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# **Optimizing Machine Learning for Enhanced Automated ECG Analysis in Cardiovascular Healthcare using RNN**

**Dhanush M, Jerald David Raj J, Ponnivalavan P, Rohith G, Rajesh V**

U.G. Student, Department of CSE, SRM TRP Engineering College, Trichy, Tamil Nadu, India

U.G. Student, Department of CSE, SRM TRP Engineering College, Trichy, Tamil Nadu, India

U.G. Student, Department of CSE, SRM TRP Engineering College, Trichy, Tamil Nadu, India

U.G. Student, Department of CSE, SRM TRP Engineering College, Trichy, Tamil Nadu, India

Assistant Professor, Department of CSE, SRM TRP Engineering College, Trichy, Tamil Nadu, India

**ABSTRACT:** The accuracy of automated ECG analysis is improved in this project using machine learning for heartbeat classification. Different models are tested, and their performance is enhanced through optimization techniques. Large ECG datasets are analyzed to reduce errors and improve detection accuracy. More reliable identification of heart conditions is ensured, contributing to advancements in cardiovascular diagnostics. The potential of machine learning in enhancing healthcare through efficient and accurate ECG interpretation is highlighted by the findings

**KEYWORDS:** ECG Classification, Arrhythmia Detection, Long Short-Term Memory (LSTM), Recurrent Neural Networks (RNN), Machine Learning, Deep Learning, Cardiovascular Diagnostics, PTB Dataset.

## **I. INTRODUCTION**

Cardiovascular diseases (CVDs) remain a leading cause of mortality worldwide, emphasizing the need for early and accurate detection to improve clinical outcomes. Electrocardiography (ECG) is a key diagnostic tool for identifying arrhythmias, yet its manual interpretation is time-consuming and requires expert analysis, limiting its scalability in resource-constrained settings. This project presents an optimized approach to automated ECG classification using Long Short-Term Memory (LSTM) networks, a variant of Recurrent Neural Networks (RNN) suited for time-series data. The system processes raw ECG signals, extracts temporal features, and classifies them as normal or abnormal, enabling real-time arrhythmia detection. Model training is enhanced through the use of the Adam optimizer, which fine-tunes learning rates and reduces error during classification. By utilizing the PTB Diagnostic ECG dataset, the proposed framework ensures high diagnostic reliability. This work highlights the transformative role of machine learning and deep learning in intelligent healthcare, offering a scalable and efficient solution for real-time cardiovascular diagnostics. The proposed system also addresses overfitting challenges, ensures generalizability across diverse patient profiles, and provides a foundation for integrating AI into wearable health monitoring devices.

## **II. LITERATURE SURVEY**

The integration of machine learning in ECG analysis has seen notable advancements, focusing on improving arrhythmia detection accuracy and efficiency. Soman K.P. and Simon S.P. (2017) explored feature extraction using Principal Component Analysis (PCA), highlighting its importance in reducing data dimensionality and enhancing model performance. Acharya U.R. et al. (2018) proposed an automated ECG classification system using CNN and LSTM, demonstrating high accuracy in arrhythmia detection without manual feature engineering. Goldberger A.L. et al. (2018) conducted a comparative study of ECG datasets, emphasizing the value of the PTB Diagnostic Database for model training due to its detailed annotations and clinical relevance.

Rajpurkar P. and Hannun A.Y. (2019) examined various deep learning models, including RNN and LSTM, emphasizing their strength in capturing temporal dependencies in ECG signals. Ribeiro M.T. et al. (2019) focused

on explainable AI, stressing the importance of transparency in clinical AI applications. Finally, Mirjalili S. et al. (2021) introduced metaheuristic optimization techniques like Adam and JADE, significantly improving model accuracy and convergence rates.

Together, these studies form the foundation for this project, supporting the use of LSTM and optimization algorithms for real-time, reliable, and interpretable ECG arrhythmia classification in cardiovascular healthcare.

### III. METHODOLOGY

The proposed system employs an LSTM-based deep learning model to classify ECG signals as normal or abnormal, providing a robust solution for real-time cardiovascular diagnostics. Data is sourced from the PTB Diagnostic ECG Database, containing labeled ECG recordings that cover a range of cardiac conditions. The preprocessing step involves normalization using StandardScaler, ensuring that the data is scaled appropriately for the model. Additionally, the data is reshaped into a 3D format to meet the input requirements of the LSTM model. The LSTM network is designed to capture long-term temporal dependencies in the heartbeat sequences, essential for accurate classification. A sigmoid activation function is used in the final layer to perform binary classification, distinguishing between normal and abnormal ECG signals. To enhance training efficiency, the Adam optimizer is employed, dynamically adjusting learning rates during training to achieve faster convergence. The model's performance is thoroughly evaluated using key metrics, including accuracy, precision, recall, and F1-score, to ensure its reliability and effectiveness in real-world cardiovascular diagnostics. Furthermore, the model is optimized for deployment in real-time systems, aiming to assist healthcare professionals in early detection of cardiac abnormalities, potentially leading to timely medical interventions. The system also includes a validation step where the dataset is divided into training and testing sets to prevent overfitting and ensure generalization.

