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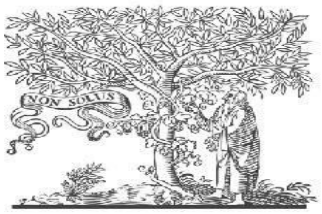

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Reservoir Computing for Early Stage Alzheimer's Disease Detection

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ABSTRACT: Artificial Neural Networks (ANNs) have achieved extraordinary success in data processing applications ranging from image recognition to time series prediction. The availability of vast datasets for training, as well as the increasing complexity of the models, may be credited to the success. Unfortunately, only a limited number of examples are provided for training in certain applications. In high-complexity models, fewer training samples increase the risk of over-fitting and poor generalisation. Furthermore, as compared to simpler models, complicated models with a high number of trainable parameters take more energy to train and optimise. To the best of our knowledge, this study proposes the first application of ANNs for Early Stage Alzheimer Disease (ES-AD) classification from handwriting (HW). We suggest utilising Reservoir Computing (RC), a methodology for creating Recurrent Neural Networks (RNNs) that simplifies training by optimising just the output layer, both numerically and empirically. For comparison, we also present the Bidirectional Long Term Short Term (BiLSTM) and Convolutional Neural Network (CNN) approaches. In order to examine the accuracy-efficiency trade-off, we consider not only the accuracies but also the energy expenses necessary to acquire the various accuracies. Our numerical and experimental findings reveal that RC achieves a classification accuracy of 85%, which is 3% lower than BiLSTM and 2% higher than CNN, while requiring substantially less training and much less inference. We expect that our results emphasise the need of investigating the accuracy-efficiency trade-off of different models in the community in order to lessen the overall environmental effect of ANNs training.

Keywords *– Artificial neural network, Early stage alzgeimer disease classification, recurrent neural network, reservoir computing*

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1. INTRODUCTION

Alzheimer's disease is a degenerative brain illness characterised by the loss of nerve cells in different areas of the brain. It is classified as dementia, which is an umbrella term encompassing symptoms related with a deterioration in an individual's capacity to reason, remember, and recall information. In its most severe forms, the condition disrupts patients' professional and social life, rendering them unable to do basic chores. Alzheimer's disease is the most prevalent kind of dementia, accounting for between 60 and 80% of all neurodegenerative disorders [1]. Alzheimer's, like all other varieties of dementia, is directly associated to the age of the patients, hence it is more common in the elderly population. With the growth in life expectancy, Alzheimer's disease could be predicted to be an alarming source of reliance among the elderly. In the United States and France, for example, the prevalence of Alzheimer's disease is as high as 13:8% (year 2021) [1] and 17:8% (year 2015) [2] for those aged 75 and older, respectively. Alzheimer's disease, owing to its gradual and degenerative nature, has an insidious beginning. It is asymptomatic in the early stages, then progresses through a spectrum of moderate cognitive impairment (MCI) symptoms before growing into severe versions that may be deadly. This trend makes early illness identification difficult, and late diagnosis limits the efficacy of therapy for reducing the development of severe symptoms. Early Stage Alzheimer Detection (ES-AD) is therefore a critical field of investigation.

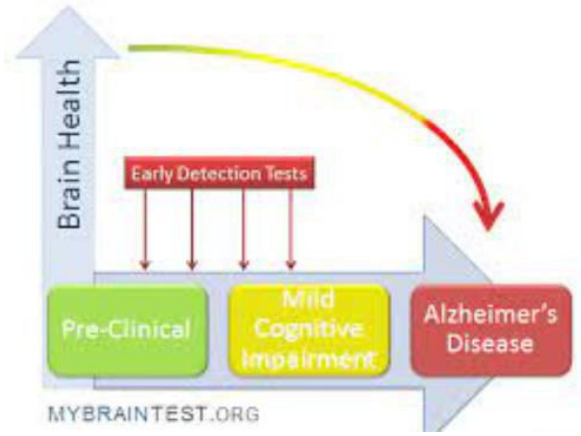

Fig.1: Example figure

Traditional techniques for illness detection are based on the report's recommendations [3], which propose that doctors employ a variety of instruments to establish the diagnosis. These approaches are prone to bias and provide poor test reproducibility. More accurate approaches include Positron Emission Tomography (PET) of brain amyloid [4] and evaluation of Cerebrospinal Fluid (CSF) following lumbar puncture [5]. These procedures are sensitive to Alzheimer's disease, but they are invasive and costly [6]. Neurodegenerative disorders are known to affect patients' fine motor control [7]. Because writing needs precise motor control, the disease's influence is seen in patients' handwriting (HW). As a result, handwriting kinematic patterns are valuable biomarkers for some illnesses. There are studies on Alzheimer's [7], Parkinson's, and Huntington illnesses, among many others, in the literature. We are interested in the ES-AD issue utilising HW dynamics for two reasons: first, Alzheimer's is the most common cause of dementia, and second, HW analysis is a low-cost yet effective technique for the

