

Non-Invasive Machine Learning Classification Models for Early Alzheimer's disease Detection

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Abstract—Machine Learning is mainly concerned with the development of algorithms that allow a computer to learn from the data and past experiences on their own. It has a great scope in healthcare, as healthcare is becoming more personalized. Here we will apply machine learning in Alzheimer's. Alzheimer's disease also known by the term AD, is a prevailing neurodegenerative disorder that attacks the cognitive skills as well as the memory of human beings. While there is no known treatment for cure, the earlier detection becomes the need of time. Also, earlier detection of its symptoms may result in a less expensive and timelier diagnosis. As the disease makes it difficult for the patient to do even the daily activities, taking actions to fight against Alzheimer's will benefit in increasing the independence of patients and quality of life if detected earlier. In this paper, a review of some simple non-invasive machine learning classification techniques is done where the prediction of disease is done based on verbal and non-verbal communication data of subjects. This data is very easy to get from the subject and so these techniques are harmless, very economical, and can help in diagnosis much earlier as compared to other techniques. After review, it is concluded that these techniques are very much efficient. Future research on these techniques may help in increased accuracy of diagnosis which may help the subjects to catch the symptoms very much earlier and save their conditions from deteriorating further.

Index Terms— Alzheimer's disease detection, Non -Invasive, Machine learning, Classification, smart home, speech analysis, and virtual environment.

I. INTRODUCTION

Dementia: A syndrome mainly characterized by the deterioration of mental skills such as memory, reasoning, language, or perceptual interpretation [8]. Alzheimer's disease is a general form of dementia that has made a vast population of elders to get affected. It is a neurodegenerative disease, which is characterized by the progressive degeneration of emotional, cognitive, and language disorders. It is a chronic and irreversible disease that strikes the brain cells and steers towards the impairment of mental functioning.

The disorder usually advances in three phases. Mild cognitive impairment (MCI) phase, moderate phase, and severe phase [2]. In the mild phase, patients face difficulties in recalling words, administration, and performing chores on their own. In the moderate phase, patients struggle in recalling their past. The alterations in self-control, the perplexing of the time and place they are in, can also be noticed in the patients. In the severe phase,

even the body movements become difficult. It disables the person to walk, sit, etc. And patients need a complete look after for their basic needs. The cognitive impairment also leads to emotional and behavioral impairments. Presently, around 4 million Indian elder citizens and 44 million overseas elder citizens are afflicted by this disease [3]. According to the estimations done so far, around 115 million adults are going to be afflicted by this by 2050, which can result in dreadful after-effects. It will affect the healthcare economy and the quality of life of patients.

The diagnosis of the disease needs much time for the patient, caretaker, and also the health workforce. The dependency and the requirements increase as we delay the treatment. Hence It's essential to detect AD in the very early stages to reduce the process of decay. Also, AD has no proper cure but some treatments are there that can help in delaying the symptoms if we can detect them early and start the diagnosis on time.

Technology such as Virtual Reality provides the recovery methods to obstruct this deterioration speed, to make sure the normal life of patients, and to maintain the enthusiasm of independent life for the elderly [11].

Our study aims to detect changes in brain function before people are aware that they have them. The study highlights the potential of new technology i.e. Machine learning, to help diagnose and monitor the disease symptoms.

Multiple invasive, as well as non-invasive tests, are there for the detection of Alzheimer's. Invasive techniques demand data from within the person's body using tests. These tests are much vulnerable for the patients and few of them are unbearable [1]. Also most of the time, they are not done in earlier stages of the disease as the early symptoms of the disease are often confused with that of old age changes, and its onset is often missed. On the contrary, non-invasive tests are quite safe and secure.

A medical procedure is defined as a non-invasive procedure when it does not require an incision into the body or any removal of tissue. There is no break into the skin or internal body. Although few tests may need peripheral devices, these non-invasive techniques are favorable for the patients for the diagnosis process. Non-invasive techniques have many benefits apart from this. We can detect the disease in its natural and early state as it mainly requires the monitoring of the patient's activities, communication, etc. Further, it will help in finding the potential treatment for the patient.

