

Enhanced Cardiovascular Disease Classification Using CNN Xception Model: A Deep Learning Approach with ECG Image Augmentation

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Abstract. Cardiovascular diseases (CVDs) remain a leading cause of mortality worldwide, emphasizing the need for early and accurate diagnosis. In this study, we propose an advanced deep learning approach for the classification of CVDs using the Xception Convolutional Neural Network (CNN) model, leveraging augmented ECG images. The dataset, collected from Kaggle, comprises 928 ECG images categorized into four classes: patients with a history of myocardial infarction (MI), patients with abnormal heartbeats, patients with MI, and normal ECGs. Image augmentation was employed, increasing the dataset to 4000 images. The dataset was split into 60% training, 20% validation, and 20% testing sets. Our model was trained over 80 epochs using Python, with performance evaluated using F1-score, recall, precision, and ROC-AUC metrics. The proposed model achieved an impressive F1-score of 98.00%, recall of 98.30%, and precision of 98.23%, demonstrating its effectiveness in accurately classifying ECG images. These results indicate the potential of deep learning techniques for improving diagnostic accuracy in cardiovascular disease

Keywords: Deep Learning, Cardiovascular diseases, ECG images, CNN, Classification

I Introduction

Cardiovascular diseases (CVDs) are the leading cause of death globally, accounting for an estimated 17.9 million lives lost each year. Early detection and accurate classification of CVDs can significantly reduce mortality rates by enabling timely and appropriate medical interventions[1]. Electrocardiogram (ECG) readings are commonly used for the diagnosis of various cardiac conditions, such as myocardial infarction (MI) and abnormal heart rhythms. However, manual analysis of ECG signals can be time-consuming and prone to human error, underscoring the need for automated systems that can assist healthcare professionals in diagnosing cardiovascular diseases with high precision[2].

Recent advances in deep learning, particularly convolutional neural networks (CNNs), have shown promise in automating the classification of medical images. CNN architectures are designed to automatically extract relevant features from images, making them well-suited for analyzing complex ECG patterns. The Xception model, a deep CNN architecture, has demonstrated superior performance in various image classification tasks due to its depthwise separable convolution layers, which reduce computational complexity while maintaining high accuracy[3].

This study aims to develop an automated system for the classification of CVDs using the Xception CNN model, trained and validated on an augmented dataset of ECG images. The dataset, sourced from Kaggle, includes ECG images from patients with a history of myocardial infarction, abnormal heartbeats, myocardial infarction, and normal individuals. Through data augmentation, the dataset was expanded to enhance the model's generalization ability and performance.

By leveraging the Xception model, we aim to achieve high classification accuracy in diagnosing cardiovascular diseases from ECG images. This research also explores the potential of deep learning techniques in improving diagnostic tools in clinical settings, with the hope of contributing to more efficient and accurate CVD diagnosis.

2 Objectives

The primary objective of this study is to develop a robust and accurate deep learning model for the classification of cardiovascular diseases (CVDs) using ECG images. Specifically, the study aims to:

- Design and implement a CNN-based model utilizing the Xception architecture for the automatic classification of ECG images into four categories:
 - Patients with a history of myocardial infarction (MI),
 - Patients with abnormal heartbeats,
 - Patients currently experiencing myocardial infarction,
 - Normal ECG images of healthy individuals.
- Enhance the performance and generalization of the model through data augmentation techniques to expand the dataset from 928 to 4000 images, thereby improving the model's ability to handle varying ECG patterns.
- Evaluate the model's performance using key metrics, including F1-score, precision, recall, and ROC-AUC, to assess its classification accuracy, sensitivity, and specificity.
- Demonstrate the clinical applicability of the proposed model by achieving high performance in diagnosing CVDs, thereby providing a reliable tool that could aid healthcare professionals in making timely and accurate diagnoses.
- Investigate the potential of deep learning models in improving the accuracy and efficiency of automated systems for ECG-based cardiovascular disease classification, contributing to the broader field of AI applications

3 Problem Statement

Cardiovascular diseases (CVDs) are a major global health concern, responsible for millions of deaths annually. Early and accurate diagnosis of CVDs is critical for preventing serious complications and reducing mortality rates. The electrocardiogram (ECG) is a widely used tool for diagnosing heart conditions; however, the manual interpretation of ECG readings is often challenging due to the complexity of the signals and the possibility of human error. This highlights the need for automated and accurate systems that can classify ECG images with high precision.

