HARDWARE IMPLEMENTATION OF AN ARM-BASED MODULE FOR ECTOPIC BEAT DETECTION AND CLASSIFICATION USING DEEP LEARNING

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Introduction:

Cardiovascular diseases are among the leading causes of death globally, making early detection and monitoring of heart abnormalities extremely important. Traditional ECG monitoring systems are often expensive, bulky, and require hospital-based setups, limiting their accessibility, especially in rural and remote areas.

Recent advancements in embedded systems and artificial intelligence have enabled the development of compact, cost-effective, and real-time health monitoring devices. This project focuses on designing an ARM-based embedded system for detecting and classifying ectopic heartbeats using deep learning techniques.

Ectopic beats are irregular heartbeats that can indicate underlying cardiac conditions. Early detection of such abnormalities can significantly improve patient outcomes. By integrating ECG signal acquisition, preprocessing, and classification into a single portable device, this system aims to provide continuous monitoring and instant feedback.

The project utilizes sensors, signal processing techniques, and lightweight convolutional neural networks (CNNs) to classify heartbeats into different categories. Additionally, IoT integration allows remote monitoring through cloud platforms.

This system is particularly beneficial for wearable healthcare applications, telemedicine, and remote diagnostics, offering an affordable solution for continuous cardiac monitoring.

Objectives:

1. To design and develop a low-cost embedded ECG monitoring system.
2. To acquire and preprocess ECG signals using AD8232 module.
3. To implement a lightweight deep learning model for heartbeat classification.
4. To detect ectopic beats and categorize them accurately.
5. To display real-time results on an LCD screen.
6. To enable remote monitoring using IoT cloud platforms.

Methodology:

The project begins with ECG signal acquisition using surface electrodes placed on the human body. These electrodes capture electrical signals generated by the heart during each cardiac cycle. The signals are fed into the AD8232 module, which amplifies and filters the raw ECG signals to remove noise and artifacts such as baseline wander and interference.
The conditioned analog signal is then converted into a digital signal using an Analog-to-Digital Converter (ADC) implemented through Arduino Uno. The digitized ECG data is transmitted to the ARM-based processor (Raspberry Pi Zero 2W) for further processing. In the preprocessing stage, digital filters such as high-pass, low-pass, and notch filters are applied to improve signal quality. Feature extraction techniques such as R-peak detection and segmentation are used to isolate individual heartbeats.
A lightweight CNN model is trained using labeled ECG datasets to classify heartbeats into different categories such as normal, ventricular, supraventricular, fusion, and unknown beats. The trained model is deployed on the embedded processor using TensorFlow Lite for real-time inference.

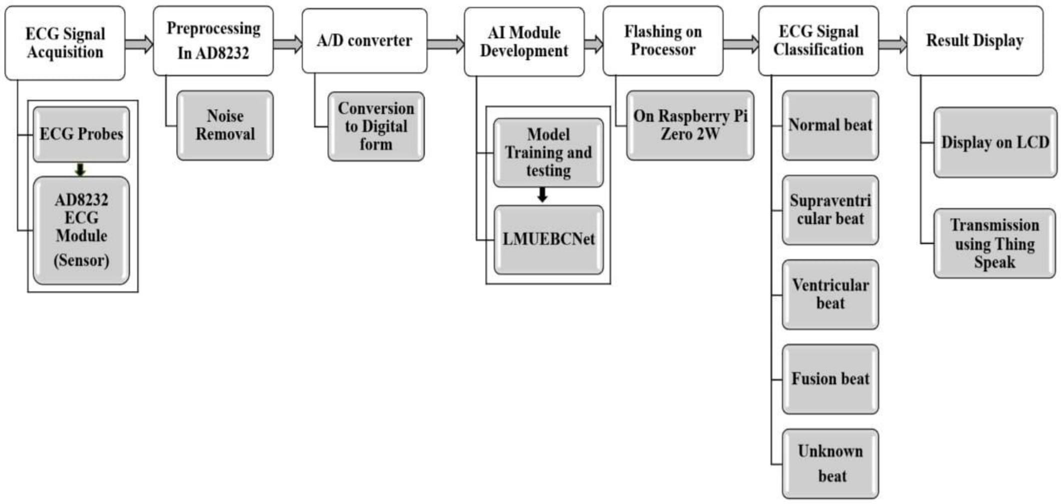

Figure 1: Block diagram of ARM-Based Module for Ectopic Beat Classification Using Deep Learning

The classification results are displayed on a 16×2 LCD screen, providing instant feedback to the user. Additionally, the system uploads ECG data and results to the ThingSpeak cloud platform using Wi-Fi for remote monitoring and analysis. The entire system is powered by a regulated power supply and designed for portability and continuous operation.