This paper provides a review of very simple non-invasive techniques that can be used for the prediction of Alzheimer's Disease (AD). These techniques are very economical and based on verbal and non-verbal communication of the persons. They include:

- a. Smart homes
- b. Speech analysis
- c. Assessment in Virtual Environment

The smart home technique focuses on the daily routine activities of the persons. Speech analysis works on features related to a person's speech; his/her way of communication; halts or pauses the person takes in communication etc. Virtual Environment as the name suggests is a 3D virtual environment but it will immerse the user in its world and then assesses the person. The assessments may include memory tests, navigation tests, etc.

The paper is subdivided into 4 further sections. Section 2 describes the role of machine learning in the detection system. Machine learning is the new technology being used in developing intelligent machines. These machines can take decisions by learning from previous data. Section 3 covers the related work done in the detection of disease using non-invasive methods. This part will describe the works procedures and their efficiency of detection. In section 4, the comparison of detection techniques is shown. The comparison table shows the accuracy metrics of different studies and some remarks are given related to those studies. And finally, section 5 will summarize the study by comparing the techniques based on parameters of analysis and pave way for future research.

II. ROLE OF MACHINE LEARNING

Artificial Intelligence, AI, is a field that is used to create intelligent machines that can learn the works by demonstrations. Machine learning is a sub-discipline of AI. Machine learning is a growing technology that enables computers to learn automatically from past data. Machine learning uses various algorithms for building mathematical models and making predictions using historical data or information. The more we will provide the information, the higher will be the performance.

Generally, Machine learning can be classified into three types: Supervised learning, Unsupervised learning, Reinforcement learning. Supervised learning requires a training data set, i.e, a set of instances that has labels associated with it. Therefore, the model will learn patterns, features, or structures that define a specific label.

The goal of supervised learning is to map input data with the output data. In unsupervised scenarios, these labels are not available, so the goal is to identify and explore structures and patterns presented in the data. Reinforcement learning is a feedback-based learning method, in which a learning model gets the feedback whether the output received is desired or not. The model learns automatically with this feedbacks and improves its performance.

There is a wide range of applications of machine learning. One of the applications is Pattern Recognition. It tries to identify the pattern i.e. a kind of regularity or trend in data.

Pattern Recognition enables a machine to recognize the structure or pattern from the datasets using Machine learning Algorithms and this structure is improved as the size of datasets is increased. It is used in many fields such as medical diagnosis, nuclear energy, stock trading, and others [5].

III. LITERATURE SURVEY

A thorough literature survey has been conducted on detection of Alzheimer's disease early using simple non-invasive techniques. Machine learning has also been applied to different kinds of datasets, available through different platforms, to detect it. We have tried to cover the following non-invasive machine learning methods:

- A. Based on smart homes
- B. Based on Speech processing
- C. Based on Virtual Environment tests

A. Based on Smart Homes

The first approach tries to predict the disease symptoms by evaluating the daily activities of persons. Persons are on continuous observation under discreet sensors [1]. These sensors capture the person's activities and provide this capture data known as smart data which is processed and analyzed by the system.

The Study by Harish [9] works mainly on detecting the depression and anxiety state of the subjects as symptoms of AD. The model proposed by this study collects the sensor data and finds the sleeping pattern, mobility pattern, frequency, and duration of daily chores and activities. The resulting model predicts whether the subject is healthy or at risk or an AD patient. The study was able to do the prediction with 94% accuracy.

Ahmad Akl [1] observed in some studies that measures related to walking speed and its variability were great contributors in predicting disease symptoms. In his study, he took real-world data of 97 subjects from ORCATECH (Oregon Centre for Aging and Technology). From the sensor data, different measures were computed in the form of walking speed i.e. weekly walking speed, coefficient of variation of weekly walking speed, coefficient of variation of morning walking speed and evening walking speed, etc. The features were fed to two algorithms named support vector machine (SVM) and Random Forest (RF). The area under the ROC curve of 0.94 shows that he was successful to a large extent.

The study [7] by Dawadi tries to analyze smart home-based behavior data of subjects and predict the cognitive and mobility scores. In his study, the data set is taken from CASAS middleware which collects sensor data while monitoring the daily behavior of 18 smart home senior residents for 2 years. The activities of monitoring include activities of daily living like eating, cooking, personal hygiene, leave home and relax. The features computed include mobility features like total distance traveled; sleep features like sleep duration; or daily living features like relaxing duration, personal hygiene duration, etc. A supervised machine learning algorithm is trained on a statistical feature set and scores are computed. The scores of RBANS and TUG act as clinical assessment scores. Dawadi's work shows a correlation of 0.72 between computed scores and the clinical assessment scores.

