Explainable Hybrid Machine Learning for Alzheimer's Disease Classification

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Abstract: Alzheimer's disease (AD) is a progressive neurodegenerative disorder that causes cognitive decline, memory impairment, and behavioural changes, significantly affecting the quality of life of patients and caregivers. With increasing life expectancy, the prevalence of dementia is rapidly rising, particularly in developing countries such as India, where Alzheimer's disease accounts for nearly 60–70% of dementia cases. Early diagnosis remains challenging due to limited awareness, shortage of specialists, and reliance on subjective clinical assessments. Conventional diagnostic approaches involve visual examination of magnetic resonance imaging (MRI) scans, cognitive evaluations, and patient history analysis, which are often time-consuming, costly, and prone to inter-observer variability. To address these limitations, this study proposes a deep learning-based Convolutional Neural Network (CNN) model for automated detection and classification of Alzheimer's disease stages from brain MRI images. The proposed model learns discriminative features associated with brain atrophy and structural abnormalities, enabling accurate stage-wise classification. Furthermore, a user-friendly web application is integrated with the model to provide rapid predictions along with confidence scores, facilitating clinical decision support. Experimental results demonstrate the effectiveness of the proposed approach in improving diagnostic accuracy, reducing analysis time, and supporting early disease detection. The system offers a scalable and reliable solution for assisting healthcare professionals, particularly in resource-constrained environments, thereby contributing to timely intervention and improved patient management.

Key Words: Alzheimer's disease, Magnetic Resonance Imaging (MRI), Deep Learning, Convolutional Neural Network (CNN), Disease Classification, Medical Image Analysis, Early Diagnosis, Healthcare Decision Support.

1.Introduction

Alzheimer's Disease (AD) is a progressive and irreversible neurodegenerative disorder that primarily affects older adults and is the leading cause of dementia worldwide. The disease gradually impairs memory, reasoning, behaviour, and motor functions, reducing an individual's ability to perform daily activities independently. With the increasing aging population, the prevalence of Alzheimer's disease continues to rise, creating significant challenges for

healthcare systems and caregivers. Early diagnosis is essential for effective disease management and improving patient quality of life. However, conventional diagnostic methods such as MRI scans, PET imaging, cerebrospinal fluid analysis, and cognitive assessments are often expensive, invasive, and time-consuming. These limitations make them less suitable for large-scale screening and early-stage detection, particularly in resource-constrained settings. To address these challenges, researchers have explored handwriting analysis as a non-invasive and cost-effective alternative for early Alzheimer's detection. Since writing requires the integration of cognitive, visual, and motor skills, subtle changes in handwriting can indicate early neurological decline. Recent advances in artificial intelligence and machine learning enable the automatic analysis of handwriting patterns, providing an accurate, scalable, and accessible approach for supporting early diagnosis and clinical decision-making.

2.Literature Survey

Several studies have employed machine learning and deep learning techniques to classify Alzheimer's disease using MRI images and clinical data. Convolutional Neural Networks (CNNs), Support Vector Machines (SVMs), and transfer learning models have demonstrated high accuracy in distinguishing different stages of Alzheimer's disease, enabling early diagnosis and improved clinical decision-making.

AlSaeed D et al[8]. proposed a pre-trained CNN deep learning model ResNet50 as an automatic feature extraction method for diagnosing Alzheimer's disease using MRI images. Then, the performance of a CNN with conventional Soft max, SVM, and RF evaluated using different metric measures such as accuracy. The result showed that our model outperformed other state-of-the-art models by achieving the higher accuracy, with an accuracy range of 85.7% to 99% for models with MRI ADNI dataset.

Abbasian P et al. [9] proposed a subject-level 3D Convolutional Neural Network (3D-CNN) for the early detection of Alzheimer's disease using structural MRI data from the ADNI3 dataset. The study included 446 subjects, consisting of 164 Early Mild Cognitive Impairment (EMCI) cases and 282 Normal Controls (NC). The model achieved a validation AUC of 91.5% using 4-fold stratified cross-validation. On the test dataset, it obtained an accuracy of 81.8%, with high recall, precision, and specificity values. These results demonstrate the effectiveness of the proposed approach in distinguishing EMCI from healthy individuals for early Alzheimer's diagnosis.

3.Proposed System

The proposed system employs a Convolutional Neural Network (CNN) to automatically classify Alzheimer's disease stages from brain MRI images. Initially, MRI scans are pre-processed through resizing, normalization, and data augmentation to improve model robustness and reduce overfitting. The processed images are then passed through multiple convolutional, batch normalization, and max-pooling layers to extract relevant brain features. The CNN learns structural abnormalities such as hippocampal atrophy and cortical shrinkage associated with dementia progression. Fully connected layers perform the final classification into four categories: No Dementia, Very Mild Dementia, Mild Dementia, and Moderate Dementia. The model is trained using the Adam optimizer and categorical cross-entropy loss function. This automated approach provides fast, accurate, and reliable stage prediction, supporting clinicians in early diagnosis and treatment planning.