Result and Conclusion:

1. In conclusion, the proposed system successfully demonstrates the implementation of a cost-effective and efficient ARM-based module for real-time ectopic beat detection and classification. The ECG signals acquired using the AD8232 sensor were effectively processed and filtered to obtain a clean and reliable waveform suitable for analysis.
2. The lightweight CNN model deployed on the embedded platform showed good accuracy in classifying different types of heartbeats, including normal and abnormal (ectopic) beats. The use of TensorFlow Lite enabled smooth execution of the model on a low-power device like Raspberry Pi Zero 2W.

3. The system was able to display real-time results on an LCD screen and also transmit data to the cloud for remote monitoring, making it suitable for telemedicine applications. The integration of multiple sensors further enhanced the functionality by enabling comprehensive health monitoring.
4. Overall, the project proves that advanced AI-based ECG analysis can be implemented on compact embedded systems, providing an affordable and accessible solution for early detection of cardiac abnormalities. This contributes significantly to improving healthcare accessibility, especially in rural and resource-limited areas.

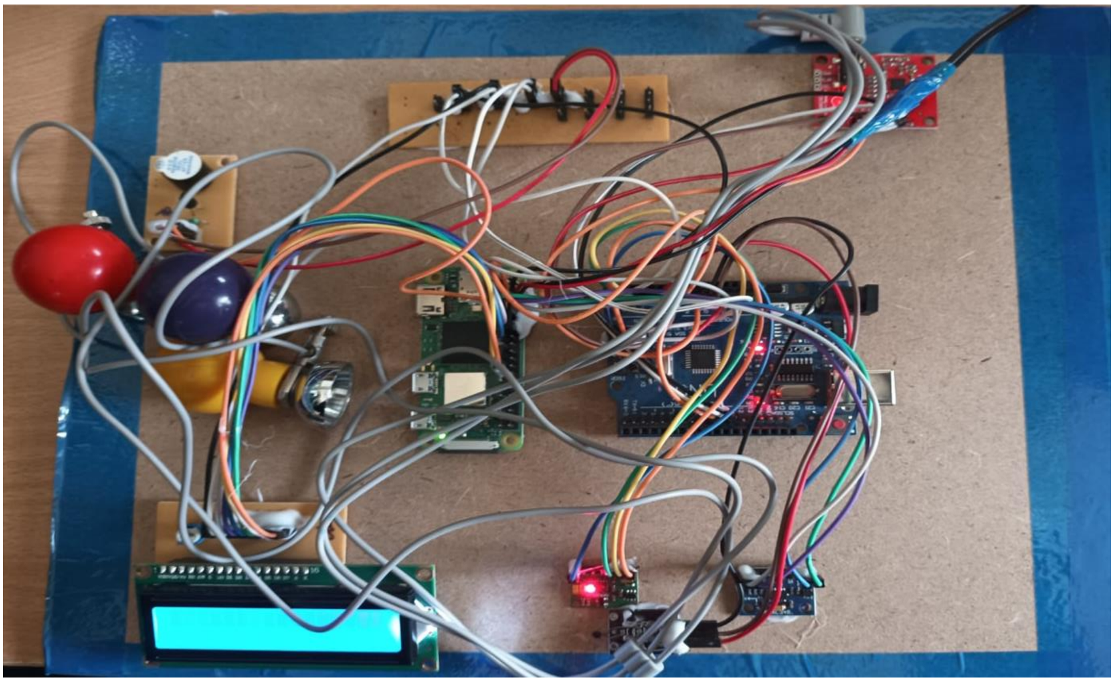

Figure 2: Ectopic beat detection and classification Circuit

Figure 3: Output of Normal ECG on LCD

Figure 4: Output of Arrhythmia ECG on LCD

Project Outcome & Industry Relevance:

1. This project contributes to the healthcare industry by providing an affordable and portable ECG monitoring solution. It is highly relevant for hospitals, clinics, and remote healthcare centers where continuous monitoring is required.

2. The system can be used in wearable medical devices and IoT-based healthcare systems for real-time patient monitoring. Biomedical device companies can further develop this prototype into a commercial product.
3. It also supports telemedicine by enabling remote diagnosis and monitoring, reducing the need for frequent hospital visits. The integration of AI and embedded systems aligns with current industry trends in smart healthcare solutions.

