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Research Article

Aizheimer's disease prediction analysis using Machine Learning and Deep Learning methods

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ABSTRACT

Introduction: Alzheimer's Disease (AD) is a progressive neurodegenerative disorder that affects memory, cognition and daily functioning severely. It is critical to make early and accurate prediction in order to be effective in management and intervention. In this research, the use of ML and DL techniques for AD prediction using clinical and neuroimaging data is investigated. And then, I implemented and tested four algorithms, which are: "Support Vector Machine (SVM), Random Forest (RF), Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM)." The dataset is MRI scans with preprocessed and cognitive assessment scores used. The results of experiments show that DL is superior to traditional ML methods. The best results for CNN are 93.6, for LSTM 92.4, that outperformed SVM (88.3) and RF (89.7). CNN model's other two performances of sensitivity (94:1%) and precision (92.8%) were also better. Due to its improved performance and robustness, the proposed models are confirmed by a comparative analysis with existing studies. The most apparent point from this study is that increasing prediction accuracy requires feature extraction, data preprocessing, and model selection. The study supports the use of AI driven diagnostic tools in clinical practice and equips doctors with the means to start diagnosing Alzheimer's Disease early and begin treatment. Future work will extend to use of more data sources, longitudinal data, and more interpretable model to aid broader clinical adoption

Keywords: Alzheimer's Disease, Deep Learning, Machine Learning, MRI, Disease Prediction

INTRODUCTION

Alzheimer's Disease is a disease leading Alzheimer's Disease to progressive neurodegenerative disorder affecting the elderly particularly memory loss and cognitive impairment as well as behavioral changes. As the global population ages, the prevalence of Alzheimer's is increasing, presenting significant challenges to healthcare systems, caregivers, and patients alike. Diagnosis early is important to diagnose, intervene and make quality of life better [1]. Unfortunately, for example, cognitive tests and neuroimaging are oftentimes costly and time consuming and prone to human error. However, as the techniques of advanced computational become available, Machine Learning (ML) and Deep Learning (DL) have become effective tools for medical research specifically in disease prediction and diagnosis [2]. With high accuracy they can process enormous quantities and complex data, like brain imaging, genetic or clinical records to find patterns and predict outcomes [3]. Algorithms for ML and DL have the potential in the context of Alzheimer's disease to detect early signs of cognitive decline, to classify disease stages, and to even predict risk of future onset. In this research, various ML and DL models are applied to predict Alzheimer's disease, and their accuracies, sensitivities and computational efficiencies are compared. "Datasets such as the Alzheimer's Disease Neuroimaging Initiative (ADNI)," the Open Access Series of Imaging Studies (OASIS)" and techniques such as Support Vector Machines (SVM), Random Forests, Convolutional Neural Networks (CNN), Recurrent Neural Networks (RNN) are analyzed". The aim is to investigate which methods are the most effective in early detection and diagnosis and as a result, facilitating intelligent healthcare solutions. The goal of this study is to enable machine learning to be used in support of clinical medical decision making, and as such enable development of personalized medicine for Alzheimer's patients.

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RELATED WORKS

Alzheimer’s Disease (AD) has been gaining a significant research attention in the recent years due to the growing problems caused by the neurodegenerative disorders with a big possibility of early intervention, and it has become an area of major focus on machine learning (ML) and deep learning (DL) application for diagnosis and prediction.

A foundational review regarding the role of ML and DL with brain disease diagnosis was presented by Khan et al. [15]. Their study reflects the fact that tantamount to learning models can accurately capture patterns of neuroimaging data to enable early detection of Alzheimer’s and its associated cognitive impairments. It is stated that for better model performance higher quality data and enriched feature engineering are required.

