COGNITIVE REHABILITATION BASED PERSONALIZED SOLUTION FOR DEMENTIA PATIENTS USING REINFORCEMENT LEARNING

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Dissertation submitted in partial fulfillment of the requirements for the Bachelor of Science in Information Technology

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DECLARATION

I declare that this is my own work and this dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. Also, I hereby grant to Sri Lanka Institute of Information Technology the non-exclusive right to reproduce and distribute my dissertation in whole or part in print, electronic or other medium. I retain the right to use this content in whole or part in future work (such as article or books).

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The above candidate is carrying out research for the undergraduate Dissertation under my supervision.

Name of supervisor: Dr. Dharshana Kasthurirathna

Name of co-supervisor: Mrs. Thilini Jayalath

Signature of supervisor: Date:

Signature of co-supervisor: Date:

DEDICATION

This study is wholeheartedly dedicated to my beloved patients, who have been my source of inspiration and gave me the immeasurable support and encouragement throughout the research.

I humbly dedicate this to my supervisor, co-supervisor and external supervisor for their valuable support and guidance.

And finally, I would like to dedicate this for all Dementia patients who need the non-pharmaceutical therapy to cure.

ABSTRACT

Dementia is one of the most challengeable health care problem faced globally with the increase of the ageing population gradually. The estimated current prevalence of dementia is 47.5 million around worldwide. This number will nearly double in every 20 years globally [1]. Dementia is basically a syndrome which cannot be cured by a specific medicine to recover from it [2]. But non-pharmacological therapy can be used to treat Dementia patients which is known as Cognitive Rehabilitation Therapy. According to the recommendation of a psychiatrists, a brain training application would be a better cure for the Dementia. The symptoms of Dementia can be slow down by assisting a Dementia patient in the early stages through a brain training application using games or activities. Due to the frequent usage of smart devices, brain training applications with games and activities will beneficial . There are number of different types of brain training applications in the world based on some of the cognitive functionalities. But there is not a customized solution for Dementia according to the relevant patient. For a better cognitive rehabilitation, Dementia patients need personalized therapies according to their stages on cognitive functionalities. Therefore, developing a personalized brain training application is a global requirement for all the Dementia patients around the world. The modern world is evolving with new developing technologies and this application includes the mind games applying technologies like Reinforcement Learning. Attention and concentration, executive functions, language skills, memory skills are the cognitive functionalities addressed through this solution. Among these functionalities, language is the most important in day-to-day life for the communication. The impairment of speaking, writing, comprehension under language skills are caused to language problems of Dementia patients. The language skills component is made considering about comprehension and speaking and it built up on jumbled words and speech to text practicing activities. The people experiencing early signs of language impairment in Dementia on first stages, can use the language component of this application step by step and boost their condition with continuous monitoring. Patients, caregivers and doctors can review the progress of the patient through reports. All the games of the language skill component and all other games have designed along with the supervision and recommendation from a Consultant Psychiatrist in Sri Lanka for helping hand to dementia patients with cognitive rehabilitation to improve the quality of life with the best suited personalized games and activities.

Keywords : Dementia, Cognitive Rehabilitation, Reinforcement Learning

ACKNOWLEDGEMENT

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List of Abbreviations

RL	Reinforcement Learning
DL	Deep Learning
NLP	Natural Language Processing
CNN	Convolutional Neural Network
MMSE	Mini Mental State Exam

1. INTRODUCTION

According to World Health Organization, Dementia is a syndrome deteriorating human memory, thinking ability, behavioral patterns and the ability to perform day-to-day activities which belong to cognitive functionalities of humans such as attention and concentration, executive functions, language skills, memory skills. And Dementia is the one of major disease among older people around worldwide. It has a physical, psychological, social and economic impact not only among dementia patients but also with the families and caregivers around the patients. Sri Lanka is one of the countries which has world's fastest ageing population [3]. Therefore, a syndrome like Dementia which is affected for the elderly people will become most prevalent in the community. Dementia is caused by damaging to brain cells. This damage interferes with the ability of active brain cells by breaking down the communication with each other. According to the disability of brain cells, there are number of Dementia categories such as Alzheimer's disease, Vascular Dementia, Lewy Body Dementia, Frontotemporal Dementia. But there is not an exact medication for any Dementia category. The most suitable mechanism is to assist the Dementia patients on early stages through a brain training application for decreasing the symptoms of brain disorders. A better cognitive therapy can be done through a personalized brain training application. It is not a challenge to use an application through a mobile phone due to the frequent usage of smart devices by the current society.