Although deep learning models, particularly Convolutional Neural Networks (CNNs), have shown great promise in medical image analysis, there is still a need for more specialized models tailored to ECG data. Additionally, many existing models suffer from limited generalization ability due to small datasets and insufficient variability in training data. To address these issues, there is a pressing need for a more advanced and efficient approach to CVD classification using ECG images, leveraging modern CNN architectures and augmented datasets.

This research aims to solve the problem of accurate and efficient classification of CVDs by utilizing the Xception CNN model and employing data augmentation techniques. By improving classification accuracy and model robustness, this study seeks to provide a reliable tool that can assist healthcare professionals in diagnosing cardiovascular diseases, thus contributing to better patient outcomes.

4 Literature Review

The use of deep learning, specifically Convolutional Neural Networks (CNNs), in medical image analysis has witnessed rapid advancements in recent years, with significant applications in the diagnosis and classification of cardiovascular diseases (CVDs). This section explores existing studies and highlights the research gaps that motivate the present study.

4.1 Deep Learning in Cardiovascular Disease Diagnosis

Deep learning has been widely applied in the field of cardiovascular disease diagnosis due to its ability to automatically learn features from data. CNNs, in particular, have become a prominent tool for analyzing medical images, including ECG data. Studies such as [4] demonstrated the effectiveness of deep learning models in diagnosing arrhythmias using ECG signals, showing that CNNs can outperform cardiologists in certain diagnostic tasks. Similarly, [5] applied a deep learning algorithm to a large dataset of single-lead ECGs to detect arrhythmias, further validating the potential of AI-driven systems in healthcare.

However, many existing models, while successful in detecting specific arrhythmias or heart conditions, often suffer from limited generalization capabilities when applied to more complex and diverse datasets. This limitation calls for more refined models and larger, more representative datasets that can improve the accuracy and robustness of such systems.

4.2 CNN Architectures for ECG Classification

Several CNN architectures have been explored for the classification of ECG signals. Early works by [6] utilized CNNs to detect and classify five different types of arrhythmia from ECG signals, achieving high accuracy. More recent studies, such as [7], used 1D

CNN models combined with long short-term memory (LSTM) networks to classify ECG signals. These hybrid models have shown improved performance in capturing temporal dependencies in ECG signals.

However, as these models are primarily based on 1D signal data, they do not fully leverage the spatial features that can be extracted from 2D ECG images. This motivates the exploration of advanced 2D CNN architectures, such as the Xception model, which has shown superior performance in several image classification tasks.

4.3 Xception Model in Medical Image Analysis

The Xception model, introduced by [8] is an advanced CNN architecture that uses depthwise separable convolutions, which allow it to perform more efficiently with fewer parameters while maintaining high accuracy. The model has been successfully applied in medical image classification tasks, such as detecting diabetic retinopathy and skin cancer [9]. In ECG analysis, however, the Xception model has not been extensively explored, presenting a research gap in its application to ECG image classification for CVD diagnosis.

4.4 Data Augmentation in ECG Classification

One of the major challenges in training CNN models for medical image analysis is the limited availability of labeled data[10-14]. To address this, data augmentation techniques, such as rotation, scaling, and flipping, have been widely used to artificially expand datasets and improve model generalization[15-19]. Data augmentation has been successfully employed in ECG classification studies [20-22], enhancing model performance by increasing the variability of training data. However, more comprehensive studies that utilize data augmentation in combination with advanced architectures like Xception are still needed.

4.5 Research Gap and Motivation

While CNNs have been applied to ECG data for CVD classification, most studies have either focused on 1D signals or employed relatively simple CNN architectures. Additionally, the majority of studies lack sufficient dataset augmentation, which limits their generalizability and performance. There is also a gap in the application of more advanced CNN architectures, such as Xception, in ECG image classification.

This study addresses these gaps by applying the Xception model to ECG image classification, combined with extensive data augmentation to enhance model performance. This approach aims to improve the accuracy and robustness of CVD classification models, contributing to the growing field of AI-based healthcare solutions.

