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Empirical Evaluation of Deep Learning Architectures in the Early Detection of Alzheimer's Disease through MRI Data Analysis

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***Abstract*— Alzheimer's disease (AD) poses a significant challenge to healthcare systems worldwide, necessitating early detection and intervention for effective management. In this paper, various Deep Learning (DL) architectures such as CNN, Residual Neural Networks (ResNet), and U-Net with Gating (UGNet), and VGG16 for detecting AD at an early stage by applying MRI data which is acquired from the Open Access Series of Imaging Studies (OASIS) dataset. In this method, MRI data is firstly preprocessed for extracting the relevant features which are used for training these models. Paramters of the evaluation metrics such as Classification accuracy, precision, specificity, and area under the receiver operating characteristic curve (AUC-ROC) are applied for assessing the performance of four DL models while AD patients. From the simulation results, it has been observed that high classification accuracy and AUC-ROC scores has been achieved in VGG16 as compared with other models. However, ResNet performs better when it comes on classifying complex image tasks in detecting AD. When convolutional and deconvolutional pathways with gating mechanisms are considered, UG-Net performs a notable performance in comparing to CNN and ResNet. These findings have supported the potentiality of DL techniques in detecting early diagnosis and intervention strategies while contributing to much-improved patient care.**

I. Introduction

As per the trends in the worldwide, Alzheimer's Disease (AD) has been considered as as one of the most significant factors in the health industry [1,2]. In this condition, the disease is being characterized by its neurodegenerative nature which leads to the gradual and progressive decline in cognitive abilities. However, the disease severely hampers in executing daily activities in the later stages which ultimately effects mortality. Also, the disease has impacted substantial economical burden on AD patients where there are certain ways are required for taking immediate and effective strategies in detecting, managing, and intervening. In order to lessen the effect of AD, the identifying and managing the condition of AD at an early condition is essential in a timely manner. Therefore, early diagnosis is one of the essential requirements which cannot be overstated because of recent improved therapeutic outcomes and affords individuals. As a result, accurate planning with different care strategies is required for caregivers and families. Such proactive measures can lead to contribute to enhancing the life quality for AD patients. The early detection of AD increases the possibility of engaging in preventive strategies and interventions. All the above-mentioned strategies generally aim at slow down the progression of AD, which offer as hope in delaying or averting the emergence of the most severe symptoms which is associated with the disorder [3,4].

The emergence of DL technologies during recent years has significantly transformed medical image analysis which open the door to new opportunities for the early identification and diagnosis of Alzheimer's Disease (AD) [5,6]. DL methods, especially CNN and their derivatives which has shown exceptionally well learning autonomously and differentiating complex image patterns and characteristics [7,8]. Nowadays, researchers are building powerful computational models for detecting the disease accurately by applying the latest technology with a particular focus on analyzing magnetic resonance imaging (MRI) data from different image datasets [9,10]. Here, in this work, the potentiality of DL models has been explored in the early diagnosis of Alzheimer's disease by applying MRI data. The application of deep neural networks, preprocessing methods, and different optimization techniques shows that the diversity and advancement in this research field [11,12].

De Santi et al. [13] introduced a new type of CNN which is designed for multiclass classifications by considering volumetric 18F-FDG PET images during their study. In this model, two post hoc explanation mechanisms, namely the Saliency Map (SM) and Layer wise Relevance Propagation (LRP), has been employed in order to enhance its interpretability. The research incorporates scans of 2552 images which are classified into three categories, namely, Cognitively Normal (CN), Mild Cognitive Impairment (MCI), and Alzheimer's Disease (AD) from ADNI dataset. EL-Geneedy et al. [14] proposed deep learning-based classifier for identifying Alzheimer's disease through the analysis of 2D T1-weighted Magnetic Resonance (MR) brain images. Here, the model reported sensitivity and specificity rates of 100% with the accuracy rate of 99.68% by considering OASIS dataset. Diogo et al. [15] explored machine learning methodology for Alzheimer Disease (AD) at an early stage by utilizing the ADNI and OASIS databases. Murugan et al. [16] proposed DEMNET model where MRI data is preprocessed first before it goes data balancing by applying SMOTE technique. This model has been applied for extracting features which creates an occlusion sensitivity map for interpretation. The performance of the proposed model achieved at an accuracy of 95.23% and an AUC-ROC of 97%.