With the development of machine learning and deep learning techniques, most of the people use these technologies according to the requirements of applications. For a customized brain training application, machine learning and deep learning technologies like RL, NLP, CNN have used. RL is an area concerned with how the software agents are responsible to take actions according to the environment in order to increase the notion of cumulative reward. RL is used for building up this application as a personalized, customized solution. NLP is a technique that the ability of computer for understanding and analyzing human languages. Using CNN, acoustic model for raw speech signals can be identified. With the help of NLP and CNN, speech recognition for game of language

skill component can be done easily. While patient is away from the doctor, patients can practice the relevant functionalities which has been recommended by the doctor to reduce the symptoms of Dementia. This brain training application will be an incredible assistant for the Dementia patients to decrease the disabilities of brain cells.

1.1 Background

Dementia is a type of a brain disorder which damages to cognitive functionalities of human brain. There are four cognitive functionalities addressed through this personalized brain training application. Attention and concentration, executive function, language skills, memory skills are those cognitive functionalities. There are many Dementia caring applications on different languages around the world. But some are for saving Dementia patients indoor and outdoor using a safety monitoring mechanism. Self-monitoring brain training applications are beneficial.

There are different categories for Dementia. Among those categories, five categories are main as follows.

- Alzheimer's disease
- Vascular Dementia
- Lewy Body Dementia
- Frontotemporal Dementia
- Mixed Dementia

Dementia patients have physical, mental, social problems, losing family bonds and also society connection due to the affection of the disease. Loss of memory, no sensitivity of time and place are some of the symptoms that can be seen through a patient with Dementia. Among these problems in Dementia, patients are suffering from it daily.

There are three stages of Dementia.

- Mild stage (Early Stage)

- Moderate Stage (Middle Stage)
- Severe Stage (Final Stage)

When considering about the above stages, it is difficult to recover a patient from these stages. Except the severe stage, the symptoms of Dementia on mild and moderate stages can be reduced gradually. For that, practicing a brain training application with cognitive rehabilitation is the only way to reduce it. A personalized therapy is done during the practice of this application according to the relevant cognitive functionality to be improved. And also, there is not a proper application to correctly guide the Dementia patients in Sri Lanka due to not having much knowledge about English language for most of elderly people in Sri Lanka. So, they cannot use the applications of other countries. It will be beneficial for Dementia patients for having a brain training application to improve cognitive functionalities with continuous monitoring on both Sinhala and English languages.

1.2 Literature Review

1.2.1 Dementia

With the development of the countries in the world, Dementia will be turned into an epidemiology due to the increase of dementia patients aged 60 years and older from 19% currently to almost 40% in year 2050. Dementia drastically affects to daily routine and personal activities and at the same time it is often associated with behavioral symptoms, personality change and numerous clinical complications. According to Maria Cristina Polidori, there is epidemiological evidence that lifestyle which is engaged in leisure activities of intellectual and social nature are associated with slower cognitive decline in a healthy way for elderly people and it may reduce the risk of incident dementia. The performance of cognitively stimulating activities according to the personal interests, abilities and education of dementia patients are caused to reduce the passive behaviors of them [3]. The study which was done in Sri Lanka determining the prevalence of Alzheimer's disease and other dementia diseases in an area of the country renders that

greater age, illiteracy and female gender has associated with the higher prevalence dementia [4].

1.2.2 Mobile Applications for Dementia patients

Family members are the key caregiving role around the dementia patients often, especially for the patients in initial stages. The new effective treatments and prevention strategies need to be developed and increased due to the increase of the dementia patients in upcoming years. When seeking for the alternatives for the dementia, technology can be used to connect dementia patients and treat those patients considerably individualizing the care between patient and caregiver according to their own needs. Christina Yamagata, Marc Kowtko, Jean F. Coppola, Shannon Joyce focused on the mobile devices as a new solution to stimulate the cognition of older adults and other patients suffering from different types of dementia. And the use of brain, memory, and solving problems using different types of games help to stimulate the brain and reduce the symptoms of dementia. The brain games, other mobile-based and computer-based solution for the stimulation therapy has enlightened the health care of dementia patients [5]. According to the presumption of by M. H. Acharya, T. B. Gokani, K. N. Chauhan and B. P. Pandya, they gave a try to fill the gap between patient and caregivers by using the application that they made. The idea behind building up that android application for dementia patient was that Android is widely accepted and open source operating system in nowadays [6].

