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Mobile based Detection and Prevention of Alzheimer's Disease

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Abstract - *Alzheimer's disease (AD) is a progressive disorder that causes brain cells to degenerate over time and eventually die. AD is the most common cause of dementia which affects the thinking, behavioral and social skills of a person. Early signs and symptoms cause problems in carrying out day-to-day tasks, decline in problem-solving ability, speech patterns, and various other problems. Parameters related to this decline in features can be used to detect AD at an early stage. This paper targets to detect and reduce the risk of having AD. We are targeting cognitive skills such as spatial navigation, memory, speed, attention, and calculation as well as voice features such as articulation rate, number of pauses, rate of speech, original duration of the speech, and total speaking duration. User's score and time are taken out from a 3-Dimensional, third-person (view) game are used to evaluate the Cognitive skills. The voice features are extracted by the user's recorded voice. These features are passed to the two different classification Machine Learning (ML) models for predicting whether the user has AD or not. To improve the accuracy of prediction, we are implementing some parts of the traditional MoCA Test virtually. All these results are taken into consideration for the final prediction. Additionally, we have implemented features that would help to keep the brain active, reduce the risk of getting AD and slow the decline in cognitive functions. We have implemented all these things in an application with a user-friendly User Interface (UI).*

Key Words: Alzheimer's disease, cognitive skills, 3D game, voice features, machine learning, MoCA

1.INTRODUCTION

Being a major problem faced by the developed countries, the World Health Organization (WHO) had declared dementia to be a priority condition through the Mental Health Gap Action Programme in 2008. As of 2019, worldwide there were around 50 million people having dementia, of which there is nearly an increase of 10 million new cases per year. Among which, WHO says, 60-70% accounts for Alzheimer's Disease [1].

Based on the impact of the disease as well as the person's personality before becoming ill, dementia affects each person differently. The signs and indications associated with dementia can be interpreted as three stages: mild, moderate, and severe. At times, it may be difficult to recognize a person with Alzheimer's in a distinct stage as these stages might overlap.

A person may function without much assistance in the early stages of the disease. Although they may be able to carry out daily activities like driving, working or being a part of social activities, they still might be having some blackouts; memory lapses like forgetting the location of objects or difficulty in remembering familiar words. This is supposed to be the longest stage wherein the patient will require ample amount of care. During this stage, the patient may suffer from problems like having confusion among words, getting angry or getting frustrated as well as may act in unexpected ways. It becomes tough for the person to convey their thoughts and to carry out their daily tasks without any help or assistance due to damage to nerve cells of the brain. Towards the late stage of the disease, the mental function proceeds to decline, and it has an increasing impact on physical capabilities and movement. In other words, one becomes near-total dependant and inactive. Notably, as memory and cognitive abilities worsen, significant personality changes occur and indulge in requiring extensive care.

The traditional brain imaging tests are costly and involves the use of radioactive agents. Also, the spinal fluid tests are complex, time-consuming & invasive. The current AD medications only help in temporarily improving the symptoms or to reduce the rate of decline of the disease.

2.LITERATURE REVIEW

The rate of patients with Dementia is increasing yearly, which is a major cause of death. Among which Alzheimer's disease accounts for one of the common types of dementia. Clinically Alzheimer's disease starts with complaints related to memory problems [2]. Previous research suggests that AD affects cognitive skills of the person, of which Spatial navigation is an important factor in preclinical identification [3]. Sea Hero Quest, a game developed by game company-Glitchers, along with Alzheimer's Research UK and their research based on this game regarding special navigation was a key factor for identifying AD. This game was crucial in obtaining ample amount of data necessary for creating world's first benchmark regarding human spatial navigation. In most of the cases, Alzheimer's disease starts with complaints in visual orientation and speech production, along with semantic or naming problems as well as complaints regarding memory problems, which in turn