5 Methodology

This section outlines the methodology used in this study, including data collection, preprocessing, the architecture of the Xception model, the training process, and the evaluation metrics.

5.1. Dataset

The dataset used in this study was collected from Kaggle and contains ECG images from four categories (as in Fig. 1 to Fig. 4.):

- ECG Images of Patients with a History of Myocardial Infarction (MI),
- ECG Images of Patients with Abnormal Heartbeats,
- ECG Images of Patients Currently Experiencing Myocardial Infarction (MI),
- ECG Images of Normal Individuals.

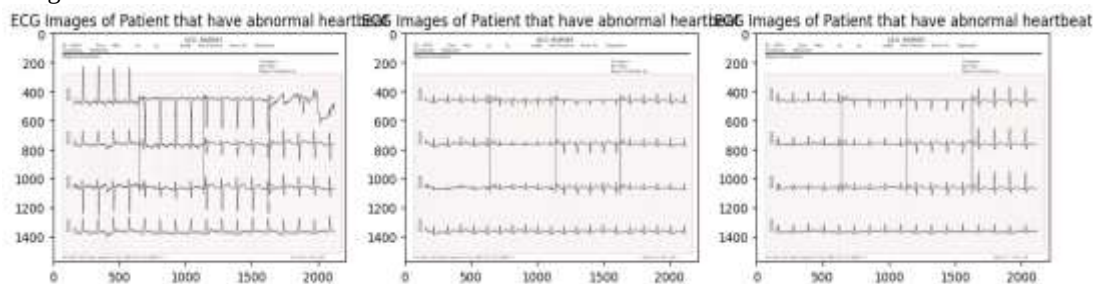


Fig. 1. Examples of ECG images of patients exhibiting an abnormal heartbeat.

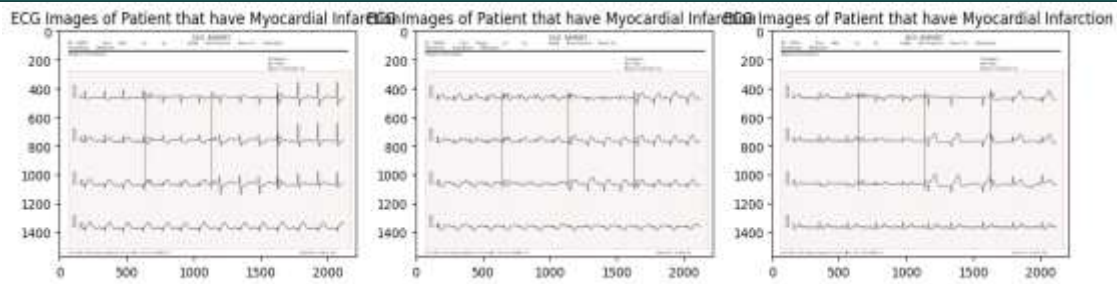


Fig. 2. Examples of ECG images of patients who have a history of myocardial infarction (MI)



Fig. 2. Examples of ECG Images of Patients with Myocardial Infarction

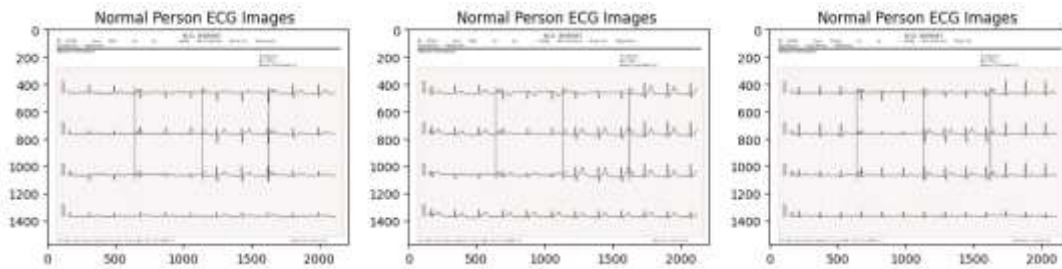


Fig. 4. Examples of Normal Person ECG Images

In total, the dataset consists of 928 images. To improve the model's ability to generalize across diverse ECG patterns, we applied data augmentation techniques, which expanded the dataset to 4000 images. The dataset was split into 60% training, 20% validation, and 20% testing sets to evaluate the performance of the model.