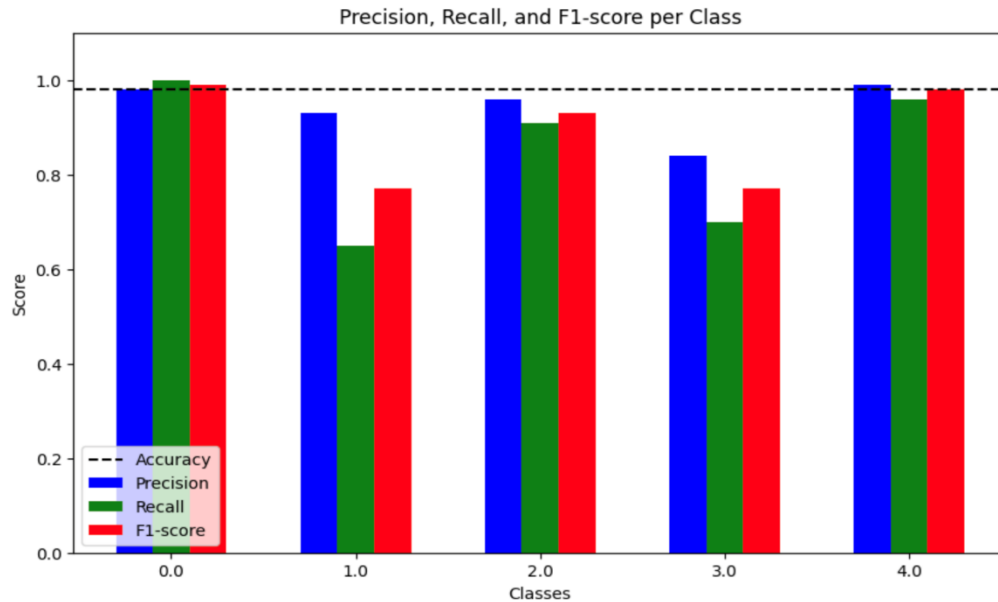
### IV. EXPERIMENTAL RESULTS

Figures shows the classification model achieved an overall accuracy of 97.67% on a test set of 21,892 samples. As shown in Table X, the model performs exceptionally well on the majority class (Class 0) with an F1-score of 0.9880, and on Class 4 with 0.9744. Class 2 also showed strong results (F1-score: 0.9320). Performance on minority classes (Class 1 and 3) was lower, with F1-scores of 0.7614 and 0.7607, indicating potential for improvement through better class balancing. Overall, the model achieved a macro average F1-score of 0.8833 and a weighted average of 0.9758, demonstrating high effectiveness despite class imbalance.

| Classification Report: |           |        |          |         |
|------------------------|-----------|--------|----------|---------|
|                        | precision | recall | f1-score | support |
| 0                      | 0.9812    | 0.9949 | 0.9880   | 18118   |
| 1                      | 0.8995    | 0.6601 | 0.7614   | 556     |
| 2                      | 0.9415    | 0.9227 | 0.9320   | 1448    |
| 3                      | 0.8112    | 0.7160 | 0.7607   | 162     |
| 4                      | 0.9923    | 0.9571 | 0.9744   | 1608    |
| accuracy               |           |        | 0.9767   | 21892   |
| macro avg              | 0.9251    | 0.8501 | 0.8833   | 21892   |
| weighted avg           | 0.9760    | 0.9767 | 0.9758   | 21892   |

Fig. 2. illustrates the precision, recall, and F1-score for each class, along with a dashed line representing the overall model accuracy of 97.67%. The model performs exceptionally well on Classes 0, 2, and 4, with particularly high scores for Class 0 and Class 4, indicating strong predictive ability for these classes. In contrast, Classes 1 and 3 show lower recall values, resulting in reduced F1-scores. This is likely due to the smaller number of samples in these classes. Overall, the chart highlights the model's strong performance while also indicating areas for improvement, particularly in handling underrepresented classes.





## V. CONCLUSION

The proposed system effectively uses LSTM networks and the Adam optimizer to improve ECG arrhythmia detection. Trained on the PTB dataset, the model achieves high accuracy and supports real-time analysis. It reduces reliance on manual diagnosis, offering a reliable and efficient solution for cardiovascular healthcare. This work demonstrates the potential of deep learning in enhancing automated medical diagnostics.

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