Working Model vs. Simulation/Study:

This project involves the development of a working hardware model with real-time ECG acquisition, processing, and classification.

Project Outcomes and Learnings:

1. Gained knowledge in ECG signal acquisition and biomedical instrumentation.
2. Learned embedded system design using ARM processors.
3. Developed skills in deep learning model training and deployment.
4. Understood real-time signal processing and filtering techniques.
5. Experienced IoT integration for cloud-based monitoring.
6. Improved teamwork, project management, and problem-solving skills.

References:

1. [1] I. Bashir et al., “Beat-by-Beat Classification of ECG Signals Using Machine Learning Algorithms to Detect PVC Beats for Predictive Cardiac Health Monitoring,” IEEE International Conference on Bioinformatics, 2022.
2. [2] Y.-L. Xie et al., “SEmbedNet: Hardware-Friendly CNN for Ectopic Beat Classification on STM32-Based Edge Device,” IEEE International Conference on Recent Advances in Systems Science and Engineering (RASSE), Nov. 2022.
3. [3] A. Srinivasulu et al., “Ventricular Ectopic Beat Classification Using KNN Multi-Feature Classifier,” International Conference on Communication, Computing and Internet of Things (IC3IoT), Feb. 2018.
4. [4] W. Zhao et al., “Deep Learning Based Patient-Specific Classification of Arrhythmia on ECG,” 41st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), Jul. 2019, doi: 10.1109/EMBC.2019.8856650.
5. [5] D. H. A. Deepak et al., “ECG Beat Classification using CNN,” IEEE International Conference on Data Science and Information System (ICDSIS), Jul. 2022, doi: 10.1109/ICDSIS55133.2022.9916004.
6. [6] X. Tang et al., “ECG Delineation and Arrhythmia Classification System Using Slope Variation Measurement by Ternary Second-Order Delta Modulation,” IEEE Transactions on Biomedical Circuits and Systems, vol. 15, no. 5, pp. 1053–1065, Oct. 2021, doi: 10.1109/TBCAS.2021.3113665.
7. [7] J. V. Vadakkan et al., “Quality-Aware Rhythm-Aware Heart Rate Variability Analysis for Soldier Health Monitoring Using Wearable ECG Devices,” IEEE TechDefense, 2024, doi: 10.1109/TechDefense63521.2024.10863793.
8. [8] X. Tang and W. TanAn et al., “ECG Delineation and Arrhythmia Classification System for Wearable ECG Sensors,” IEEE Transactions on Biomedical Circuits and Systems, vol. 15, no. 5, Oct. 2021, doi: 10.1109/TBCAS.2021.3113665.

9. [9] L. Sun and Y. Wang et al., “ECG Classification System in IoT-Based eHealth,” IEEE Internet of Things Journal, vol. 9, no. 10, pp. 7178–7195, May 2022, doi: 10.1109/JIOT.2021.3108792.
10. [10] S. Kim et al., “Lightweight Convolutional Neural Network for Arrhythmia Classification on Low-Power Wearable Electrocardiograph,” 44th Annual IEEE EMBC, Jul. 2022, doi: 10.1109/EMBC48229.2022.9871156.
11. [11] L. El Bouny et al., “ECG Heartbeat Classification Based on Multi-Scale Wavelet CNN,” ICASSP, May 2020, doi: 10.1109/ICASSP40776.2020.9054749.
12. [12] S. S. Dhakshaya et al., “Classification of ECG using Convolutional Neural Network (CNN),” ICRAECC, Mar. 2019, doi: 10.1109/ICRAECC43874.2019.8995096.

Future Scope:

The future scope of this project includes:

1. The future scope of this project includes enhancing the system accuracy by using advanced deep learning models and larger datasets. Integration with mobile applications can provide a user-friendly interface for monitoring and alerts.
2. The device can be miniaturized further to develop wearable health monitoring systems such as smart bands or patches. Additional health parameters like blood pressure and respiration rate can be incorporated to create a complete health monitoring solution.
3. Cloud analytics can be improved using AI-based predictive models to detect potential cardiac risks in advance. Integration with hospital databases can enable better patient record management.
4. The system can also be extended for continuous remote patient monitoring in telemedicine applications, especially in rural and underserved regions. With further development, this project has strong potential for commercialization and patent filing in the biomedical device industry.