1.2.3 Speech Recognition using Deep Learning

Over the previous decades, a huge amount of research has been done on the use of machine learning for speech processing applications, especially speech recognition. However, in the past few years, researches have focused on utilizing deep learning for speech-related applications. This new area of machine learning has yielded far better results when compared to others in a variety of applications including speech, and thus became a very attractive area. Deep learning models can also operate as a greedy layer wise unsupervised pre-training. This means that it will learn hierarchy from extracted features from each layer at a time. Feature learning is achieved by training each layer with an unsupervised

learning algorithm, which takes the features extracted from the previous layer and uses it as an input for the next layer. Deep learning algorithms have been mostly used to further enhance the capabilities of computers so that it understands what humans can do, which includes speech recognition. Speech is being the main method of communication among human beings, received much interest for the past five decades right from the introduction of artificial intelligence. The conventional speech recognition systems are based on representing speech signals using GMMs that are based on HHMs. This is due to the fact that a speech signal can be considered as a piecewise stationary signal or in other terms a short time stationary signal. In this short time scale, the speech signal can be approximated as a stationary process, thus it can be thought of as a Markov model for many stochastic processes [7].

In past few years, it is focused on utilizing Deep Learning (DL) for speech related applications. DL algorithms have been mostly used to further enhance the capabilities of computers so that it understands what humans can do, which includes speech recognition. The conventional speech recognition systems are based on representing speech signals using Gaussian Mixture Models (GMM) that are based on HMM. This is since a speech signal can be considered as a piecewise stationary signal or in other terms a short time stationary signal. In this short time scale, the speech signal can be approximated as a stationary process, thus it can be thought of as a Markov model for many stochastic processes. However, the Convolutional Neural Networks (CNN) have shown effectiveness when using in computer vision or image recognition tasks. Also, with some appropriate changes in the CNN for image analysis purposes such that it incorporates speech properties, the CNN can be utilized in speech recognition as well [8]. Automatic Speech Recognition (ASR) systems convert the speech signal into its corresponding text. Traditional ASR systems are based on GMM. End-to-end ASR systems are gaining much popularity due to simplified model-building process and abilities to directly map speech into the text without any predefined alignments. Three major types of end-to-end architectures for ASR are attention-based methods, connectionist temporal classification,

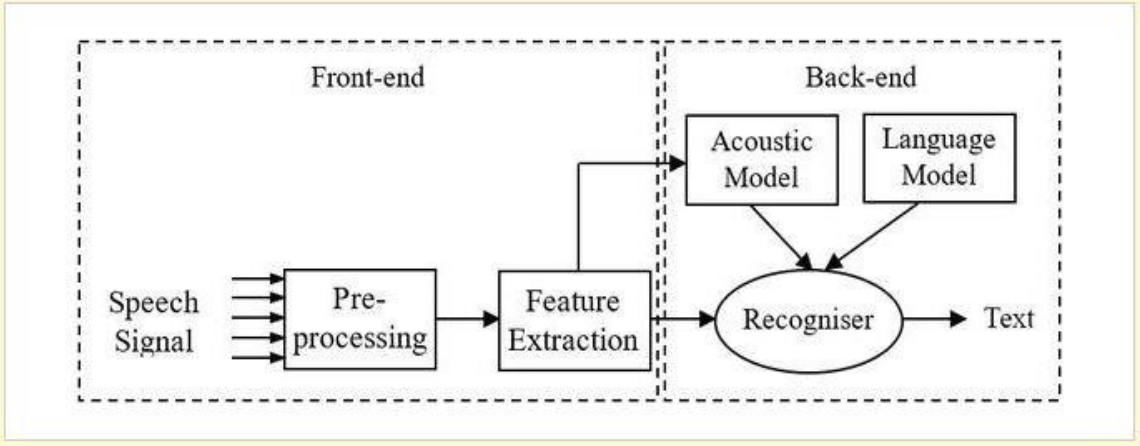

Figure 1: General framework of automatic speech recognition system

and CNN-based direct raw speech model. End-to-end model may take raw speech signal as input and generates phoneme class conditional probabilities as output [9].

Speech has not been used much in the field of electronics and computers due to the complexity and variety of speech signals and sounds. However, we can process speech signals easily and recognize the text with the modern processes, algorithms, and methods. Speech recognition system directly acquires and converts speech into text. Speech recognition is done via the internet by connecting to Google's server. The application is adapted to input messages in English. Speech recognition for Voice uses a technique based on HMM. It is currently the most successful and most flexible approach of speech recognition. Process involves the conversion of acoustic speech into a set of words and it is performed by software component. Accuracy of speech recognition systems differ in vocabulary size and confusability, speaker dependence vs. independence, modality of speech (isolated, discontinuous, or continuous speech, read or spontaneous speech), task and language constraints. Dictionary is used to connect acoustic models with vocabulary words. Language model reduces the number of acceptable word combinations based on the rules of language and statistical information from different texts. Speech recognition systems based on hidden Markov models are the most widely applied contemporary modern technology [10].