affects episodic memory. It typically affects short-term memory in its early stages. But, as the disease progresses, people start experiencing long-term memory loss. Memory can be defined as a process of encoding information as well as storing and retrieving information or the presentation of this information to an organism's nervous system which can be used by the organism to react or position itself towards a new stimuli. Memory can be categorised based on different neurophysiological and neuroanatomical resulting in correlations such as short-term (memory) Vs long-term memory or implicit vs declarative (memory). Short-term (memory) has a limited capacity of a few "chunks" which lasts only from seconds to minutes. It is dependent on the regions of the parietal lobe and the frontal lobe. Whereas, the long-term memory, for almost unlimited duration, is said to have limitless storage capacities. This is said to be dependent on de novo protein synthesis and on the changes in the molecular components of the neuronal networks which are involved in the specific cortical areas that attribute to different types of memory [2]. Declarative memory is made up of facts and events which can be recalled consciously. It includes episodic memory and semantic memory. Age is found to be a crucial factor in distribution of the disease, which can be divided into three categories: a late old age category with clinical incipience after age 85, an intermediary category with incipience in what we call as early old age (60 to 85), and a young category, with manifestation origin approximating within ages 40 to 60 [4]. As per findings, it was found that varying attention is common in patients diagnosed with average-to-critical AD [5]. It was also found that deficits in calculation skills can occur in the early or mild stages of AD [6-9].

Many researchers have also identified speech to be a major feature in early diagnosis of AD. At an early stage, researchers have also found recognisable language deficit [10]. In Alzheimer's disease, functions related to memory & language are closely associated, as memory functions are required for linguistic functioning. Moreover, difficulties in productive speech also affect memory functions and speech comprehension as they are corelated [11]. Temporal parameters for reading fluency like articulation rates and speech rates are distinguishable features between the asymptomatic and mild AD patients. Some researchers have categorised the group of mild Alzheimer's Disease patients based on factors such as the hesitation ratio variables, speech tempo and the articulation rate, whereas, others have suggested that articulation rate and speech rate were among the best distinguishing features [12]. It is observed that articulation rate as well as other features such as number of pauses and the total time taken for task of reading in mild and severe Alzheimer's disease patients was majorly found different from others. Moreover, a variation also was noted among severe, moderate and mild Alzheimer's disease patients [11].

2.1 Gaps Identified in the literature

Different works suggest different cognitive functions for the diagnosis of AD. But, most of these tests conducted are monotonous and they involve in targeting only some of the cognitive skills. Also, these tests do not focus on targeting both, cognitive as well as speech features. Including both the aspects (speech and cognitive skills) would result in a higher accuracy in the overall prediction. The traditional proposed systems primarily focus on just the detection part. As per our knowledge there has been no such feature for prevention/assistance of the disease.

3.PROPOSED WORK

This work aims at reducing the overall cost of the tests by conducting them in a virtual and fun way using Mobile Game. Along with that this work also aims at not just the detection part but also in providing assistance to the AD patients as well as helping the normal users in prevention of the disease by keeping their brain active. All this would be incorporated in an app which would be available to all. This might also eliminate the need of going to the clinic to conduct these tests physically.

3.1 Phase I- Game

The phase-1 of detection consists of a mobile game as recent statistics have shown that mobile games have become the part of our everyday activity, offering fun and leisure to millions of users. Games in general can help to keep anxiety at bay and promote relaxation. Studies have also shown that playing mobile games have many advantages such as to increase in the ability to memorize, decision making and more. Besides, it is enjoyed by all ages. So, the use of mobile game has been incorporated to make the detection phase a fun and enjoyable process.

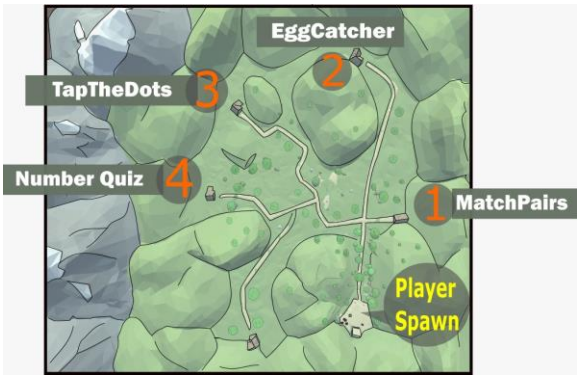

Fig -1: Game map with checkpoints having minigames

Proposed game targets the cognitive skills of the user such as spatial navigation, memory, speed, attention and calculation as these skills can be crucial in detection of AD. The user would be spawned in a 3D environment wherein they would be shown a map on which the location of 4 minigames (Match Pairs, Egg Catcher, Tap the Dot and Number Quiz) are shown (Fig. 1). The user has to remember their locations as well as reach the checkpoints in the same order as shown on the map (Fig. 1). The mini game at each

checkpoint would only be triggered if the user follows the same order.