In this study, the diagnosing Alzheimer's Disease at an early stage by applying four DL techniques has been established by applying CNN, ResNet, UGNet, and VGG16. Here, MRI scans has been acquired by applying Open Access Series of Imaging Studies (OASIS) dataset where the performance of these DL methods are assessed in the early identification.

II. Dataset Description

For the research work, The Open Access Series of Imaging Studies (OASIS) dataset has been considered where various neuroimaging and clinical data are examined for structural functionalities in the brain. Here, two classifications Mild Cognitive Impairment (MCI) and Alzheimer's Disease (AD) has been taken into consideration. This dataset has been prepared by the collaboration of several esteemed institutions which includes Washington University, the University of California San Francisco, and the University of California Los Angeles. In this dataset, high-resolution T1-weighted MRI scans are included in the normalized form where essential anatomical details are provided for in-depth analysis. In addition to that, various tools related to demographics and related clinical data such as age, gender, educational background, and clinical assessments including Mini Mental State Examination (MMSE) scores has been appended in the OASIS dataset. For categorizing each subject, these elements are vital in terms of further research and study in the field. For maintaining the uniformity across variations in the acquired data, preprocessing steps such as skull stripping, intensity normalization, and spatial normalization are analyzed for studying standard brain templates. Various methods are employed by researchers for applying the dataset for enhancing the early detection techniques for monitoring the progression of the disease in more accurate manner.

CNN are employed which plays a pivotal role in processing the MRI images acquired from OASIS dataset [17]. On the basis of neuroimaging and clinical data, various induvials are classified as one of the objectives aimed to harness insights from the OASIS dataset. MRI scans of moderate dementia has been shown in Fig.1.

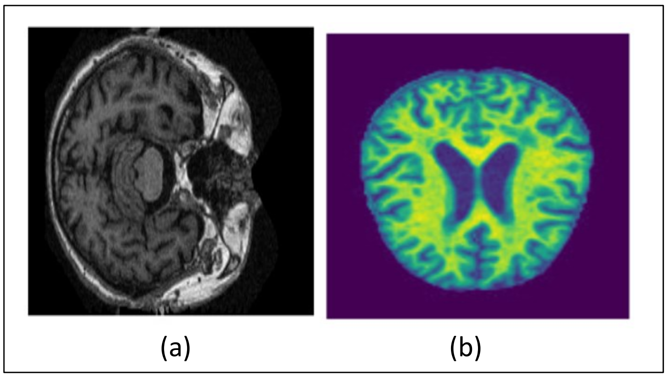


Fig.1 (a) MRI Scan of Moderate Dementia from OASIS (b) MRI scan for Moderate Dementia from masked images

III. Proposed Methodology

In this proposed technique, there are overall four steps before deploying to Machine Learning models for processing the MRI images. The four steps are data collection and preparation, handling class imbalance, Exploratory Data Analysis (EDA), and Data augmentation.

A. Data collection and preparation: For collecting the data, Kaggle API has been applied by various researchers where "imagesoasis" file can be downloaded. This file contains Alzheimer rich collection of MRI data. After downloading the file, the contents of the data folder can be extracted where the data should be in organized form for subsequent analysis. Moreover, libraries such as, TensorFlow and split-folders are applied for further processing the data in an orderly fashion. These advanced tools increase the simplification of intricated data where the integrity of the data is preserved. Also, the data is compatible in processing the various high complex deep learning architectures. For enhancing the efficiency and effectivity, this approach has been applied for the importance in delivering advancements in software and in the area of medical imaging, particularly Alzheimer's disease.

