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RESERVOIR COMPUTING FOR EARLY STAGE ALZHEIMER'S DISEASE DETECTION

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ABSTRACT: In data processing applications ranging from image identification to time series prediction, Artificial Neural Networks (ANNs) have achieved amazing success. The availability of enormous datasets for training, as well as the rising complexity of the models, may be contributed to the success. Sadly, only a limited number of examples are available for training in some applications. With high-complexity models, fewer training samples increase the risk of over-fitting and poor generalisation. In addition, complex models with a large number of trainable parameters need more energy to train and optimise than simpler models. To the best of our knowledge, this work presents the first use of ANNs for Early Stage Alzheimer Disease (ES-AD) classification from handwriting (HW) (HW). We advocate leveraging Reservoir Computing (RC), a way for building Recurrent Neural Networks (RNNs) that simplifies training by optimising only the output layer, both numerically and experimentally. We also provide the Bidirectional Long Term Short Term (BiLSTM) and Convolutional Neural Network (CNN) techniques for comparison. In order to assess the accuracy-efficiency trade-off, we consider not only the accuracies but also the energy costs required to attain the different accuracies. RC obtains a classification accuracy of 85%, which is 3% lower than BiLSTM and 2% better than CNN, but needing significantly less training and inference. We anticipate that our findings will highlight the necessity to investigate the accuracy-efficiency trade-off of various models in the community so as to reduce the overall environmental impact of ANNs training.

Keywords *– Artificial neural network, categorization of early-stage Alzheimer's disease, recurrent neural network, and reservoir computing*

1. INTRODUCTION

Alzheimer's disease is a neurodegenerative disorder characterised by the death of nerve cells in various brain regions. It is classed as dementia, which is an umbrella term comprising symptoms associated with a decline in a person's reasoning, memory, and recall abilities. In its most severe manifestations, the illness interferes with patients' work and social lives and renders them incapable of doing simple activities. Alzheimer's disease is the most common form of dementia, accounting for 60 to 80 percent of all

neurodegenerative diseases [1]. Alzheimer's disease, like all other forms of dementia, is directly related to the patient's age; thus, it is more prevalent in the senior population. Alzheimer's illness might become a worrisome source of dependency among the elderly as life expectancy increases. In the United States and France, for example, the prevalence of Alzheimer's disease among individuals aged 75 and older is as high as 13.8% (year 2021) [1] and 17.8% (year 2015) [2] respectively. Due to its slow and degenerative character, Alzheimer's disease has an insidious onset. Initially asymptomatic, it advances through a range of moderate cognitive impairment (MCI) symptoms before becoming potentially fatal severe forms. This tendency makes early disease identification difficult, and late diagnosis reduces the effectiveness of treatment in preventing the onset of severe symptoms. Diagnosis of Alzheimer's at an Early Stage (ES-AD) is thus a crucial area of research.