The study [2] by Alberdi evaluates the possibility of detecting cognitive or other behavior changes in subjects using smart home data. Cognition, mood, and mobility scores are computed after a regular period to detect the change. In his work-study, the data set was taken from CASAS and Neuropsychology and Aging laboratory of Washington University. It contained data of 29 older adults for an average period of 2 years. Different features were evaluated related to mobility, cognition, and mood. And using classification models, reliable changes in mobility, cognition, and mood scores could be seen in different periods for different subjects.

The study [3] by Austin assesses loneliness by monitoring the smart home data. Although this study doesn't show any relation between loneliness and Alzheimer's, this feature may be considered for further study.

B. Based on Speech Processing

The next approach leans towards the use of 'Automatic Analysis of Spontaneous Speech (ASSA)' to predict AD [9]. This process requires speech samples of the person which will be evaluated to interpret whether the person is affected with Alzheimer's or not.

Saturnino luz [12] works on the fact that Alzheimer's patients have language dysfunctionality in communication. So by analyzing the speech of subjects, we can detect the disease symptoms. The detection system proposed by luz depends on vocalizations and paralinguistic speech features. They may include statistics summary like mean, variance, minimum, maximum entropy for vocalizations events and speech rate, number of utterances, etc in other features. By applying the Bayesian machine learning classifier, the system outputs the classifier model which helps in predicting whether the subject is AD or not. He was able to achieve an F1 score of 0.70 in his work.

Ammar's work [4] also proposes a strong model for the classification of AD patients from healthy persons. In his work, the data set was taken from dementia Bank. It contained speech samples of subjects and their manual transcriptions where they were describing a cookie theft picture. The number of samples was 242 for healthy persons and 242 for AD, 484 in total. Three types of features were extracted including syntactic, semantic, and pragmatic features. He carried the classification by performing feature selection and preparing the classifier model. Ammar used three classification models in his study: neural networks, SVM, and decision trees. In the end, his study proves that linguistic features extracted from speech samples are effective biomarkers for detecting the disease. He achieved 79 % accuracy by using an SVM classifier.

The study [15] aims to propose a neuropsychological screening method for the detection of disease symptoms. This study works on analyzing the speech samples taken during the memory test of subjects. In this work, 84 subjects' data was collected, in which 48 were affected with the disease while 36 were healthy individuals. Three speech samples were recorded for each subject, in which one speech was about describing their previous day and two were about descriptions of one-minute-long two animated movies shown to them. By using the signal processing techniques, different speech features were extracted like speech rate, pauses, duration, and many more. These features were fed to machine learning algorithms provided in the WEKA tool. The algorithms tested were naive Bayes, random forest, and support vector machine. Random forest classifier was able to separate the patients from healthy individuals with an F1-score of 78.8 %.

Rosas [6] believes that the richness of the dictionary and fluency of speech is not very good in people suffering from Alzheimer's. Rosas focused his work mainly on these two aspects. In his work-study, speech samples of 20 persons were considered, 10 having Alzheimer's and 10 normal. Lexical features included the percentage of words with length less than or equal to 4, the percentage of words with a length greater than or equal to 5, lexical diversity, interjections, etc. The features related to fluency were short pauses, long pauses, and unusual words. Two classification algorithms were applied to these features: 3 layers neural network and a support vector machine. The neural network was able to classify the persons with 70% accuracy while the Support vector machine was able with an accuracy of 86 %.

C. Based on Virtual Environment tests

The third non-invasive approach uses virtual environment technology for earlier detection of Alzheimer's disease. Virtual Environments (VE) are computer simulation environments. They give a sense of presence to the users. VE can immerse the user within the virtual 3D world.

According to Shamsuddin's study [16], topographical disorientation is the earliest sign for the detection of disease. The infected Subject may find it difficult to reach the destination. He proposed the development of a virtual environment named VREAD. It is software that can be used for testing the navigational skills of users. It contained 3 modules: VR practice, VR Park, and VR games. VR practice, a training module, enables users to get comfortable with the software. The remaining two modules are used to test the subject's navigational skills. Both modules have five levels. The subject goes through testing for each of the five levels and different data attributes are collected like correct path, incorrect path, correct sequences, incorrect sequences, timing, and scores. The data attributes are recorded and analyzed by using the software named WEKA. WEKA applies machine learning and provides us the resulting model. According to this work, the tool could give 90% accurate results.