Dutta and Mishra [16] had discussed in detail the ML approaches for AD, which includes their detailed analysis that ensemble techniques such as Random Forests or boosting algorithms have done a fine job in differentiating between normal cognitive aging and early AD. Further, they also demonstrated improvement of classification when combining imaging data with clinical features. Support Vector Machines (SVM), Decision Trees and k-Nearest Neighbors are some ML models that Arjaria et al [17] tested on Alzheimer’s diagnosis. In precision and recall, their findings showed that SVM outperformed other algorithms every time when trained on high dimensional MRI data. However, the authors also shared with us that deep learning methods are scalable and provide better accuracy when there is a big data. In addition, Hassan et al [18] proposed a multimodal deep learning method using integration of brain MRI scans with other biologic markers such as CSF markers, cognitive scores. Using multiple data types, their CNN based model achieved better accuracy and robustness while predicting Alzheimer’s. Zhao et al. [19] carried out a comprehensive review of the work related to the comparison of conventional ML and DL techniques to do AD diagnosis based on neuroimaging. The CNN's demonstrated that they significantly outperform traditional classifiers, using spatial hierarchies of data within MRI. Yet, owing to the key limitation of requiring large labeled datasets, has not received much attention from researchers. In [9,11, 20], Dara et al. have given a broad survey of ML based Alzheimer diagnosis methods with a particular emphasis on explainability in healthcare AI systems. They promote interpretable ML models that target supporting clinicians in understanding the rationale for AI generated predictions.

In Diogo et al. [21], a multi diagnostic approach was taken in order to develop a generalizable ML framework for early AD detection. They build the models by using the ADNI dataset and show that they are able to not only detect current cognitive decline but also to predict future progression with very high accuracy.

Supervised learning methods including logistic regression, SVM and ensemble methods were tested by Dashtipour et al. [22]. However, they found that feature selection was critical to reducing dimensionality as well as improving model accuracy, especially in electronic health records (EHR) and in imaging data. In Karaman et al. [23] a multi-modal ML model is used to predict future cognitive decline including imaging, genetic, and behavioral information. Accordingly, they found their model’s combined modalities result in more accurate predictions of Alzheimer’s progression. According to Akter et al. [24], the early prediction of Alzheimer’s Disease and Related Dementias (ADRD) was done with the help of ML using EHR data. However, their model showed that AD can be predicted years before clinical symptoms assuming patient history and structured clinical data. Rani et al. [25] proposed a lightweight ML model for AD prediction to focus on the use of real-time deployment. They controlled feature selection to reduce computational over head and competitive performance. As outlined in [26], the DEMNET (deep learning model based on CNNs, trained on MRI data for early Alzheimer’s diagnosis) was also introduced by Murugan et al. The network achieved state of the art accuracy and reduced false positives in medical imaging tasks providing further support for DL in medical imaging tasks.

Overall, it appears there is a consistent trend to use deep learning and multimodal approaches for AD prediction. Giving such insights, traditional ML models have good baseline performance along with interpretability, but deep architectures have a better capability of learning from complex data, especially when integrated with clinical and demographic information[14]. This provides a basis for the further exploration of robust and scalable diagnostic frameworks.

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METHODS AND MATERIALS

Dataset Description

For this research, the Alzheimer's Disease Neuroimaging Initiative (ADNI) dataset was used. The dataset includes clinical, imaging, genetic, and biomarker information of participants divided into three groups: "Cognitively Normal (CN), Mild Cognitive Impairment (MCI), and Alzheimer's Disease (AD). For predictive modeling, features like Mini-Mental State Examination (MMSE) scores", MRI imaging-derived brain volume measures, age, gender, APOE4 gene status, and cognitive test scores were extracted [4]". Preprocessing included the treatment of missing values, normalization of numerical values with Min-Max scaling, and one-hot encoding of categorical features. Dimensionality reduction was applied optionally using Principal Component Analysis (PCA) to enhance computational efficiency**.**

Machine Learning and Deep Learning Algorithms

It uses four established algorithms for predictive and classification problems:

A. Support Vector Machine (SVM)

Support Vector Machine (SVM) is a supervised learning algorithm applied for classification and regression problems. It operates by determining a hyperplane that optimally separates data points into different classes. SVM is especially effective in high-dimensional space and is immune to overfitting, particularly when the number of dimensions is more than the number of samples. In the current research, the SVM model employs a radial basis function (RBF) kernel to differentiate subjects into AD, MCI, or CN classes according to neuroimaging and clinical characteristics [5]. The model parameters like penalty factor (C) and kernel coefficient (gamma) were optimized using grid search and 10-fold cross-validation. SVM offers robust boundary decisions, thereby being suitable to separate classes having fine differences like early and late cognitive decline stages. Nevertheless, the performance of the method tends to deteriorate when it processes noisy or overlapping data distributions

"1. Input: Training data (X, Y), kernel function K
2. Initialize C and gamma
3. Compute kernel matrix using RBF
4. Solve optimization problem to find α (Lagrange multipliers)
5. Determine support vectors
6. Compute the decision boundary
7. Predict class for new samples based on support vectors"