Deep learning methods are being applied in various recognition tasks for recognizing images, speech, and different kinds of music. CNN especially shows remarkable recognition performance for computer vision tasks. In addition, RNNs show considerable success in many sequential data processing tasks. Investigating the result of the SER algorithm is based on CNNs and RNNs trained using an emotional speech database. Deep learning involves hierarchical representations with increasing levels of abstraction. By traversing sequentially constructed networks, the results corresponding to each selected audio frame are classified using a sum of probabilities [11].

Brendon Stubbs and Lee Hollins mentioned that rehabilitating cognitive functions assist to improve the patient's motivation, activate the brain by making the patient enjoyable and happy [12]. There are existing games to improve cognitive functionalities of dementia patients. When considering about dementia patients, those patients are in different kind of stages and specially this disease is dealing with the patient's brain. So, because of that it always differs from patient to patient. It is not possible to give the same game for every patient. That is why this research was focused on developing a personalized, most suitable game for each individual patient. In there, the application observes the stage of each patient separately and predict the best next levels according to the way how patient play the game by using RL.

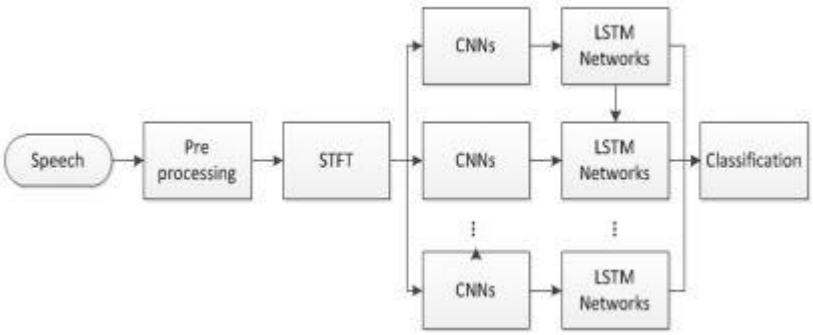

Figure 2: Block diagram of our time distributed network-based SER method

1.3 Research Gap

Most of the applications Dementia prevention applications have only focused to active brain cells of Dementia patients. Therefore, a better cognitive rehabilitation cannot be done through those applications. Because of that, the tendency of reducing the symptoms of Dementia is in a low level. To get preventing from the risk of Dementia, it is necessary to have a personalized therapy with cognitive rehabilitation.

Lumosity is a popular brain training application which is mostly focused on memory and processing speed of Dementia patients. Even though this application is a brain training application, it is not personalized according to patient's condition considering about cognitive functionality to be improved according to the Dementia type and its stage. Elevate is another application to prevent Dementia and it is designed to improve attention, speaking skills, memory and mathematic skills. It is also not focused to personalize the application according to the patient. But it is focused more about cognitive functionality related activities such as attention, speaking and memory. Brain Games and Eidetic are also brain training applications. But Eidetic is for learning phone numbers, pin codes, birthdays using a repetition technique. Both of these applications have not considered about personalizing or customizing the activities.

Through all the existing applications for Dementia, which is mentioned above, patients can review progress reports except the Brain Games application. Lumosity and Elevate applications are suitable for elderly Dementia patients. All these applications have made using English Language. In Elevate application, there are some activities for speaking practices of Dementia patients due to impairment of language problem on speaking. But other than that, there are not games for other language impairments on that application. All the games included in that application based on English language. But the problem is most of the Sri Lankan elderly people have not much necessary knowledge about English Language. Considering about this problem, the newly created DCare application is built for both Sinhala and English languages. In that application, there are activities on arranging jumbled words for improving comprehension of Dementia patients and

activities for speaking practices. And it is personalized and suitable for elderly people because it has considered about several cognitive functionalities separately. All the performance of the patient can be reviewed as a report through the application.

The features which were described in the above paragraphs have summarized as a comparison between different types of brain training applications in the below table (Table1.1).