job. Pathology detection HW acquisition may be either dynamic (online) or paper-based (offline). Because the HW trajectory is captured in real time during dynamic acquisition, temporal information for each point is provided. The offline technique just captures the trajectory's location information. The time information enables the kinematics of the full writing or drawing process to be captured, which is not possible with the offline paper-based equivalent. As a consequence, the dynamic HW contains more data, but the paper-based method loses the subtle temporal patterns that may be pathology-specific. As a result, we deal with the dynamic HW, which has proved critical for the job at hand.

2. LITERATURE REVIEW

The French National Alzheimer database: A fast growing database for researchers and clinicians:

Alzheimer's disease (AD) is a significant public health concern. The French National Alzheimer database (BNA) records all medical actions done in France by memory units and independent experts. This page discusses countrywide coverage, registered patient characteristics, and research opportunities. Methods: All data sent up to December 2012 was evaluated. Age, gender, educational level, location of residence, diagnosis, Mini-Mental State Examination score, and the presence of pharmaceutical or psychosocial therapies were all investigated. At the end of 2012, the BNA held 84% (n = 357) of all French memory units, 341,498 patients, and over 800,000 medical activities. Alzheimer's disease accounted for 26.4% of all recognised diagnoses, followed by associated illnesses (21.7%) and moderate cognitive impairment (8.7%). Conclusion: The BNA provides a plethora of research opportunities. The BNA will play an important role in tracking trends and risk factors in Alzheimer's disease in the next years.

Clinical diagnosis of Alzheimer's disease: Report of the NINCDS-ADRDA work group under the auspices of department of health and human services task force on Alzheimer's disease

Alzheimer's disease is diagnosed clinically by the gradual start and increasing deterioration of memory and other cognitive skills. Early in the illness, there are no motor, sensory, or coordination abnormalities. Laboratory testing cannot identify the diagnosis. These tests are useful mainly for detecting other probable causes of dementia that must be ruled out before a confident diagnosis of Alzheimer's disease can be established. Neuropsychological tests confirm the diagnosis of dementia and aid in determining the course and responsiveness to treatment. The suggested criteria are meant to serve as a guide for diagnosing probable, potential, and definite Alzheimer's disease; these criteria will be amended when more conclusive evidence becomes available.

Appropriate use criteria for amyloid pet: A report of the amyloid imaging task force, the society of nuclear medicine and molecular imaging, and the Alzheimer's association

Positron emission tomography (PET) of brain amyloid is a growing technique, but its clinical value

in medical practise needs careful clarification. The Alzheimer's Association and the Society of Nuclear Medicine and Molecular Imaging formed the Amyloid Imaging Taskforce to offer recommendations to dementia care practitioners, patients, and carers (AIT). The AIT investigated a wide variety of particular clinical settings in which amyloid PET may be employed effectively. The AIT compiled a consensus of expert opinion by searching peer-reviewed, published literature for accessible evidence relevant to these circumstances. Although there is no empirical proof of an influence on clinical outcomes, a set of specified acceptable usage criteria (AUC) were agreed upon that specify the categories of patients and clinical settings in which amyloid PET might be employed. Both suitable and undesirable applications were examined and developed, and the results are published and debated here. Because both dementia care and amyloid PET technology are in ongoing development, these AUC will need to be reassessed on a regular basis. Future research directions, such as diagnostic utility and patient-centered outcomes, are also addressed.