Counting on the novel, low-cost and non-invasive aspects of the virtual environment, Fernandes [8] also tried to use the virtual environments method for the detection of Alzheimer's symptoms. His work focused on analyzing the learning and memory of the subject. Here the virtual environment is nothing but just a scene of a room having different objects. The tests introduced by Fernandes were the virtual objects memorization test, abnormal objects recognition test, and virtual vs real sound test. Virtual object memorization test tries to test the memory and learning of subjects. It shows different objects on the screen and asks different questions like the name of objects, the position of objects, they were shown on the screen, etc. The second test, the abnormal objects recognition test does the perceptual study of the user. It shows abnormalities on the screen like clock time not per the illumination of light. The third test, the virtual versus real sounds test, again tests the mentality and

cognition of subjects. In this, Different sounds like clock ticking, rain, train are played and asked to recognize by the subject. Based on these tests, scores are computed.

Study [14] environment name is VR-DOT (Virtual Reality Day –out task) where different neuropsychological tests are performed for assessing physical and cognitive abilities of older adults. It includes functional measures of attentiveness, memory, remembrance, executive functions, language, etc. to assess the health of adults. It also considers finger tapping, grip strength, stride length, gait speed, and chair stands to assess the physical health of adults. For validating scores, the study correlates the results with MMSE (Mini-mental State Examination) and Bristol scale test scores.

TABLE I: INFORMATION OF DIFFERENT RESEARCH WORKS BASED ON METHODOLOGY

Study	First Author	Modality	Dataset	Subjects	Data_Set_Features	Machine learning Classifier
[1]	Ahmad Akl	Smart homes	ORCATECH	18 MCI 79 Normal	Walking speed, variation in walking speed, age, gender, etc.	Support Vector Machine
[2]	Ane Alberdi	Smart homes	CASAS	29 older adults	Day level activity features related to sleep, mobility, routines; their complexity, and duration.	Random Forest
[9]	Harish S	Smart homes	Not Mentioned	Not Mentioned	Sleep disturbances, the total time on the bed, movements inside rooms, etc.	Random Forest, SVM
[7]	Prafulla Nath Dawadi	Smart homes	CASAS middleware	7 Healthy 6 At Risk 5 AD	Sleep, movement, and activity like cooking-related features	SVM
[12]	Saturnino Luz	Speech Analysis	Dementia Bank	214 AD 184 Normal	Vocalization, Speaking rate, number of utterances, etc.	Bayesian classifier
[15]	Toth.	Speech Analysis	Own	48 AD 36 Normal	speech rate, pauses, duration	Random forest classifier
[4]	Randa Ben Ammar	Speech Analysis	Dementia Bank	242 AD 242 Normal	Linguistic features(Syntactic, Semantic, Pragmatic)	Support Vector Machine with KNN
[6]	Rosas	Speech Analysis	Carolina Corpus Conversation database	10 AD 10 Normal	Pathology of speech (Confusion or daze, short pauses, long pauses, Unusual words, Interjections, long words, etc)	Support Vector Machine, 3-layer Neural Network
[16]	Shamsuddin	Virtual Environment	Own Sample Group	31 participants	VREAD environment test scores (based on navigation)	Naïve Bayes Classifier
[14]	Tamanas	Virtual Environment	NGO clinics of the Papanikolaou University Hospital, Greece	72 Normal 65 MCI 68 Mild - AD	V-DOT scores (based on navigation and physical abilities like finger tapping, grip strength)	NA

IV. COMPARISON

Let's take a look at the comparison of all non-invasive methods researchers have reviewed so far based on their efficiency. All of them tried to predict the disease based on different features and applying different machine learning classifiers. The comparison of accuracy metrics is shown as below in Table II:

V. CONCLUSION

Our study aimed to find simple techniques for the detection of Alzheimer's symptoms that are economical and very harmless for a person to go through. Another important aspect to be considered was to find a technique that can find the disease symptoms as early as possible so that we can control the deterioration rate of disease in the person, although we cannot cure it. So the parameters taken into account for performance analysis are: the validity of prediction: with how much accuracy, the technique is able to detect the symptoms; the simplicity and