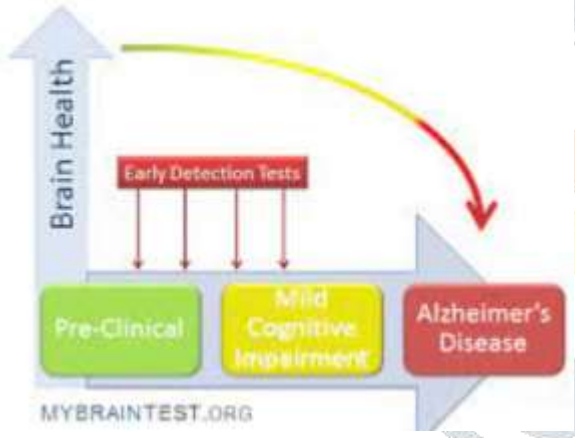

Fig.1: Example figure

Conventional procedures for disease detection are based on the report's [3] recommendations, which advise that physicians use a range of diagnostic tools. These methods are susceptible to bias and have low test repeatability. Positron Emission Tomography (PET) of brain amyloid [4] and measurement of Cerebrospinal Fluid (CSF) after lumbar puncture [5] are more precise methods. These techniques are sensitive to Alzheimer's disease, but intrusive and expensive [6]. Fine motor control is known to be impaired by neurodegenerative diseases [7] Since writing requires fine motor control, the condition manifests itself in the handwriting of sufferers (HW). Hence, handwriting kinematic patterns are useful indicators for some diseases. The literature include research on Alzheimer's [7], Parkinson's, and Huntington diseases, among many others. We are interested in the ES-AD problem using HW dynamics for two reasons: first, Alzheimer's disease is the most prevalent cause of dementia, and second, HW analysis is a low-cost yet effective approach for the task. Acquisition of pathology detection HW may be either dynamic (online) or on paper (offline). During dynamic acquisition, the HW trajectory is acquired in real time, hence temporal information is supplied for each location. The offline method just records the trajectory's position data. The temporal information permits the capturing of the kinematics of the whole writing or drawing process, which is not achievable with paper-based alternatives. As a result, the dynamic HW has more data, but the paper-based technique lacks pathology-specific delicate temporal patterns. As a consequence, we must deal with the dynamic HW, which has proven essential for the current task.

2. LITERATURE REVIEW

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

Alzheimer's disease (AD) poses a severe threat to public health. The French National Alzheimer database (BNA) documents all medical procedures performed in France by memory units and independent specialists. This article examines national coverage, registered patient characteristics, and potential for research. Methods: Every data sent until December 2012 was analysed. Age, gender, degree of education, place of residence, diagnosis, Mini-Mental State Examination score, and presence of pharmacological or psychosocial treatments were all evaluated. The BNA had 84% (n = 357) of all French memory units, 341 498 patients, and over 800,000 medical actions as of the end of 2012. Alzheimer's disease represented 26.4% of all recognised diagnoses, followed by related diseases (21.7%) and mild cognitive impairment (8.2%). The BNA offers a vast number of research options. In the next years, the BNA will play a significant role in monitoring Alzheimer's disease trends and risk factors.

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 clinically diagnosed by the slow onset and progressive decline of memory and other cognitive abilities. There are no motor, sensory, or coordination problems in the early stages of the disease. Laboratory tests cannot diagnose the condition. Before a solid diagnosis of Alzheimer's disease can be made, these tests are mostly helpful for discovering other possible causes of dementia that must be ruled out. Neuropsychological tests confirm the diagnosis of dementia and help determine its progression and treatment response. These criteria will be revised as more solid information 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 rising method, however its therapeutic significance must be clarified. Amyloid Imaging Taskforce was founded by the Alzheimer's Association and the Society of Nuclear Medicine and Molecular Imaging to make recommendations to dementia care practitioners, patients, and carers (AIT). The AIT explored a vast array of specific therapeutic scenarios in which amyloid PET may be used successfully. The AIT established a consensus of expert opinion by scouring the peer-reviewed, published literature for evidence pertinent to these situations that was easily available. While there is no empirical evidence of a correlation between amyloid PET and clinical outcomes, a set of acceptable use criteria (AUC) has been established to define the types of individuals and therapeutic circumstances in which amyloid PET may be utilised. Examined and created were both desired and unwanted uses, and the findings are presented and discussed here. Due to the continual improvement of dementia treatment and amyloid PET technologies, this AUC will need to be reevaluated often. Future research objectives are also discussed, including diagnostic utility and patient-centered outcomes.

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

The Alzheimer's Association established a multidisciplinary committee to determine acceptable use criteria for the safe and optimal use of the lumbar puncture method and cerebrospinal fluid (CSF) testing in the Alzheimer's disease pathology detection diagnostic procedure. Methods: The workgroup created key research questions to lead the systematic examination of the evidence and clinical indications typically seen in clinical practise, based on major patient categories for whom lumbar puncture and CSF analysis may be regarded as a diagnostic tool. On the basis of their expertise and interpretation of the data from the systematic review, members rated each indication as acceptable or unsuitable. The workgroup concluded 14 indications, of which six were declared acceptable and eight were ruled undesirable. In anticipation of the development of more precise CSF analysis systems, this report gives vital information to healthcare professionals as well as implementation and future research suggestions. AUC; Amyloid PET; CSF A-42, diagnostic usefulness; MCI; Modified Delphi; framework for PICOTS (population, interventions, comparisons, outcomes, timing, and settings); SCD; p-tau181; t-tau, LP.