B. Handling class imbalance: After evaluating the initial assessment of the dataset, the size and distribution can be carefully evaluated across different classes. By utilizing the statistical methods and visualization instruments, class imbalance can be considered by giving the careful attention to the Moderate Dementia category. With the application of advanced techniques, the specific focus is required on accuracy and efficiency should be maintained at any cost. However, the structure of the dataset should be evaluated by applying effective machine learning models so that no disparity in the variations in the data is not comprised which is helpful in assessing the performance of predictive models, particularly in medical diagnoses like dementia.

C. Exploratory Data Analysis (EDA): For clear understanding for complicated feature patterns and clear distinctions in a particular dataset, EDA is required at every stage. With the application of state-of-the-art methods, large number of variations are observed in different categories. In this approach, difference are observed within the data in a dataset which leads to further analysis. Additionally, accurate dimensions in a particular image can lead to standardization of the images for preprocessing in subsequent stages. In order to maintain quality of high standards in terms of data quality and integrity, images are constantly formatted which are used for future analysis in terms of building effective predictive models.

D. Data Augmentation: In this step, ImageDataGenerator class is generated by application of Kera's library with implementation of data augmentation strategies. A complete set of augmentation techniques are implemented taking the consideration of horizontal and vertical flips. In addition to that, pixel values are rescaled in the range to 0 to 1 with adjusting different parameter settings. In this process, variety of data with certain depth can be analyzed in the training dataset. As a result, more diversities of the results can be varied by generalizing the proposed model. Therefore, these models can learn from these set of examples where accuracy is greatly improved on unknown date. The proposed work has been shown in the form of block diagram as explained in Fig.2.

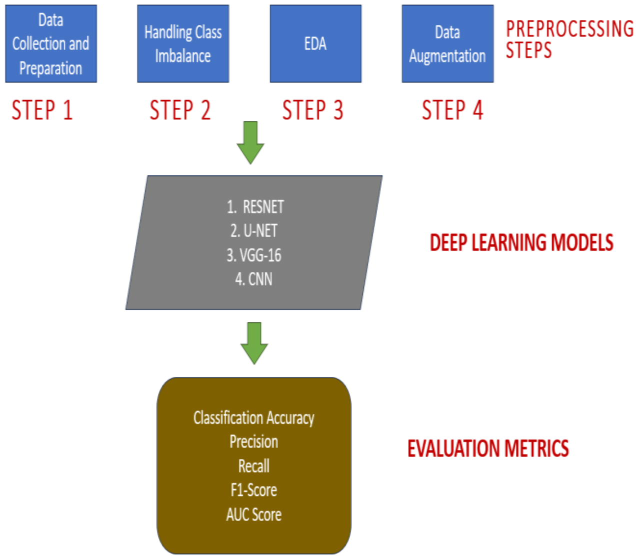


Fig.2 Working of proposed methodology

IV. Simulation Results and Discussion

The proposed work has been executed on the Jupyter Notebook working environment installed on the Personal Computer. The specifications of the PC are Intel Core i7 10^{th} Generation, 1TB Hard Disk capacity with 1GB RAM, graphics card of NVIDIA GEFORCE GTX of 250 MB card for processing high quality images. Here, 80% of the total images are trained for training, 10% for validating the images, and rest 10% for testing images. Evaluation metrics are used in measuring the effectiveness and analytical precision of the various deep learning models across different classes. These metrics are essential for assessing the quality of the DL models, where the non-diagonal elements represent instances correctly matched with their actual labels, while other entries indicate misclassifications made by the models. Therefore, the components of the evaluation metrics such as Classification Accuracy, Precision, Recall, F1 score, and AUC score have been computed for evaluated for each of the DL models as mentioned in Table 1.