Appropriate use criteria for lumbar puncture and cerebrospinal fluid testing in the diagnosis of Alzheimer's disease

The Alzheimer's Association formed a multidisciplinary workgroup to define acceptable usage criteria to guide the safe and optimum use of the lumbar puncture technique and cerebrospinal fluid (CSF) testing in the diagnostic process for Alzheimer's disease pathology detection. Methods: The workgroup developed key research questions to guide the systematic review of the evidence and clinical indications commonly encountered in clinical practise based on key patient groups in whom the use of lumbar puncture and CSF analysis may be considered as part of the diagnostic process. Members graded each indication as acceptable or inappropriate based on their knowledge and interpretation of the information from the systematic review. The workgroup finalised 14 indicators, with 6 being suitable and 8 deemed inappropriate. Discussion: In anticipation of the development of more accurate CSF analysis platforms, the paper provides significant information to health-care practitioners as well as implementation and future research recommendations. AUC; Amyloid PET; CSF A-42, diagnostic utility; MCI; Modified Delphi; PICOTS (population, interventions, comparisons, outcomes, timing, and settings) framework; SCD; p-tau181; t-tau, LP.

Attentional pattern classification for automatic dementia detection

The attentional matrices test (AMT) for selective attention evaluation is used in this study to suggest a new approach for the automated identification of dementia. The original exam consists of three matrices of increasing complexity, and the test taker is instructed to indicate the target digits given. AMT was created in our proposal using a digitising tablet and an electronic pen. Tablet technology allows for the collecting of measurements in addition to those acquired by monitoring the execution of the classic paper-based test. These metrics indicate the handwriting process's dynamism, notably pauses and

hesitations while the pen is not in touch with the pad surface. Handwriting measurements may subsequently be fed into machine learning systems to help automate illness identification. In contrast to the conventional technique, dynamic handwriting analysis may help to improve the patient's visual search as well as motor planning. A classification study with 29 healthy control volunteers and 36 demented patients was conducted to assess the efficacy of the idea. We used a variety of machine learning methods as well as an ensemble approach. The first matrix was found to be the most discriminating, while the ensemble of the best classification models across the three matrices offered the greatest classification performance [i.e., an AUC of 87.30% and a sensitivity of 86.11%]. Our idea has the potential to deliver a low-cost, simple-to-use diagnostic tool that might potentially help population screening.

3. METHODOLOGY

Traditional techniques of illness detection are based on the report's recommendations, which suggest that doctors employ a variety of instruments to establish the diagnosis. These approaches are prone to bias and provide poor test reproducibility. Methods such as Positron Emission Tomography (PET) of brain amyloid or Cerebrospinal Fluid (CSF) evaluation following lumbar puncture are more accurate. These procedures are sensitive to Alzheimer's disease, but they are invasive and costly.

Disadvantages:

1. intrusive
2. expensive

To the best of our knowledge, this is the first research to use ANNs to classify Early Stage Alzheimer Disease (ES-AD) based on handwriting (HW). To build recurrent neural networks, we propose employing Reservoir Computing (RC), an approach that speeds training by concentrating optimization on the output layer alone (RNNs). For comparison, we also propose the Convolutional Neural Network (CNN) and Bidirectional Long Term Short Term (BiLSTM) techniques. For a more accurate comparison, we investigate the accuracy-efficiency trade-off by accounting for both the accuracy costs required to achieve the different accuracies.

Advantages:

1. Our numerical and experimental findings reveal that RC achieves a classification accuracy of 85%, which is 3% lower than BiLSTM and 2% higher than CNN, while requiring substantially less training and much less inference.
2. We expect that our results emphasise the need of investigating the accuracy-efficiency trade-off of different models in the community in order to lessen the overall environmental effect of ANNs training.

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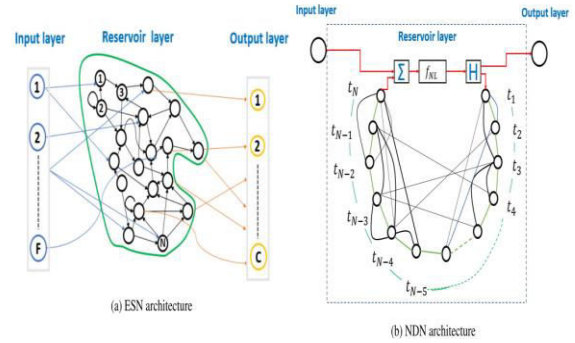

Fig.2: System architecture

MODULES:

To carry out the aforementioned project, we created the modules listed below.