5.2. Data Preprocessing

Preprocessing of the ECG images was a crucial step to ensure the consistency and quality of the input data for the model. The preprocessing steps included[23-27]:

- Resizing all images to match the input dimensions required by the Xception model (299x299 pixels).
- Normalization of pixel values to ensure all input data lies in a similar range, improving model convergence during training.
- Data Augmentation techniques were applied to the training set to artificially increase the diversity of the images. These techniques included random rotations, flipping, zooming, and scaling, helping the model generalize better to unseen data[28-30].

5.3. Model Architecture

The proposed model for classifying cardiovascular diseases is based on the Xception architecture, which is an extension of the Inception model, but with depthwise separable convolutions. This architecture was chosen due to its ability to efficiently extract

meaningful features from images, making it suitable for medical image classification tasks[31-33]. The Xception model is composed of the following components(as in Fig. 5)[34-36]:

- Entry Flow: Initial layers responsible for extracting low-level features from the input images.
- Middle Flow: Multiple separable convolution layers that capture more abstract and complex features.
- Exit Flow: Final layers that downsample the features and produce class probabilities.

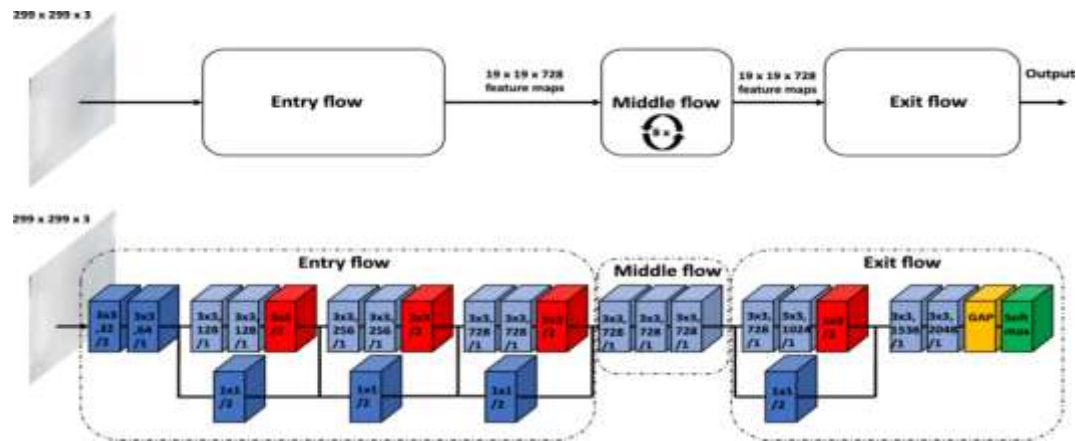


Fig. 3. The architecture of the proposed CNN model

For this task, we modified the final layer of the Xception model to output four classes, corresponding to the four ECG categories.

5.4. Training Process

The model was trained using the following configuration[37-40]:

- Optimizer: We used the Adam optimizer, which combines the advantages of adaptive gradient descent methods.
- Loss Function: Categorical cross-entropy was chosen as the loss function since we are dealing with a multi-class classification problem.
- Batch Size: A batch size of 32 was used for training.
- Number of Epochs: The model was trained for 80 epochs, and early stopping was applied to prevent overfitting.
- Learning Rate: A learning rate scheduler was employed to reduce the learning rate if the model's performance plateaued during training.

5.5. Evaluation Metrics

The performance of the model was evaluated using the following metrics[41-44]:

- F1-Score: To measure the balance between precision and recall.
- Precision: To measure the accuracy of the positive predictions.
- Recall: To assess the sensitivity of the model in identifying positive cases.
- ROC-AUC (Receiver Operating Characteristic - Area Under the Curve): To evaluate the model's ability to discriminate between the classes.

5.6. Validation and Testing

After training, the model was validated and tested on the hold-out datasets (20% for validation and 20% for testing). The final model performance was assessed based on its ability to classify unseen ECG images into the four target categories.

