International Journal of Scientific Research and Engineering Development-– Volume 9 Issue 2, Mar-Apr 2026
Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

MRI-Based Early Alzheimer's Stage Classification Using 3D Convolutional Neural Network and Transfer Learning

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***Abstract*—THIESIS: "MRI-Based Early Alzheimer's Stage Classification Using 3D Convolutional Neural Networks and Transfer Learning"**

Alzheimer's disease is a progressive neurodegenerative disor- der that mainly features a continuous decline in memory and cognitive functions. The diagnosis given early and accurately is important for effective treatment planning of the disease and to improve the overall patient outcome. MRI is widely used in clinical practice to identify structural changes in the brain, which are associated with Alzheimer's disease. However, manual interpretation of MRI scans is a time-consuming task and prone to inter-observer variability.

This work presents an automated framework for the early- stage classification of Alzheimer's disease using 3D Convolutional Neural Networks and transfer learning techniques. The proposed model analyzes volumetric MRI brain images for the extraction of spatial and structural features that distinguish multiple stages of the disease. Transfer learning is applied to leverage pre-trained deep learning models, which enhances the performance of the classification with reduced training complexity.

The proposed system is designed to assist clinicians by of- fering accurate and early diagnostic support, enhancing clinical decision-making, and facilitating timely intervention in the man- agement of AD.

***Index Terms*—Alzheimer's Disease Detection, Magnetic Res- onance Imaging, Three-Dimensional Convolutional Neural Net- works, Deep Learning Techniques, Medical Image Processing, Neurodegenerative Disease Analysis, Volumetric Brain Imaging, Automated Diagnostic Systems, Clinical Decision Support Tools, Brain Structural Analysis, Feature Learning, Disease Classi- fication Models, Artificial Intelligence in Healthcare, Medical Imaging Systems, Alzheimer's Stage Classification, Computer Vision Algorithms, Pattern Recognition Algorithms, Cognitive Decline Detection, Early Intervention Tools.**

I. Introduction

AD stands for Alzheimer's disease, which is a very common neurodegenerative disorder affecting elderly people. It results in a gradual loss of memory, a decreased ability to think, and problems with performing everyday tasks. Medical research demonstrates that the changes induced in the brain occur many years before any symptoms become visible, making early diagnosis a very significant process. The conventional way of diagnosis, based on expert assessment, relies thoroughly on human judgment and does not necessarily identify AD in its early phases [1].

Magnetic Resonance Imaging (MRI) is widely used in the study of brain anatomy and in the identification of changes due to Alzheimer's disease, such as the reduction in the size of critical areas, such as the hippocampus. With the increasing use of artificial intelligence, deep learning algorithms have become efficient in the analysis of medical images. Convo- lutional Neural Networks (CNN) have the ability to learn useful features in images without any human intervention. But two-dimensional CNN evaluates the slices of an MRI independently, which could sometimes overlook the critical spatial information in the image [3], [7].

II. Problem Statement

Alzheimer's disease is a progressive neurological disorder characterized by memory loss along with impairments in cognitive function, which impacts the quality of life of the elderly greatly. Early detection of the disease is essential for proper medical intervention. The current diagnostic technique for the disease relies heavily on medical assessments and cognitive functioning tests, which are not very effective in diagnosing Alzheimer's in its early stages.

This implies that a system requiring automatic and accurate classification of early phases of Alzheimer's disease using MRI data is warranted. The system would ideally utilize three-dimensional spatial data effectively and integrate trans- fer learning and ensemble learning to improve classification accuracy and efficiency. The proposed solutions would allow medical professionals to undertake early detection and diag- noses related to managing Alzheimer's disease effectively.

III. Related work

There exist a number of researches on the application of machine learning and deep learning approaches to diagnose Alzheimer's disease based on medical image data. The early research work was based on traditional machine learning, wherein features were derived from MRI images and classified using SVM, kNN, Random Forest, and a number of other classifiers. Even though the research work was somewhat successful, it heavily depended on manual feature selection and domain knowledge [4], [7].

Patients with Mild Cognitive Impairment (MCI), Alzheimer's disease patients. The models used were proven to have higher accuracy than conventional methods; yet, when analyzing MRI data in a two-dimensional manner, there was often a loss of relevant spatial information that existed between slices.

For overcoming this shortcoming, recently, three-dimensional CNNs (3D-CNN) models, which examine whole volumetric images from MRI scans, have been explored. The advantage of these models lies in maintaining spatial information in the brain, and hence, improved performance in identifying structural changes caused by Alzheimer's disease has been observed with 3D-CNN models as compared to 2D models in several works done in this area [5], [8].

IV. Objectives

- To create an automated system capable of identifying early stages of Alzheimer's disease using MRI brain scans.
- To design a three-dimensional Convolutional Neural Network (3D-CNN) that can capture detailed spatial patterns in volumetric MRI data.
- To use transfer learning with pre-trained models to improve the system's accuracy and reduce the time required for training.
- To implement ensemble learning by combining multiple CNN models, ensuring more reliable and robust predictions.
- To evaluate and optimize the system's performance using metrics such as accuracy, recall, and F1-score.
- To develop a tool that aids healthcare professionals in making timely and accurate decisions for Alzheimer's disease diagnosis.

