementation phase combines AI-driven classification, signal processing techniques, and hardware into a single, real-time monitoring system. Accurately identifying R-peaks in ECG signals and classifying arrhythmias using a trained neural network model are crucial components of this approach.

ECG Signal Denoising and Filtering

To ensure accurate ECG signal analysis, several filtering techniques were employed to eliminate various forms of noise commonly present in biomedical signals. The raw ECG data collected from the AD8232 sensor is subjected to a series of filtering steps. The detrending procedure effectively removes baseline wander, ensuring that the signal is free from any linear trends. A high pass Butterworth filter with a cutoff frequency of 0.1 Hz is applied to eliminate low-frequency noise and baseline drift, while a low-pass Butterworth filter with a cutoff frequency of 45Hz successfully removes high filtered noise, such as muscle artifacts and electrical interference. The smoother ECG signal which is processed using a Savitzky-Golay filter, maintains the original waveform shape while reducing noise.

R-peak Detection

For R-peak detection, a multi-algorithm approach is implemented, combining Christov Hamilton, and Engzee algorithms to enhance peak detection robustness, particularly in noisy or variable amplitude signals. Physiological constraints, including minimum and maximum RR intervals are applied to ensure validity of detected R-peaks. The preprocessing pipeline significantly improves the accuracy of R-peak detection, providing a reliable foundation for further HRV analysis and arrhythmia detection in the subsequent steps of the study. The results demonstrate the effectiveness of the proposed signal denoising and R-peak detection methodology for robust ECG analysis.

Arrhythmia Classification

Following R-peak detection, from the ECG signals relevant HRV features are extracted. These features serve as input to a neural network model designed to classify the rhythm as either normal or arrhythmic. The neural network model is trained on the MIT-BIH arrhythmia dataset [5] To address class imbalance in the dataset, the Synthetic Minority Over-sampling Technique (SMOTE) is applied during training. This ensures a more balanced learning process and reduces the risk of model bias toward majority classes.

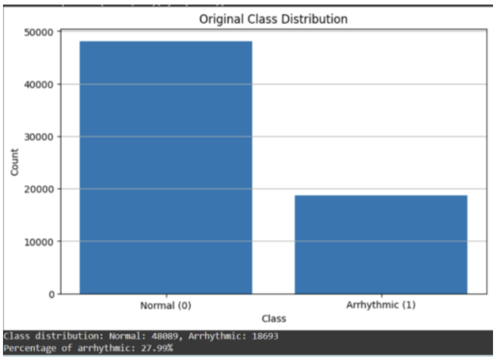

Fig 4 Class distribution before SMOT

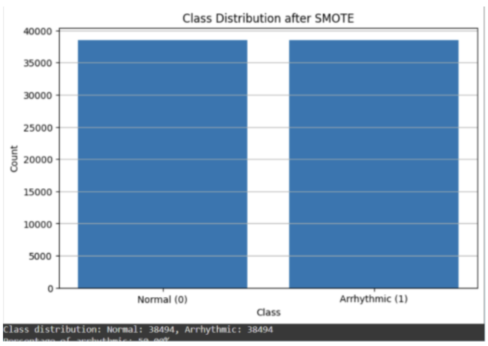

Fig 5 Class distribution after SMOT

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The neural network model achieved a training accuracy of 94% and a testing accuracy of 93%, demonstrating strong performance in real-time arrhythmia detection. The model is deployed within the mobile application, allowing seamless, on-device classification of live ECG data and immediate feedback to the user.

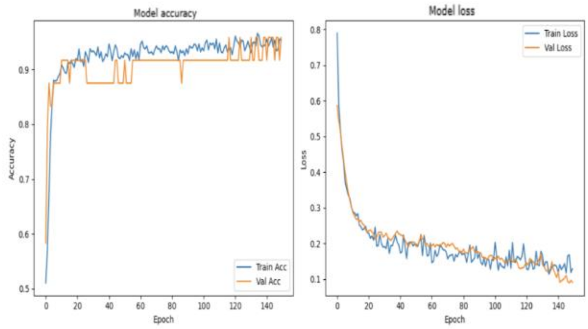

Fig 6 Training and Loss accuracy obtained

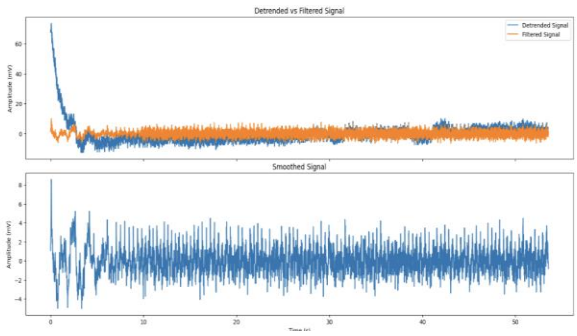

Fig 7: Pre-processed ECG Signal obtained

V. CONCLUSION

In this study, the creation and deployment of a portable, AI-integrated ECG monitoring system intended for real-time cardiac health evaluation is effectively demonstrated. The initiative tackles a vital demand in the healthcare industry—continuous and accessible cardiac monitoring—by fusing affordable hardware, reliable signal processing methods, and clever classification algorithms. Reliable data collection was made possible by the Arduino Uno's integration of the AD8232 ECG sensor, and wireless transfer via Bluetooth guaranteed smooth communication with the mobile application. Signal preprocessing techniques have improved the quality of ECG data by lowering noise and emphasising significant characteristics like RR intervals and R-peaks. These were essential for extracting Heart Rate Variability (HRV) measures, which were useful markers of autonomic function and arrhythmia early warning indicators. With excellent accuracy and dependability, the neural network model trained on the MIT-BIH Arrhythmia Database[5] demonstrated effectiveness in identifying cardiac abnormalities.

The mobile application made complex medical data understandable and actionable for people without medical training by giving users a real-time, user-friendly interface to monitor their heart health. The system's usability, security, and clinical relevance are further improved by the addition of dual-login capabilities, secure cloud-based storage through Firebase, and a real-time alerting system.

In conclusion, the project serves as an example of how combining AI with affordable biomedical hardware and mobile technology can result in significant advancements in healthcare. It may lessen the strain on clinical resources by enabling people to take part in preventive health management. To increase the system's diagnostic capabilities, future research might incorporate wearable technologies, improve the AI model with more information, and investigate more sophisticated predictive analytics. In the age of digital healthcare, this work establishes a solid basis for intelligent, scalable, and patient-centered health monitoring systems.

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