6 Discussion

The findings of this study demonstrate the effectiveness of the Xception model in classifying cardiovascular diseases (CVDs) from ECG images. Fig. 6 shows the area under Roc. Fig. 7 shows the training and validation accuracies while Fig. 8 shows

The training and validation loss.

The testing of the proposed model exhibited high results. With an F1-score of 98.00%, recall of 98.30%, and precision of 98.23%, the model shows strong potential for application in clinical settings. This discussion section delves into the implications of the results, compares them with existing literature, and outlines the study's limitations and future directions.

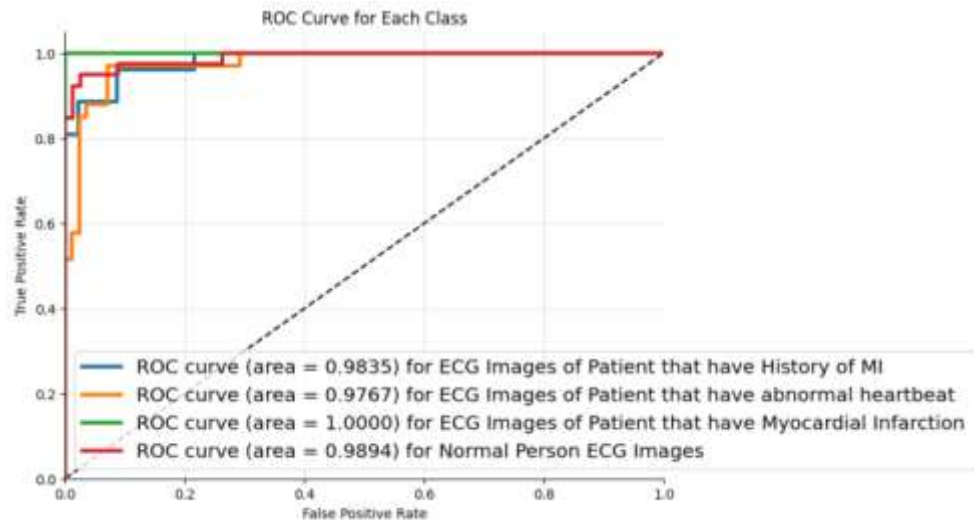


Fig. 6. Plot ROC curves

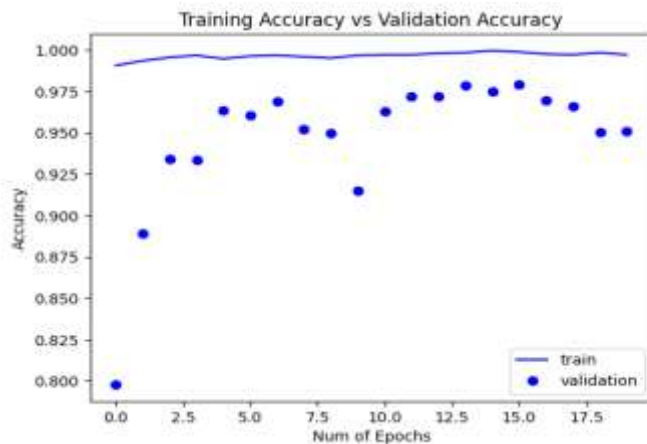


Fig. 7. Training and validation accuracy

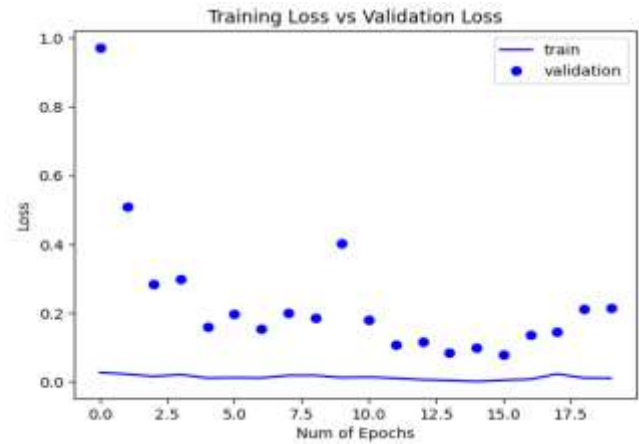


Fig. 8. Training and validation loss

6.1. Implications of Findings

The high performance of the Xception model suggests that automated ECG classification can significantly aid healthcare professionals in diagnosing cardiovascular conditions more accurately and efficiently. Given the complexity of ECG signal interpretation, leveraging deep learning techniques may reduce the likelihood of human error and improve diagnostic speed, potentially leading to better patient outcomes.