TABLE II: COMPARISON OF RESEARCH STUDIES BASED ON DIFFERENT MEASURES

Study	First Author	Accuracy Metrics				Remarks
		Acc.	AUC (PRE)	AUC (ROC)	F1score	
[1]	Ahmad Akl	NA	0.93	0.97	NA	Although the requirements of sensor data are hard to meet, still it gave a great contribution in finding the disease symptoms earlier and accurately, based on variations of walking speed.
[2]	Ane Alberdi	NA	0.54	0.65	NA	It was just able to prove that we can find mobility, cognition, and mood using smart home sensor data. And the accuracy of these scores was also not good enough.
[9]	Harish S	0.94	NA	NA	0.95	The theoretical concept may seem good but this study didn't throw light on practical work. The author just gave the results, leaving out the experimental details.
[7]	Prafulla Nath Dawadi	0.72 (Correlation - r)	NA	NA	NA	It could not prove the validity of the CAAB approach, due to the lack of subject population taken in the dataset.
[12]	Saturnino Luz	0.68	NA	NA	0.70	The study took a good step by focusing on the vocalizations instead of transcriptions of speech. It paved a better way for further research.
[15]	Toth.	NA	NA	NA	0.78	The study presents a promising tool for predicting the symptoms. ASR, Automatic Speech Recognition, is a tool that worked on phonetic features and categories of pauses like filled, silent, etc. Although further work is required to increase the accuracy of detection.
[4]	Randa Ben Ammar	0.79	NA	NA	NA	This study presents the model based on the content of speech. The rest of the features is left out for future research.
[6]	Rosas	0.86	NA	NA	NA	This study presents a great model, working on a great set of features for the prediction of symptoms. Increasing the size of the population can enhance the output model and its accuracy.
[16]	Shamsuddin	0.90	NA	NA	NA	The developed software VREAD is a very promising tool for the future. It just requires further research for accurate results.
[14]	Tamanas	NA	NA	0.93	NA	The selection of features considered for evaluation could help the system to detect symptoms earliest.
[8]	Juan Fernandez	NA	NA	NA	NA	The author did not prove the validity of test scores.

efficiency: with how much ease and resources, the technique is applied; and earliest detection: how much earlier the technique is able to detect the disease symptoms.

In the study, we found three techniques in suitability. These were: Smart home monitoring; speech analysis; and assessment tests in a virtual environment. Smart home monitoring could find the symptoms by monitoring subject's daily activities and his behavior; speech analysis was able to do it by the way of talking of subject; while virtual environment could detect it by taking assessment tests of subject's in a virtual environment. After going through the study of these techniques, we deduced that all of these techniques have their pros and cons.

The accuracy of predicting the symptoms in smart home monitoring techniques is quite large. Various studies have worked on detection using smart home data features related to mobility, anxiety and were successful in detecting the symptoms to a large extent. The disadvantage is that it requires sensor data for a very long period. To detect the symptoms, we must have sensor data of the subject's home with us available.

The next technique was speech analysis. This technique neither required any equipment to be used while testing, nor any previous data or history details of subjects. It simply required the speech sample of the person to be tested. The studies related to this technique present a set of features. Some of them are dependent on transcriptions of speech while others use vocalization features. By analyzing different aspects of speech, we can detect the presence or absence of disease symptoms. The drawback is that person's speech may vary in different times in different locations and in different situations. So we need to consider these aspects while analyzing the speech data.

Virtual environment assessment techniques are very easy to test. They are performed in a very simple way on subjects. Subjects are supposed to be in a virtual environment and assessed their cognition and memory. They

can be very promising techniques in the future but for now, this technique requires more research, as the validity of the technique is still not proven fully. Also, this technique requires work on finding the relationship between the test scores and the stage of disease in the patient.

Comparing all these three techniques based on the parameters given above, the validity of prediction is highest in smart homes as it analyses the monitoring data of a very long period. Another parameter was simplicity. The ASSA as well as virtual assessment techniques are very efficient as they don't require much resources. Last parameter is earliest detection. The ASSA technique may find the symptoms earliest as relatives may find the change in speech behavior and go for the test. Virtual assessment technique may also find the memory and cognitive decline earlier using the assessment tests.

Although all these techniques present a great work towards earlier and accurate diagnosis, still there is space for future study in them so that a more accurate and earlier diagnosis can be done. The earlier diagnosis can decrease the death rate caused due to Alzheimer's and save many lives.

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