V. Literature Survey

A. Overview

Alzheimer's Disease (AD) is a progressive neurological disorder that has been widely researched using medical imaging. Early work was centered around extracting features from MRI images using traditional machine learning algorithms like SVM, k-NN, and Random Forest. These algorithms were prone to manual feature extraction and had poor accuracy [4].

With the advent of deep learning, Convolutional Neural Networks (CNNs) gained popularity for the automatic analysis of MRI images. The early methods employed 2D CNNs on 2D slices of the MRI images, which improved the accuracy of the results but missed crucial spatial information present in the slices. To address this issue, 3D CNNs were proposed for the analysis of 3D MRI images [5], [7].

Transfer learning has also been used to take advantage of pre-trained models such as ResNet, Inception, and VGG to improve performance on small datasets. Ensemble learning techniques, which involve using multiple models together, have also been used to improve robustness and reliability. It has been found that using custom CNN models along with pre-trained models in an ensemble setting helps improve accuracy in the early detection of AD [3], [6].

However, despite these improvements, there is still a need for a system that combines 3D-CNNs, transfer learning, and ensemble learning. This project aims to improve these techniques to create an ensemble-based 3D-CNN system that will be able to give accurate and reliable classification of Alzheimer's disease.

B. Public Datasets

1) ADNI (Alzheimer's Disease Neuroimaging Initiative): Description: A widely used dataset in Alzheimer's research. It provides MRI and PET scans, as well as clinical and cognitive test data. It has healthy controls, Mild Cognitive Impairment patients, and Alzheimer's patients.

2) OASIS (Open Access Series of Imaging Studies): Description: Provides MRI scans regarding healthy aging and Alzheimer's disease, both cross-sectional and longitudinal. Also provides structural MRI scans in addition to demographic and clinical information.

3) AIBL (Australian Imaging, Biomarkers & Lifestyle Study of Ageing): Description: This dataset contains MRI, PET, and cognitive function information of older individuals, with a focus on the progression of AD.

4) MIRIAD (Minimal Interval Resonance Imaging in Alzheimer's Disease): Description: Longitudinal MRI dataset with a few scans of AD patients performed over a short period of time.

5) IXI Dataset: Description: MRI scans of normal subjects, often used as a control group in neuroimaging studies.

6) MedSeg Alzheimer's Dataset (from Kaggle): URL: https: // Description: Pre-labeled MRI scans of Alzheimer's patients at different stages (Mild, Moderate, Severe) and normal subjects.

7) NACC (National Alzheimer's Coordinating Center): URL: https:// Description: MRI, PET, and clinical data from several Alzheimer's Disease Centers.

VI. Proposed System

The proposed system is an intelligent system designed for the detection of the early stages of Alzheimer's disease using the deep learning approach on the MRI images of the brain. The proposed system uses the concept of a 3D Convolutional Neural Network (3D CNN) and the idea of transfer learning to analyze the entire structure of the human brain.

Firstly, the MRI scans are acquired and preprocessed to remove noise and ensure that the acquired images are standardized. The preprocessed images are then fed into the 3D CNN model to automatically detect patterns related to normal, mild cognitive impairment, and Alzheimer's disease. Transfer learning makes it easier to enhance the performance of the proposed system using knowledge from the pre-trained system.

Finally, the system is capable of predicting the stage of Alzheimer's disease and the results obtained can help a doctor make a faster and more correct medical decision in specific situations concerning the health of a patient.

VII. Methodology

A. Dataset Description

The proposed system uses publicly available MRI datasets like the Alzheimer's Disease Neuroimaging Initiative (ADNI) [2]. The dataset contains 3D T1-weighted MRI images classified into Cognitively Normal (CN), Mild Cognitive Impairment (MCI), and Alzheimer's Disease (AD) groups.

B. Preprocessing

MRI preprocessing involves skull stripping, intensity normalization, spatial registration, and resizing of MRI images to a predefined size.

C. 3D Convolutional Neural Network

The 3D CNN model is designed with a series of 3D convolutional layers followed by batch normalization, ReLU activation, and max pooling layers. These layers are responsible for extracting spatial features from three dimensions of MRI images. Fully connected layers and a softmax classifier are used for final classification.

D. Transfer Learning

Transfer learning is implemented by using the pre-trained weights of the 3D CNN model. The lower layers are frozen to preserve generic feature learning, and the higher layers are fine-tuned using Alzheimer's MRI images. This method saves training time and improves accuracy.

E. Evaluation Metrics

The performance of the model is measured using accuracy, precision, recall, F1-score, and confusion matrix analysis.