Attentional pattern classification for automatic dementia detection

This work employs the attentional matrices test (AMT) for selective attention assessment to propose a novel method for the automated detection of dementia. The original exam consisted of three increasingly complicated matrices, and the test-taker is expected to identify the supplied target numbers. In our idea, AMT was constructed utilising a digitising tablet and an electronic pen. Tablet technology enables the collection of measures in addition to those obtained by observing the execution of the traditional paper-based exam. These measurements highlight the dynamic nature of the handwriting process, namely pauses and hesitations when the pen is not in contact with the pad surface. Eventually, handwriting measures may be incorporated into machine learning algorithms to automate disease detection. In contrast

to traditional methods, dynamic handwriting analysis has the potential to enhance both the patient's visual search and motor planning. To evaluate the effectiveness of the concept, a classification research including 29 healthy control volunteers and 36 dementia patients was undertaken. We used a number of machine learning techniques including an ensemble approach. The first matrix was determined to be the most discriminating, while the ensemble of the best classification models across all three matrices provided the highest classification performance [i.e., an AUC of 87.30% and a sensitivity of 86.11%). Our concept has the potential to provide a low-cost, easy-to-use diagnostic instrument that might aid in population screening.

3. METHODOLOGY

Conventional methods of disease detection are based on the report's recommendations, which recommended that physicians use a range of diagnostic tools. These methods are susceptible to bias and have low test repeatability. More accurate techniques include Positron Emission Tomography (PET) of brain amyloid and Cerebrospinal Fluid (CSF) examination after lumbar puncture. These techniques are sensitive to Alzheimer's disease, but intrusive and expensive.

Disadvantages:

1. invasive
2. costly

This is the first study to our knowledge to employ ANNs to categorise Early Stage Alzheimer Disease (ES-AD) based on handwriting (HW). Reservoir Computation (RC) is a method for building recurrent neural networks that accelerates training by focussing optimization on the output layer alone (RNNs). We also suggest the Convolutional Neural Network (CNN) and Bidirectional Long Term Short Term (BiLSTM) approaches for comparison. For a more precise comparison, we analyse the accuracy-efficiency trade-off by taking into account both the accuracy costs necessary to attain the various accuracies.

Advantages:

1. According to our numerical and experimental data, RC achieves a classification accuracy of 85%, which is 3% lower than BiLSTM and 2% higher than CNN, while needing much less training and inference.
2. We anticipate that our findings will highlight the necessity to investigate the accuracy-efficiency trade-off of various models in the community so as to reduce the overall environmental impact of ANNs training.

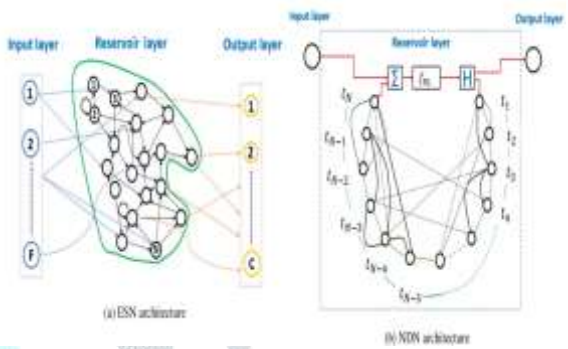

Fig.2: System architecture

MODULES:

For the aforementioned project, we developed the following modules.

- Data exploration: utilising this module, we will enter data into the system.
- Processing: utilising this module, we will read data for processing.
- Separating data into train and test models: This module separates data into train and test models.
- Construct a Support Vector Machine - Random Forest - Decision Tree - Artificial Neural Network - Voting Classifier - CNN - CNN + LSTM - BiLSTM - RC based RNN - Kmediods and evaluate the accuracy of the algorithms.
- Registration and login for users: Using this module will result in registration and login.

- Using this module will contribute to prediction.
- Prediction: displayed final predicted

4. IMPLEMENTATION

Support Vector Machine (SVM): Support Vector Machine (SVM) is a typical approach of Supervised Learning used for both classification and regression problems.

Random Forest: A Random Forest Method is a supervised machine learning technique used extensively in Machine Learning for Classification and Regression problems. We know that a forest is composed of many trees, and that the greater the number of trees, the more robust the forest.

Decision tree: A decision tree is a non-parametric supervised learning method that may be used to classification and regression problems. It features a hierarchical tree structure comprised of a root node, branches, internal nodes, and leaf nodes.

ANN: Artificial Neural Network (ANN) is a kind of neural network that utilises brain processing to generate algorithms that may be used to model complex patterns and predict problems.

Voting classifier: A voting classifier is a machine learning estimator that trains and predicts depending on the outcomes of many base models or estimators. Voting choices may be paired with aggregating criteria for each estimator output.