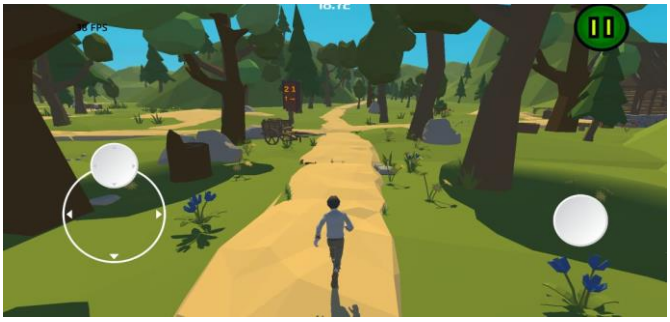

Fig -2: 3D game environment

To further assist the user, some navigation signs are also placed at certain locations in the environment. Each checkpoint will trigger a minigame targeted to focus one of the cognitive skills. The minigames are as follows:

1) Match pairs (Memory Fig. 3): The user would have to match the cards having the same image. This would be testing the memorizing skill of the user. Total game time would be of 220 seconds. It would be consisting of 5 levels. For each level, scoring 3 stars would result in securing +4 points, 2 stars for securing +3 points and 1 star for securing +2 points. Here since time plays a crucial factor as to how fast the user completes the minigame, the time as well as the score is taken into consideration for this minigame.

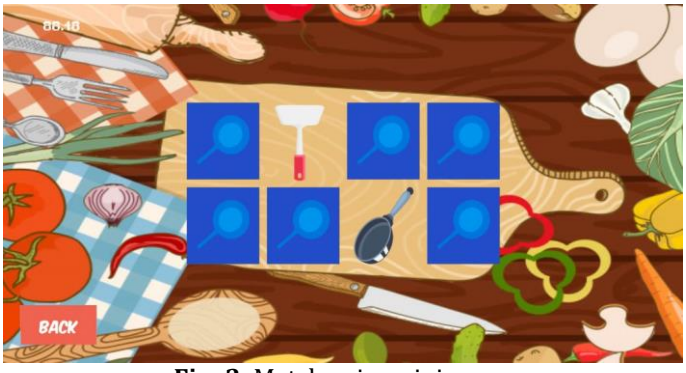

Fig -3: Match pairs minigame

Scoring System (Table 1): There are 5 levels, each level would be generating the stars based on the number of guesses(x). A guess is considered as a match between 2 cards, be it the correct or an incorrect match.

2) Egg catcher (Reaction Time Fig. 4): On completion of the first minigame, if the user travels to the next allotted checkpoint, the game Egg catcher would be triggered. In this the user has to catch the falling eggs in a basket by hovering it, although there is a twist in the game. There would be some stones falling along with the eggs. To make the differentiation easy, the stones have been denoted to be black in color and the eggs as white. The user needs to avoid these stones and only collect the falling eggs. This would focus on testing the speed or the reaction time of the user, as they would have to react within a fraction of a second to decide whether to catch the falling object or not. The user would have 3 lives(tries) and maximum limit of 120 seconds to catch as many eggs as possible. A correct catch would be resulting in a score of +1 point, whereas the incorrect one would result into a score of -1 point as well as would result in a loss of 1 life. The total score as well as the completion time would be taken into consideration.

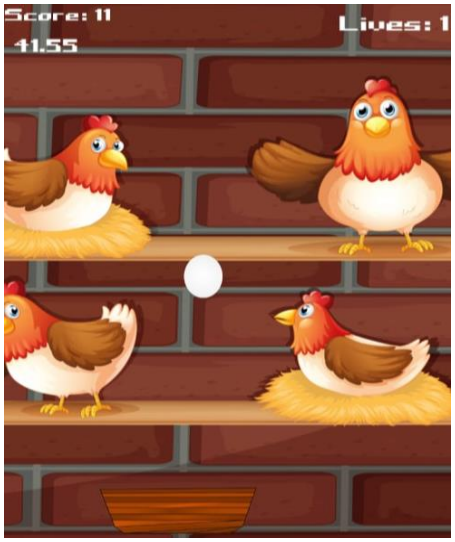

Fig -4: Egg catcher minigame

Table -1: Scoring System

Level	Guesses(x)	Star	Points
1,2	0-5	3	+4
	6-9	2	+3
	greater than 10	1	+2
3,4	0-11	3	+4
	12-15	2	+3
	greater than 15	1	+2
5	0-17	3	+4
	18-21	2	+3
	greater than 21	1	+2