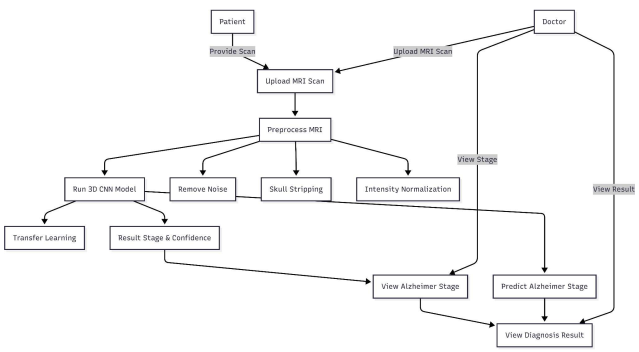

Fig. 1. Architecture of the proposed 3D Convolutional Neural Network for Alzheimer's disease classification

VIII. Dataset and Preprocessing

The MRI images used in this project were obtained from the Alzheimer's Disease Neuroimaging Initiative (ADNI) dataset [2]. The dataset includes 3D brain MRI images of normal individuals, patients with mild cognitive impairment (MCI), and patients with Alzheimer's disease. The dataset is widely used in the medical field and offers high-quality images that can be used to train deep learning models.

Before the images were passed to the model, they were carefully prepared through a preprocessing technique. First, all the MRI images were preprocessed to eliminate unwanted noise and unnecessary sections. The images were then normalized to have the same size and shape so that the model could easily process them. The intensity values of the images were also normalized to have a consistent level of data. This ensured that the model had a better learning ability and produced better and more accurate results.

IX. Implemented Details

The model was developed using a 3D deep learning model to analyze the MRI images of the brain. The first step was to clean and resize the MRI images to be used by the model. The images were then fed into the model, which was able to learn patterns associated with Alzheimer's disease. A pre-trained model was used to enhance the accuracy of the model [3]. The model was then tested using new images of the brain to determine whether the brain was normal, had MCI, or Alzheimer's disease.

X. Development Environment

The system for detecting Alzheimer's disease was implemented using the Python programming language, which is easy to work with and ideal for machine learning and data analysis. The deep learning model was implemented using TensorFlow and Keras, which are ideal for building and training neural networks [6].

Libraries such as NumPy and Pandas were utilized to efficiently handle and manage the MRI data. Jupyter Notebook was utilized as the primary working environment since it enables easy coding, testing, and visualization of results in one environment.

This software environment facilitated the development, training, and testing of the Alzheimer's disease classification model in a smooth and organized manner.

XI. Model Configuration

The system employs a 3D deep learning model to analyze MRI images of the brain. Before the images are processed by the model, they are all cleaned and resized. The model consists of various layers that enable it to learn significant patterns in the brain associated with Alzheimer's disease.

These layers help in the extraction of features and then classify the scan into Normal, MCI, or Alzheimer's. The pre-trained model is used as the base model so that the system learns faster and provides better results. The training process uses the Adam optimizer to optimize performance.

XII. Evaluation Metrics

To test the effectiveness of our Alzheimer's disease detection system, we employed a few common evaluation metrics. These metrics will give us an idea of the accuracy and reliability of our model when it scans the MRI images of the brain.

A. Accuracy

Accuracy: This measures the number of MRI scans that the system was able to classify correctly. It provides a general idea of how well the model is performing.

B. Precision

Precision: Precision measures the number of actual cases that were predicted to be Alzheimer's or MCI. Precision will give us an idea of how reliable the positive predictions are.

C. Recall

Recall is the measure of how well the system is able to identify patients who actually have the disease. High recall indicates that the system is able to miss fewer patients with Alzheimer's or MCI, which is a very important aspect of a medical diagnosis.

D. F1-Score

The F1-score is a combination of both precision and recall into a single measure. It provides a fair assessment of the performance of the model, particularly when the number of instances in each class is unequal.

E. Confusion Matrix

The confusion matrix reveals the number of MRI images that were classified correctly and incorrectly into the categories of Normal, MCI, and Alzheimer's. This will help us understand where the model is going wrong.

XIII. Results

The model was validated using MRI brain scans obtained from the ADNI database [2]. Prior to training, all images were preprocessed and resized to ensure that the model could handle them. The data was split into a training and testing set to determine the performance of the system on unseen images.

After the training process, the system was able to classify the MRI images into three categories: normal brain (CN), mild cognitive impairment (MCI), and Alzheimer's disease (AD). Because the model is able to process the full 3D image of the brain rather than slicing it, it was able to grasp the shape of the brain better. This made it easier for the system to identify small changes in the brain that are associated with Alzheimer's.

The model worked particularly well in detecting MCI patients, which are normally difficult to identify during the early stages. The results indicated fewer errors between the stages, which indicated that the system was able to distinguish between normal, early-stage, and Alzheimer-affected brains.

The use of transfer learning made the model more precise and stable. This approach aided in the faster training of the system and minimized the occurrence of mistakes due to insufficient data. In conclusion, the results validate that the proposed system is reliable and efficient for the early diagnosis of Alzheimer's disease through MRI images.

XIV. Conclusion

Overall, the paper indicates the potential for artificial intelligence to provide assistance in the actual process of diagnosis. The function has the potential to aid in quicker and more precise diagnostic decisions, the outcome thereof being better for the patients involved. Moving into the future, this avenue has the potential for improvement in a number of ways, including the addition of various types of data sets and the application of the explainability concept.

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