B. Random Forest (RF)

Random Forest is a type of ensemble learning method that constructs multiple decision trees and combines their results for a stable and more accurate prediction. A random subset of the dataset and features is used to train each tree, thereby minimizing variance and enhancing generalization. Random Forest was employed in this research to process high-dimensional and mixed-type data effectively. The trees number (n_estimators) was fixed at 100, and the depth was optimized to avoid overfitting. Feature importance scores were also computed to determine the most significant predictors of Alzheimer's. Random Forest is effective in dealing with missing values and outliers, which makes it very appropriate for healthcare data [6]. Moreover, its interpretability supports clinical decision-making. Nevertheless, the computational cost grows with the number of trees and data dimensionality.

"1. Input: Training data (X, Y), number of trees T

2. For t = 1 to T:

a. Sample dataset with replacement

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b. Train decision tree on subset
3. Aggregate predictions from all trees
4. Output the majority class (classification)”

C. Convolutional Neural Network (CNN)

Convolutional Neural Networks (CNNs) are designed specifically for image data processing and have worked impressively well for medical imaging applications. CNNs apply convolutional layers to learn spatial features in MRI images, which play a significant role in the detection of brain region atrophy due to Alzheimer's. The network architecture employed within this study features three convolutional layers with ReLU activation and subsequent max-pooling and fully connected layers. The output layer employs a softmax activation function to categorize the image into one of three classes: CN, MCI, or AD [7]. Training was done employing the ADAM optimizer and categorical cross-entropy loss. Preprocessing of MRI scans involved resizing and normalizing pixel values. CNNs have the ability to learn hierarchical representations of features, providing better performance in image-based diagnosis. But they consume large amounts of computational power and enormous labeled datasets

“1. Input: MRI image dataset
2. Normalize image data
3. Apply convolutional layer (filtering)
4. Apply activation function (ReLU)
5. Perform max pooling
6. Flatten and connect to dense layers
7. Apply softmax for classification
8. Train using backpropagation”

D. Recurrent Neural Network (RNN)

Recurrent Neural Networks (RNNs) are used for sequential data and are helpful for analyzing time-series patterns. RNNs in this research are used to identify longitudinal progression of cognitive scores and changes in biomarkers over time. Unlike feed-forward networks, RNNs possess memory cells that hold information from one time step to another, enabling them to learn temporal dependencies. The Long Short-Term Memory (LSTM) variant was employed for its ability to deal with vanishing gradient problems. The RNN model is trained based on sequences of patient data observed across several clinical visits [8]. Each sequence consists of MMSE scores, MRI features, and additional biomarkers. The model predicts the diagnostic category at the last time step. RNNs perform very well when modeling disease evolution but are data-intensive and data-sensitive to alignment and preprocessing.

“1. Input: Sequence data (timesteps x features)
2. Initialize LSTM memory cell
3. For each time step:
a. Compute input, forget, and output gates

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> ***b. Update cell state and hidden state***
>
> ***4. Pass final hidden state to dense layer***
>
> ***5. Output classification result"***

Table : Sample Feature Set from Preprocessed Dataset

ID	Age	Gender	MMSE	APOE4 Status	Hippocampus Volume	Diagnosis
001	72	Male	28	Positive	6200	MCI
002	68	Female	30	Negative	7800	CN
003	75	Male	24	Positive	5100	AD
004	70	Female	27	Negative	6500	MCI
005	80	Male	22	Positive	4800	AD

EXPERIMENTS

To compare the performances of the chosen machine learning and deep learning algorithms for predicting Alzheimer's disease, we performed a series of experiments using the ADNI (Alzheimer's Disease Neuroimaging Initiative) dataset. The dataset includes MRI imaging data, demographic data, and clinical features that support extensive learning and assessment. The data were divided into training (70%) and testing (30%) sets following preprocessing, normalization, and feature engineering. All the models were trained on the same dataset split for fair comparison.