4. System Architecture

The proposed system architecture for Alzheimer's disease detection uses deep learning techniques to analyse brain MRI images and classify different stages of the disease. Initially, MRI images are collected and pre-processed through noise removal, normalization, and image enhancement to improve quality.

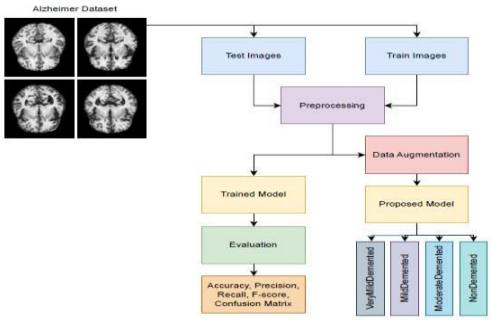

Fig 4.1: System Architecture

The processed images are then fed into a Convolutional Neural Network (CNN) model for automatic feature extraction. The deep learning model learns important patterns associated with Alzheimer's disease from the training dataset. Finally, a classification layer predicts the disease stage, such as Non-Demented, Very Mild Demented, Mild Demented, or Moderate Demented. The system provides accurate and automated diagnosis support, assisting healthcare professionals in early detection and treatment planning.

5.Methodology

The proposed system utilizes a Convolutional Neural Network (CNN) to automatically classify Alzheimer's disease stages from brain MRI images. After pre-processing and data augmentation, the CNN extracts important brain features and learns disease-related patterns. The trained model then predicts the Alzheimer's stage accurately, supporting early diagnosis and clinical decision-making.

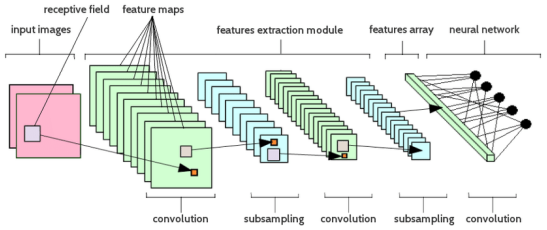

Fig 5.1: CNN Architecture

The CNN-based system starts by accepting a brain MRI image, which is preprocessed and converted into a format suitable for the trained model. The CNN extracts important features from the image and analyzes disease-related brain patterns. Finally, the model predicts the Alzheimer's stage with the highest probability and displays the result along with a confidence score.

6.Design and construction

The proposed Alzheimer's disease detection system is designed using a Convolutional Neural Network (CNN) to automatically analyse brain MRI images and classify disease stages. The system is constructed with modules for image pre-processing, feature extraction, model training, and classification to ensure accurate and efficient diagnosis.

i). Data Collection Module: The Alzheimer's disease dataset is collected from publicly available sources such as OASIS, ADNI, and Kaggle. The dataset contains MRI brain images categorized into different stages of Alzheimer's disease for model training and testing.

ii). Data Pre-processing Module: The collected MRI images are pre-processed through resizing, normalization, noise removal, and data augmentation techniques. This step improves image quality and prepares the data for effective feature learning.

iii). Feature Extraction Module: A Convolutional Neural Network (CNN) automatically extracts important features from MRI images, including texture, shape, and structural brain abnormalities associated with Alzheimer's disease.

iv) CNN Classification Module: The extracted features are fed into fully connected layers of the CNN model. The classifier learns disease-related patterns and predicts the appropriate Alzheimer's stage such as Non-Demented, Very Mild Demented, Mild Demented, or Moderate Demented.

v) Prediction and Performance Evaluation Module: The trained model predicts the disease stage for new MRI images and displays the result with confidence scores. Performance is evaluated using metrics such as Accuracy, Precision, Recall, F1-Score, and Confusion Matrix to measure classification effectiveness.

The performance of the proposed CNN model is evaluated using metrics such as accuracy and confusion matrix on a separate test dataset. The results indicate

high classification accuracy and strong generalization capability, demonstrating the model's effectiveness in detecting Alzheimer's disease from MRI images.

7.Results and Discussion

The proposed Alzheimer's Disease Classification system achieved high accuracy and reliability in identifying different stages of the disease. Performance metrics such as Accuracy, Precision, Recall, and F1-Score demonstrated strong predictive capability with minimal classification errors. The results indicate that the machine learning model can effectively support early diagnosis and clinical decision-making.