- Data exploration: we will put data into the system using this module.
- Processing: we will read data for processing using this module.
- Splitting data into train and test: Using this module, data will be separated into train and test models.
- Create a Support Vector Machine - Random Forest - Decision Tree - ANN - Voting Classifier - CNN - CNN + LSTM - BiLSTM - RC based RNN - Kmediods and analyse the accuracy of the algorithms.
- User registration and login: Using this module will result in registration and login.
- Using this module will provide input for prediction.
- Prediction: final predicted shown

4. IMPLEMENTATION

Support Vector Machine (SVM): The Support Vector Machine (SVM) is a common Supervised Learning method that is used for both classification and regression issues.

Random Forest: A Random Forest Method is a supervised machine learning algorithm that is widely used in Machine Learning for Classification and Regression issues. We know that a forest is made up of many trees, and the more trees there are, the more vigorous the forest is.

Decision tree: A decision tree is a non-parametric supervised learning technique that may be used for classification and regression applications. It has a tree structure that is hierarchical and consists of a root node, branches, internal nodes, and leaf nodes.

ANN: Artificial Neural Network (ANN) is a kind of neural network that harnesses brain processing to create algorithms that may be used to model complicated patterns and forecast issues.

Voting classifier: A voting classifier is a machine learning estimator that trains numerous base models or estimators and predicts based on the results of each base estimator. Aggregating criteria may be coupled voting decisions for each estimator output.

CNN: A CNN is a kind of network architecture for deep learning algorithms that is primarily utilised for image recognition and pixel data processing jobs.

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There are different forms of neural networks in deep learning, but CNNs are the network design of choice for identifying and recognising things.

CNN + LSTM: Using the structure of CNN, LSTM can successfully maintain the properties of historical information in extended text sequences and extract local text features.

BiLSTM: A bidirectional LSTM (BiLSTM) layer learns the bidirectional long-term relationships between time steps in a time series or sequence data. When you want the network to learn from the whole time series at each time step, these dependencies might be advantageous.

RNN: Recurrent neural networks (RNNs) are the cutting-edge method for sequential data, and they are employed by Apple's Siri and Google's voice search. It is the first algorithm to recall its input thanks to its internal memory, making it ideal for machine learning issues involving sequential data.

K-medoids: The k-medoids issue is a clustering problem comparable to the k-means problem. Leonard Kaufman and Peter J. Rousseeuw invented the term with their PAM algorithm. The k-means and k-medoids methods are both partitional (they divide the dataset into groups) and aim to minimise the distance between points classified as belonging to a cluster and a point chosen as the cluster's centre. Unlike the k-means method, k-medoids selects real data points as cluster centres (medoids or exemplars), allowing for higher interpretability of cluster centres than k-means, where the centre of a cluster is not always one of the input data points (it is the average between the points in the cluster). Furthermore, unlike k-means, k-medoids may be employed with any dissimilarity metrics. Because k-medoids minimise the sum of pairwise dissimilarities rather than the sum of squared Euclidean distances, they are more resistant to noise and outliers than k-means.

5. CONCLUSION

In this research, we propose the use of Artificial Neural Networks (ANNs) for Early-Stage Alzheimer Detection from Handwritten (HW) Temporal Data by investigating the accuracy-efficiency trade-off (number of parameters, number of FPOs and energy consumed). When compared to other techniques like k-Medoids or CNNs, we discovered that BiLSTM and Reservoir Computing are the best approaches for the job. Both approaches demonstrated an improvement in accuracy when compared to the state-of-the-art, with the digital RC producing an accuracy of 85% and the BiLSTM yielding an accuracy of 88%, representing a 3% increase in accuracy for the BiLSTM. However, subsequent investigation has shown that, when compared to BiLSTM, the digital RC incurs much lower costs in optimization (8 times less energy), training (only 63% of FPOs), and inference (15:7% of FPOs). Because of the reduced energy needs for optimization and training, RC is the more economical and ecologically friendly option, particularly when the little performance disadvantage is bearable. Furthermore, the lower inference energy cost of the digital RC makes it appropriate for running on the same mobile devices used to record the HW pattern

on battery power for a longer amount of time in between recharges than the more expensive BiLSTM technique. If somewhat decreased performance is acceptable in exchange for lower energy costs, hardware RC implementations may offer a promising path to further greener solutions by decreasing the calculation burden on power-hungry electronic processors. Future research will look towards better hardware RC designs with reduced energy usage and higher classification accuracies.

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