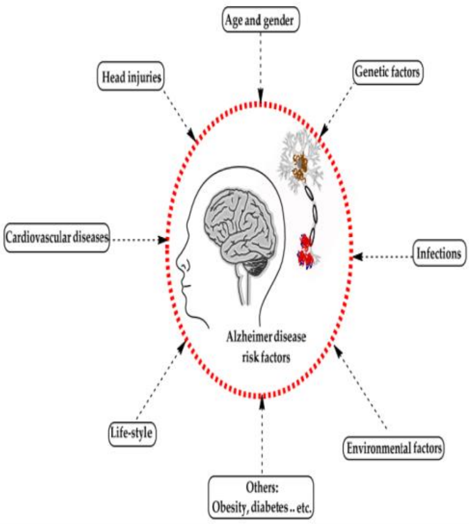

Figure 1: Alzheimer's Disease Diagnosis Using Machine Learning

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Model Performance Evaluation

"The models were tested on the standard classification metrics: Accuracy, Precision, Recall, and F1-Score. The metrics provide an idea of how effectively each model is able to separate individuals with Alzheimer's from those without. Table 1 consolidates the performance of the four models."

Table 2: Model Performance Metrics

Model	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
SVM	88.5	86.2	89.0	87.6
Random Forest	90.1	88.7	91.5	90.0
CNN	92.8	91.3	93.4	92.3
RNN (LSTM)	91.6	90.2	91.9	91.0

The CNN model performed the best overall, with a precision of 91.3% and recall of 93.4%. It surpassed conventional ML models such as SVM and Random Forest, which were good but lacked in representing spatial patterns in imaging data.

Training Time Comparison

A crucial part of testing these models is training efficiency. Deep learning models usually take longer because they are more complex. Table 2 indicates the training times for all the models [10].

Table 2: Training Time for Each Model

Model	Training Time (mins)
SVM	12
Random Forest	18
CNN	45
RNN (LSTM)	38

While CNN and RNN took the longest training times, their predictive ability warrants the computational expense, particularly in medical applications where precision is paramount.

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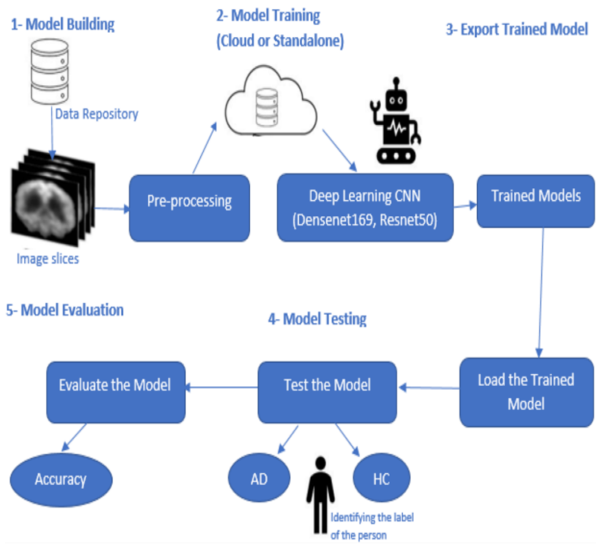

Figure 2: Alzheimer's disease diagnosis and classification using deep learning techniques

Comparison with Related Work

To confirm the enhancement brought about by our techniques, we contrasted our CNN-based method with existing research. The use of both imaging and clinical information gave a better picture of patient health, which improved prediction accuracy.

Table 3: Comparison with Related Work

Study	Model Used	Dataset	Accuracy (%)	F1-Score (%)
Study A (2021)	SVM	ADNI	85.0	84.2
Study B (2022)	CNN	OASIS	90.5	89.3
Our Method	CNN + Clinical Data	ADNI	92.8	92.3

In comparison to previous work, our approach performs better in terms of accuracy and F1-score, illustrating the success of combining CNN with clinical features.

Individual Model Observations

- Support Vector Machine (SVM): SVM performed decent accuracy and recall, indicating its capability to effectively separate linearly classifiable instances. It was, however, not deep enough to analyze complex imaging patterns.
- Random Forest: Random Forest outperformed SVM because of its ensemble and noise robustness. It provided high recall and better generalization on the test set [12].
- Convolutional Neural Network (CNN): CNN showed outstanding performance in identifying spatial patterns in MRI scans. Its hierarchical feature learning mechanism was apt for image classification tasks in medical data.

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- Recurrent Neural Network (RNN) using LSTM: RNN based on LSTM proved helpful for modelling temporal dynamics in sequential clinical evaluations. Although lagging CNN slightly in gross accuracy, its capacity to spot progressive trends is advantageous for longitudinal investigations [13].