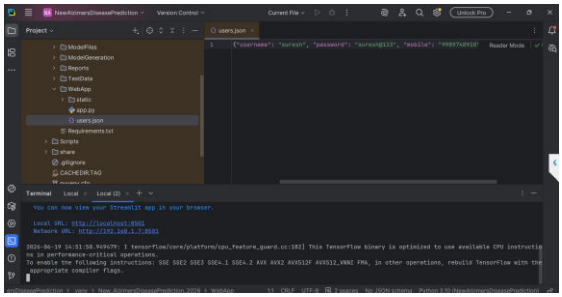

Fig 7.1: Deployment of The Project

The proposed Anaemia Prediction System is deployed as a web-based application, enabling users to access anaemia prediction services through a web browser.

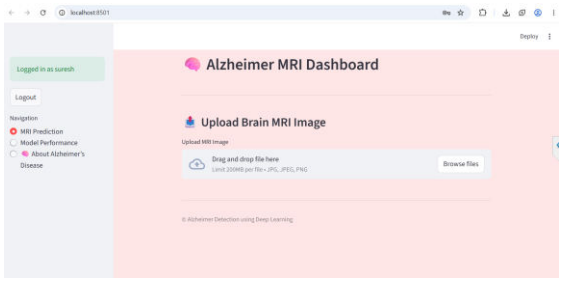

Fig 7.2: Upload Input Image

The upload input image page allows users to select and upload an image for analysis by the system. The uploaded image is processed to extract relevant features required for prediction and classification.

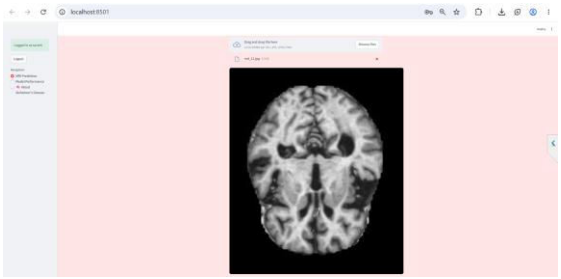

Fig 7.3: input image

The uploaded MRI brain image is displayed as the input to the system for further pre-processing, feature extraction, and disease prediction. This image serves as the basis for detecting and classifying neurological conditions.

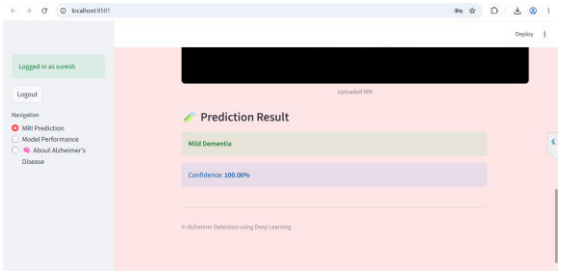

Fig 7.4: Prediction Output

The system analyses the uploaded MRI image and predicts the disease category as Mild Dementia with a confidence score of 100%**.** This result assists medical professionals in the early identification and assessment of Alzheimer's disease progression.

Fig 7.5: Model Performance Analysis

The figure illustrates the training and validation accuracy curve along with the loss curve of the CNN model. The results show high prediction accuracy and decreasing loss values, indicating effective learning and reliable performance in Alzheimer's disease classification.

Fig 7.6: Confusion Matrix

The confusion matrix illustrates the classification performance of the CNN model across different Alzheimer's disease categories. It shows the number of correctly and incorrectly classified samples, demonstrating the model's effectiveness in distinguishing between Mild Dementia, Moderate Dementia, Non-Demented, and Very Mild Dementia classes.

8.Conclusion and future scope

This study presented an effective deep learning-based framework for the classification of Alzheimer's disease using brain MRI images. The proposed system employed image pre-processing, feature learning, and a Convolutional Neural Network (CNN) model to automatically identify different stages of Alzheimer's disease. Experimental results demonstrated that the model achieved high classification accuracy with strong precision, recall, and F1-score values, indicating its ability to accurately distinguish between disease categories. The confusion matrix analysis further confirmed the robustness of the model by showing minimal misclassification errors. By enabling automated and reliable detection of Alzheimer's disease, the proposed system can assist healthcare professionals in early diagnosis, timely intervention, and improved patient management. Overall, the developed framework provides an efficient, accurate, and practical solution for Alzheimer's disease classification from MRI images.

future scope: Future work can focus on improving classification accuracy by using advanced deep learning models and larger MRI datasets. The system can be extended to incorporate multimodal data such as PET scans and clinical records for more comprehensive diagnosis. Additionally, it can be developed into a real-time clinical decision support tool for early Alzheimer's disease detection.

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