Additionally, the model's ability to achieve high accuracy across various classes indicates its robustness and adaptability, making it a valuable asset in environments with diverse patient populations and varying ECG presentations.

6.2. Comparison with Existing Literature

This study's results align with previous research that has demonstrated the potential of CNNs for ECG analysis. For instance, the authors in [1] reported high accuracy levels in arrhythmia detection, which supports the efficacy of deep learning models in this domain. However, while prior studies often utilized simpler architectures or focused on specific arrhythmias, the current research extends the application of the more advanced Xception model to a broader range of CVDs.

Moreover, the use of extensive data augmentation techniques is particularly noteworthy, as it addresses a common limitation in medical image analysis—insufficient data diversity. Previous studies have shown that augmentation can enhance model performance [10], and this study corroborates those findings by demonstrating significant improvements in classification accuracy.

6.3. Limitations of the Study

Despite the promising results, this study has several limitations that warrant consideration:

Dataset Size: While the augmented dataset consisted of 4000 images, the initial dataset of 928 images may not fully represent the diversity of ECG patterns in the broader population. Future research should consider incorporating larger and more diverse datasets to improve generalizability.

Misclassifications: The confusion matrix revealed some misclassifications, particularly between abnormal heartbeats and current myocardial infarction. This indicates that further refinement of the model may be necessary to enhance its discriminative capabilities in such nuanced cases.

Single-Lead ECG Focus: The dataset utilized in this study primarily consists of single-lead ECG images. Future studies could explore multi-lead ECG data to leverage additional features and potentially improve classification accuracy.

6.4. Future Directions

To address the limitations identified in this study, future research could focus on the following avenues:

Larger Datasets: Expanding the dataset by collecting more ECG images from diverse populations and clinical settings can enhance the model's ability to generalize across different patient demographics.

Advanced Techniques: Exploring additional techniques, such as transfer learning, ensemble methods, or hybrid models that combine CNNs with other machine learning algorithms, may further improve classification performance.

Real-World Validation: Conducting clinical trials or studies in real-world settings to validate the model's performance and utility in actual patient care scenarios will be essential for its eventual implementation in healthcare practices.

7 Conclusion

This study successfully demonstrated the application of the Xception model for the classification of cardiovascular diseases (CVDs) using ECG images. The high evaluation metrics, including an F1-score of 98.00%, recall of 98.30%, and precision of 98.23%, underscore the model's efficacy in accurately distinguishing between various ECG categories, including those indicative of myocardial infarction and abnormal heart rhythms.

7.1 Key Contributions

The primary **contributions of this research are as follows:**

7.1.1. Advanced Classification Approach: By employing the Xception model, this study highlights the potential of deep learning techniques in improving the accuracy and efficiency of CVD diagnosis from ECG images, offering a reliable tool for healthcare professionals.

7.1.2. Robust Data Augmentation: The effective use of data augmentation significantly enhanced model performance, demonstrating that augmentation techniques are crucial for training deep learning models in medical image analysis, particularly when dealing with limited datasets.

7.1.3. Comprehensive Evaluation: The study employed a rigorous evaluation framework, utilizing metrics such as F1-score, precision, recall, and ROC-AUC to ensure a thorough assessment of the model's performance.

7.2 Future Implications

The findings of this research pave the way for further exploration into automated ECG classification systems that can be integrated into clinical workflows. Future studies should focus on expanding datasets, incorporating multi-lead ECG data, and validating model performance in real-world settings to enhance its clinical applicability.

In conclusion, the Xception model presents a promising avenue for advancing cardiovascular disease diagnosis through ECG analysis, potentially leading to improved patient outcomes and streamlined clinical processes. Continued research in this area is essential to realize the full potential of machine learning in healthcare.

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