3) Tap the dot (Attention Fig. 5): By reaching the next checkpoint, Tap the dot minigame would be triggered. The user would have to tap/pop the white dots and avoid tapping on the Red ones. This would be testing the attention skill of the user as to how efficiently they are able to differentiate between the two colors. Tapping the White dots will result in securing +1 point whereas tapping the red one will result in securing -1 point. The game has a maximum time limit of 120 secs. Here, only the score of the user would be taken into consideration for further computations.

Fig -5: Tap the dot minigame

4) Number Quiz (Calculation Fig. 6): The final checkpoint would trigger the game called Number Quiz which primarily focuses on the testing the calculation skills of the user. The deterioration in calculating abilities is a distinguishable cognitive feature of Alzheimer's Disease. The game consists of arithmetic questions involving additions and subtraction of single and multi-digits. Selecting the correct answer to the given question results in scoring +4 points. There is a time limit of 180 seconds to the game. The time taken as well as the total score of this mini-game would be considered for further computations. Here time signifies how fast the user can solve the quiz, whereas score is an important factor to check how correctly they solved it.

After completing all the checkpoints, finally total path tracing time of the user for navigating the map will be calculated. This would help in determining the spatial navigation skill of the user. All these parameters are recorded and passed onto the machine learning model for classification results of phase-I.

Fig -6: Number quiz minigame

Phase-I prediction: In the proposed method, augmented dataset has been used. Developed game was tested on normal people to compile the game dataset that is labelled as 'No' (Not having AD). Based on these results the dataset is augmented to be labelled as 'Yes' (People having AD). This was further used to train the ML classification model. Random Forest classification model worked best on the compiled dataset. Chart. 1 shows the comparison between different machine learning algorithms on our game dataset.

3.2 Phase II- Voice Analysis

After successfully completing Phase I, the user would then be moved onto the next phase of detection. Alzheimer's disease can be classified more precisely by the assistance of linguistic analysis as compared to different cognitive skill assessments. This helps in increasing the overall accuracy of prediction. In this phase the user will be given a sentence to read: primarily in English or Hindi. The audio of the user would be recorded while reading the given sentence. Audio features will then be extracted from this recorded sample. The recorded audio will be stored in '.wav' format on which the feature extraction will be done. Voice features such as articulation rate, number of pauses, rate of speech, original duration of speech and total speaking duration will be extracted from recorded audio and passed to the Machine Learning model for prediction. This method is flexible and the model can be further trained for different languages depending on the availability of dataset.

Dataset: Created an augmented dataset by collecting recorded voice samples of normal people (25 individuals), then extracted features from their audio samples and compiled the dataset to be labelled as 'N' (not having AD). With the help of Dementia Bank [16,17] data the augmented results were compiled that were to be labelled as 'Y' (having AD). Finally, the compiled dataset was passed on to train the ML model. Chart. 2 shows the comparison between different machine learning algorithms on our voice dataset.

3.3 Phase III- Montreal Cognitive Assessment (MoCA)

A validation test of the globally accepted screening assessment (MoCA) for detecting cognitive impairment, in 2005, showed that MoCA was a better tool than the traditional and the well-known Mini-Mental State Examination (MMSE) for the detection of Mild Cognitive Impairment (MCI) and Early AD [13]. MoCA was proven to be an appropriate cognitive screening tool which considered different cognitive domains. It also helped in achieving a better understanding to the individuals' cognitive profile [14]. In the detection phase, this test is conducted in a virtual way which includes the same questions that are used in the clinical tests. Also, the scoring pattern is same for those questions.