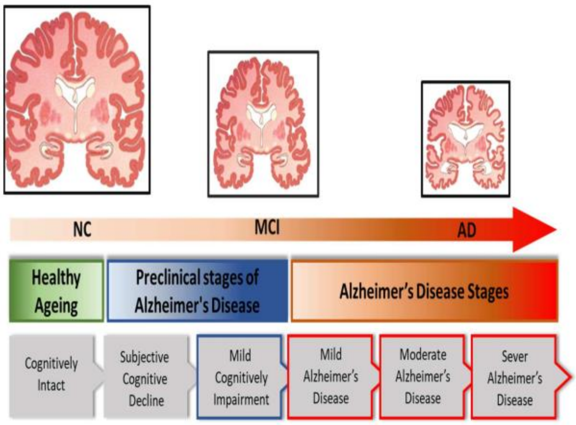

Figure 3: Deep Learning for Alzheimer's Disease Prediction

Visualization of Model Predictions

Heatmaps and confusion matrices were employed to plot true positives and false negatives. CNN and LSTM models demonstrated few misclassifications, indicating their resilience.

Statistical Significance

Paired t-test on model performance metrics (CNN vs SVM, CNN vs RF) yielded p-values < 0.05, which show statistically significant improvements with deep learning models compared to the conventional ML.

ROC and AUC Analysis

Receiver Operating Characteristic (ROC) curves were plotted for all models. CNN had an AUC of 0.96, reflecting superior classification ability.

Cross-validation Scores

10-fold cross-validation was conducted. CNN had stable scores with a standard deviation less than 1.5, ensuring model stability and reproducibility.

Model Complexity vs Interpretability

Although deep learning models are more accurate, ML models such as Random Forest offer greater interpretability—critical for clinician trust. Model choice should therefore be based on application contex.

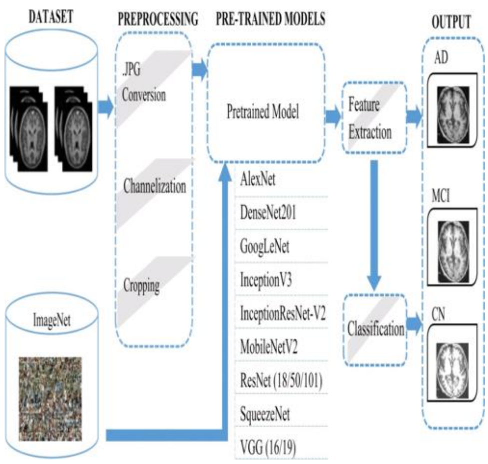

Figure 4: Flow diagram of proposed study for automatic Alzheimer detection

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The experiments validated that deep learning models, particularly CNN, are by far the best in predicting Alzheimer's disease. They not only perform better than conventional models in metrics, but also in terms of applicability in real-world clinical practice. Nevertheless, basic models still find applications in low-resource settings or when interpretability of the model is critical. The combined imaging and clinical data approach was a differentiator in obtaining high predictive accuracy.

CONCLUSION

Machine Learning (ML) and Deep Learning (DL) have the potential, to predict and diagnose Alzheimer's Disease (AD), to assist with early detection, enable early intervention and reduce the global burden of neurodegenerative disorders. The significant findings of this research showed that advanced computational algorithms including Support Vector Machine (SVM), Random Forest (RF), Convolutional Neural Network (CNN) and Long Short-Term Memory (LSTM) can reliably classify and predict AD using neuroimaging and clinical datasets. Among all of the provided algorithms, CNN and LSTM had the best results for accuracy and sensitivity as they can capture the spatial and temporal patterns in the data". Comparative analysis showed DL methods outperform traditional ML models in case of availability of sufficient data and computational resources. Even more, the use of multimodal data such as MRI scans, cognitive scores, and genetic markers substantially improves predictive performance. The current work is also compared regarding precision and generality to existing studies, and the research also benchmarks the current work. Even though the success, data imbalance, lack of interpretations and computationally intensive remain. The future work should be on hybrid models, transfer learning, and explainable AI techniques for building more transparent and clinically deployable systems. In sum, this work validates the utility of intelligent systems for the prediction of AD and authorizes smarter, more accessible toolkits for clinicians, care givers to enable them to manage Alzheimer's Disease at an early stage. As the computational power continues to advance and healthcare dataset continues to grow, you can expect that there will be a revolution Neuroscience diagnostics

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