CNN: CNNs are often used for image recognition and pixel data processing. In deep learning, there are several types of neural networks, but CNNs are the preferred network architecture for identifying and recognising objects.

CNN + LSTM: LSTM can effectively retain the qualities of historical information in longer text sequences and extract local text features by using the structure of CNN.

BiLSTM: A bidirectional LSTM (BiLSTM) layer discovers the long-term bidirectional correlations between time steps in a time series or sequence data. These dependencies may be helpful when you want the network to learn from the whole time series at every time step.

RNN: Recurrent neural networks (RNNs) are the cutting-edge technique processing sequential data, and Siri and voice search on Google use them. It is the first algorithm with an internal memory that allows it to remember its input, making it perfect for machine learning problems requiring sequential data.

K-medoids: The k-medoids problem is a clustering challenge similar to the k-means issue. With their PAM algorithm, Leonard Kaufman and Peter J. Rousseeuw developed the word. Both k-means and k-medoids are partitional (they split the dataset into groups) and try to decrease the distance between points labelled as belonging to a cluster and the cluster's centre. k-medoids, unlike k-means, picks genuine data points as cluster centres (medoids or exemplars), providing for more interpretability of cluster centres than k-means, where the centre of a cluster is not necessarily one of the input data points (it is the average between the points in the cluster). In addition, unlike k-means, k-medoids may be used to any dissimilarity measure. k-medoids are more robust to noise and outliers than k-means because they minimise the sum of pairwise dissimilarities instead of the sum of squared Euclidean distances.

5. EXPERIMENTAL RESULTS

Fig 3 Home Page

Fig 4 Register Form

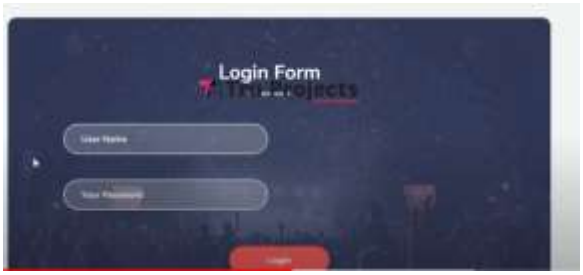

Fig 5 Login form

Fig 6 Input Image

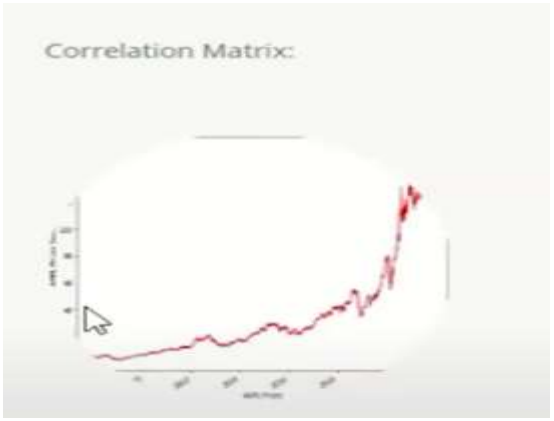

Fig 7 Correlation Matrix

Fig 8 Input Values

Fig 9 Predicted Result

6. CONCLUSION

In this study, we investigate the accuracy-efficiency tradeoff of Artificial Neural Networks (ANNs) for Early-Stage Alzheimer Diagnosis using Handwritten (HW) Temporal Data (number of parameters, number of FPOs and energy consumed). Compared to alternative methods such as k-Medoids or CNNs, we found that BiLSTM and Reservoir Computing are the most effective ways for this task. The digital RC achieved an accuracy of 85%, whilst the BiLSTM achieved an accuracy of 88%, a 3% increase in accuracy for the BiLSTM. Nevertheless, later research has shown that the digital RC incurs far lower costs than BiLSTM for optimization (eight times less energy), training (only 63% of FPOs), and inference (15:7% of FPOs). Because to the decreased energy requirements for optimization and training, RC is the more cost-effective and environmentally friendly alternative, especially when the little performance penalty is tolerable. Furthermore, the lower inference energy cost of the digital RC makes it suitable for operating on the same mobile devices used to record the HW pattern on battery power for a longer period of time between recharges than the costlier BiLSTM approach. If reduced performance in return for lower energy costs is acceptable, hardware RC implementations may provide a viable route to future greener solutions by reducing the computation load on energy-hungry electronic processors. Future study will target improved hardware RC designs with lower energy consumption and greater classification precision.

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