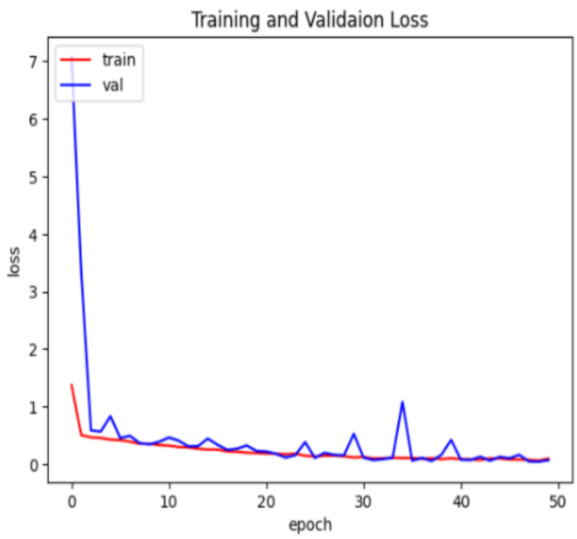
Table 1: Values of different Evaluation Metrics for four Deep Learning Models

S. No	Model Name	AUC Value	Accuracy	Precision	Recall	F1-Score
1.	CNN	0.51	0.99	0.24	0.24	0.24
2.	VGG16	0.51	0.91	0.78	0.80	0.79
3.	ResNet-50	0.508	0.78	0.19	0.25	0.218
4.	U-Net	0.409	0.76	0.25	0.25	0.25

This table presents a comparative analysis of four different deep learning models – CNN, VGG16, ResNet-50, and U-Net – based on several key performance metrics in a classification task: AUC (Area Under the ROC Curve) Value, Accuracy, Precision, Recall, and F1-Score. CNN shows a high accuracy rate of 0.99, indicating that it correctly predicts 99% of the outcomes. VGG16 offers a more balanced performance with an AUC value of 0.51 and notably higher precision (0.78), recall (0.80), and F1-score (0.79) compared to CNN. Its accuracy is 0.91, indicating it correctly predicts 91% of the outcomes, which, combined with its higher precision and recall, makes it a strong contender. ResNet-50 has a slightly lower AUC value of 0.508 and accuracy of 0.78. It also shows low precision (0.19) and recall (0.25), with an F1-score of 0.218, indicating it may struggle with correctly identifying positive cases and avoiding false positives. U-Net has the lowest AUC value (0.409) and an accuracy of 0.76. Its precision, recall, and F1-score are all at 0.25, indicating a moderate level of performance but the lowest among the models presented. VGG16 emerges as the best model among the four, based on the balance across all evaluated metrics. ResNet-50 and U-Net show lower performance across the board, with U-Net ranking as the least effective model based on these metrics.

Fig.3 displays the values of training and validation accuracies as well losses with respect to number of epochs. It has been observed that at the end of 40 epochs, training and validation loss is almost zero whereas the validation accuracy has achieved at 98% at the end of 50 epochs. For obtaining the classification accuracy, the batch size has been keft at 32.

(a)



(b)

Fig. 3 Training and Validation Accuracy and Loss of VGG 16

V. Conclusion and Future Scope

In this study, various deep learning frameworks such as Convolutional Neural Networks (CNN), Residual Neural Networks (ResNet), U-Net with Gating (UGNet), VGG16, and Transfer Learning methodologies are utilized for the early detection of AD using MRI scans from the OASIS dataset. The research approach involves preprocessing MRI data to identify pertinent features for training these models. The performance of each model is evaluated using key metrics such as Classification Accuracy, Sensitivity, Specificity, and Area Under the Receiver Operating Characteristic Curve (AUC-ROC), aiming to differentiate between AD patients and healthy individuals accurately. The simulations reveal that the VGG16 model outperforms others in terms of accuracy and AUC-ROC, highlighting its effectiveness as a reliable tool for early AD detection.

In the future, this work opens for further exploration and refinement of recent and combined and effective deep learning models in the early detection of Alzheimer's disease. Future studies could focus on integrating multimodal data sources, including genetic, biochemical, and additional neuroimaging data, to develop more comprehensive and accurate diagnostic models. There is also potential for exploring the integration of machine learning algorithms with clinical decision-making processes, providing healthcare professionals with powerful tools for patient assessment and personalized treatment planning.

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