Table -2: Cognitive areas and scoring of MoCA test [15]

Cognitive Functions	Montreal Cognitive Assessment (Total Points)	
Orientation	6 Tasks (6 points)	
Memory	Learning	Learning of 5 words (No points-2 trails allowed)
	Delayed recall	5 words (5 points)
	Cued recall (optional)	5 words (5 points)
	Recognition (optional)	5 words (5 points)

Naming	3 pictures (3 points)
Visuospatial functions	Copy/Draw cube (1 point) Drawing a clock (3 points)
Vigilance	Tapping the hand with hand at the occurrence of letter A (1 point)
Language	Repeating 2 sentences (2 points)
Abstract thinking	Similarities (2 points)
Alternating Trail Making	1 trail (1 point)

3.4 Voting

After completion, each phase would be giving a certain output. Phase- I and Phase-II output would be consisting of Yes (Y) or No (N), which would be given by the ML classification models for the respective phases. Similarly, Phase- III would also be giving a score which can be used to evaluate whether the user has dementia. Further, a collective voting of these results will be taken which then would determine the final result of the detection phase. The voting taken would be done on basis of majority of the outputs being Yes(Y) or No(N) by the respective phases, which would then be displayed as the final result of the detection phase.

4. PREVENTIVE MEASURES

This work not only focuses on the detection phase, but also incorporates preventive measures to provide assistance in day-to-day tasks for the AD patients. To lead a brain-healthy lifestyle by identifying and controlling the personal risk factors which can maximize the chances of lifelong brain health, thus preserving the cognitive skills. This may help in prevention of AD.

Some of the ways to keep our brain active are regular exercise, following a healthy diet, being mentally active, quality sleep.

Taking into consideration the above aspects, some features have been incorporated into the mobile application which can help in prevention of the disease. The primary feature includes a daily activity tracker. The user would have to complete 5 basic tasks daily, which would be tracked and displayed on home screen. These simple tasks are targeted in helping to improve the cognitive skills of the user. Based on the completion of these activities, the activity tracker of the user would progress. The 5 daily tasks to be followed by the user are:

1) Brain Games: These would consist of small mini games, which may help to keep the brain active. These may contain puzzles, quizzes and tricky but fun to play games. These incorporated games are easy to play and are enjoyed by all age groups. The user would have to play at least one of these games. Doing so would result into the daily activity tracker to progress by one bar.

2) Exercise: This feature is included to help the user to maintain the overall health. Here, the user would have the option to view some basic exercise videos which may include yoga asanas and other basic exercises to help stimulate the brain's ability to maintain old connections as well as make new ones. These exercises can be performed by all age groups as they are easy to do.

3) Music: Rejuvenating music helps to recuperate users as well as helps to make them more socially active. Music has many effects ranging for reducing stress to enhancing memory. Moreover, music has a positive impact on AD patients as well as enhances general positive functioning in elderly patients with dementia, and reducing negative behaviours typical of their condition. Due to these effects, listening to music has been included as one of the important daily tasks.

4) Healthy diet tips: The user would be given daily diet tips. These tips would include aspects such as information on omega-3 fats, diet to cut down on sugar, enjoying a Mediterranean diet by providing basic recipes as well as tips to manage weight. These things help in the long run for not just prevention of AD, but also for preventing various other diseases such as Cardiovascular diseases, Diabetes, etc.

5) Family photo gallery: The best medicine for Alzheimer's Disease is the love, care and affection of the near and dear ones. Over time, the patients tend to forget the precious memories of the quality time they have spent together with their close ones which causes a strain on these bonds. By including the feature of photo gallery, it helps to connect the family members with the patients/users. The family members can upload their photos over here which can be viewed by the user. This would have a positive effect as seeing or viewing photos help people trigger some memories. This causes a sense of joy because as they say, photos are not just an image, but are a means to capture precious memories.

6) Appointments: The user diagnosed with Alzheimer's can request an appointment to the registered Doctor on our app for further consultancy. The user has to enter the date and time of appointment. Afterwards the user can check appointment status whether the doctor has accepted or rejected his appointment. The doctor can monitor the patient's condition based on the test result as well as can track incline/decline in their cognitive functions. This would help the doctor for further assessment of the patient.

7) Apart from these features, there are some additional features such as water reminder, daily routine or task reminders and medication reminders. Water reminders would help the user to keep themselves hydrated by notifying them the amount of water they should drink at intervals, as dehydration is one of the common problems faced by AD patients. Medication and daily routine reminders would help in notifying the user based on the set reminders.

5. EXPERIMENTATION AND RESULTS

For compilation of the voice dataset, audio features from the user's recorded voice sample would be extracted using the python library called my-voice-analysis (version 0.7). Voice features such as articulation rate, number of pauses, rate of speech, original duration of speech and total speaking duration from the audio sample are extracted by using the library's inbuilt functions.

This work involves the use of two Machine Learning models, for game score dataset and the voice dataset. Three ML algorithms were implemented: Random forest (sklearn library), Neural Network (Tensorflow library) and Logistic Regression (sklearn library). Among the three, Random forest (with n_estimators=100) outperformed the rest by having F1 Score of 0.97 (Game Dataset) and 0.91 (Voice dataset) as shown in Chart. 1 & Chart. 2.

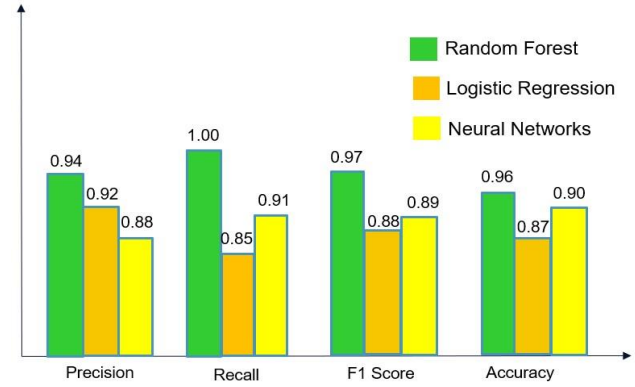

Chart -1: Comparison between different ML algorithms for game dataset

Input features (game score model): Speed (Score of Egg Catcher Minigame), Speed_Time (Completion Time of Egg Catcher Minigame), Memory (Score of Match Pairs Minigame), Memory_Time (Completion Time of Match Pairs Minigame), Calculation (Score of Number Quiz Minigame), Calculation_Time (Completion Time of Number Quiz Minigame), Attention (Score of Tap the Dot Minigame), Path_Tracing_Time (Completion Time of Tap the Dot Minigame).

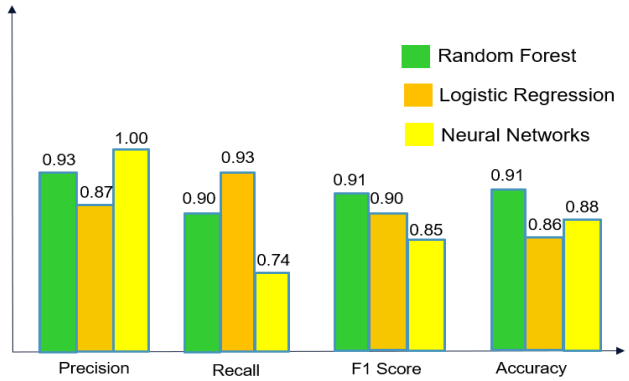

Chart -2: Comparison between different ML algorithms for voice dataset

Input features (voice model): articulation rate, number of pauses, rate of speech, original duration of speech, total speaking duration, language.

Output: Has AD/Doesn't have AD (Y/N).

6. QUANTATIVE RESULT

This work proposes to solve the above raised problems such as reducing or eliminating the initial testing cost for the diagnosis. This will make it easy to conduct the tests at home as per the patient's will along with the early detection of the disease. It will also provide assistance in taking preventive measures for avoidance of the disease. Further, this work also proposes to assist the diagnosed patient to cope up with the disease. The ease of use and a user-friendly UI enables the application to be used by all. Under ideal conditions, provided with enough training dataset, the application would provide accurate results as the key differentiating factors have been incorporated for the detection of the disease.

7. CONCLUSION AND FUTURE WORK

The random forest algorithm had an F1 score of 0.97 over the game dataset and 0.91 over the voice dataset as shown in Chart. 1 & Chart. 2. These datasets included the key differentiating features for detection of the disease like the five major cognitive skills such as spatial navigation, memory, speed, attention, and calculation for the game dataset as well as the major speech features such as articulation rate, number of pauses, rate of speech, original duration of speech and total speaking duration for the voice dataset. After combining results of the tests for identifying the above factors along with the virtual MoCA test, the prediction of the result for the diagnosis is done with the help of voting. This work includes various other helpful features which can help the user for taking preventive measures as well as in assistance if diagnosed with the disease.

In future, the number of input features to the ML model can be increased, resulting in better accuracy of detection. Also, more differentiating voice features can be identified, and different variety of games can be included as well.

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