Table 1: comparison between existing applications and newly created DCare application

Features	**Lumosity**	**Brain Games**	**Elevate**	**Eidetic**	**DCare (new)**
Personalized application	✗	✗	✗	✗	✓
Games have created on considering cognitive functionalities	✗	✗	✓	✗	✓
Review progress report	✓	✓	✓	✓	✓
Send progress report to caregiver and doctor via email	✗	✗	✗	✗	✓
Compatibility on Sinhala language	✗	✗	✗	✗	✓
Speaking practicing activities based on languages	✗	✗	✓	✗	✓

1.4 Research Problem

With the increase of the ageing population, the number of Dementia patients will be increased gradually because most of the people under adult's range are facing to this syndrome and as well as the number of Dementia patients are increased double in every 20 years globally [3]. The reality of Dementia case is that there is not a proper medication to get recovery from it. This is the preliminary significant issue caused for this syndrome. To get rid from Dementia risk, it should be exactly to have a cognitive rehabilitation therapy. When considering about language skill impairment problem, patients are needed to be rehabilitate on different skills such as speaking, comprehension etc. The considerable problem of the language skill cognitive functionality is that there is less amount of applications to rehabilitate patients on that. And also, the non-proficiency of Dementia patients in Sri Lanka with the English language is another kind of a obstacle that they are facing to refrain using a brain training applications.

The best way to keep the patients securely at home is that a well-planned guidance through a caregiver for the patient. It would be possible to give that guidance through a brain training application on all the cognitive functionalities. Considering about all the factors mentioned above, giving a solution for the impairment of the language skills cognitive functionality using activities using speech to text communication is the way to keep the patients, their family members and caregivers day-to-day life easier.

1.5 Research Objectives

The activation on cognitive functionalities of Temporal lobe and Frontal Lobe is under a low level of the patients who are suffering from Dementia disorder. Among all the cognitive functionalities, language skills are the most important thing when communicating with other people and conveying ideas in the society. Through this component, it is mainly focused on bringing out and electronic based solution which means mobile application including activities on comprehension and speaking with the enhancement of those skills on both Sinhala language and English language. Those

activities are recommended by a consultant Psychiatrist according to the way decreasing language impairment of Dementia patients on language skill functionality. All the activities are designed with user friendly interfaces which are suitable according to the elderly people.

There are some specific objectives to this brain training application. Games are based to reduce the speaking and comprehension disability of Dementia patients and orientate the patients to their normal daily routine. And it will be a great benefaction for both caregiver and patient. Through the cognitive rehabilitation therapy, this attempt is to hold on moving the Dementia condition from one stage to the next stage. Rehabilitating the patient with a continuous monitoring system is another intention through this application. Giving a comfortable life for Dementia patients is the uncountable final achievement through this brain training application.

2. METHODOLOGY

2.1 Methodology

At the beginning of the research project, project initiation was done. Under this stage feasibility study was completed. There are several feasibility studies was done to clear out the importance, benefits and some of the obstacles to be identified.

The first study was on Economic. In there, the priority was on cost and benefits of the project. This feasibility study was to ascertain those cost and its benefits. Our proposed solution is for the Dementia patients who are on mild and moderate stages. So, this application is some kind of a benefit for the patients to recover from this disorder. Dementia has economical impact around the world since there is no exact medication and there are very cost-effective therapies to control the situation of Dementia patients. And it is unbearable for patients. This implemented brain training application is capable enough for Dementia patients to recover under a bearable cost. The second study was on operational feasibility. In there, the operational level of the final product on the end user was the most focused area. The proposed solution interacts with the caregiver and the doctor also. Among that, the progress of the patient can be seen by them. And this application is proficient with both Sinhala and English languages considering more about the Dementia patients in Sri Lanka. Technical feasibility study was covered technical resources accessible for proposed solution and installation, other things about those resources to develop the ultimate product. The last study was scheduling feasibility study. This is most important study area of the project. Sketching out the project and estimated timeline of the project was decided at this study.

After that requirements were gathered. The requirements gathering was done under the supervision of consultant Psychiatrist and also data were collected through a survey consisted with fifteen multiple choice questions. The purpose of this survey is to get the considerable responses with many numbers of people for the given questions. Based on all these requirements, the team decided to implement the brain training application for

both Sinhala and English languages based on games and activities considering all four cognitive functionalities.

2.1.1 Overview

According to the following Figure 2 it is showed the complete view of the language component.

The main idea of the system is to bring out a mobile application for Dementia patients which includes different types of mobile games or activities to rehabilitate the patients in a cognitive way. Through this language component, it is built activities for the rehabilitation of language skill functionality.

Based on the MMSE testing report, the doctor recommends the particular functionality to be selected for the patient. According to that caregiver can select the relevant functionality after creating an account for the patient on this application and logging through that account. In this case caregiver should give the all the correct details of the patient into the system.

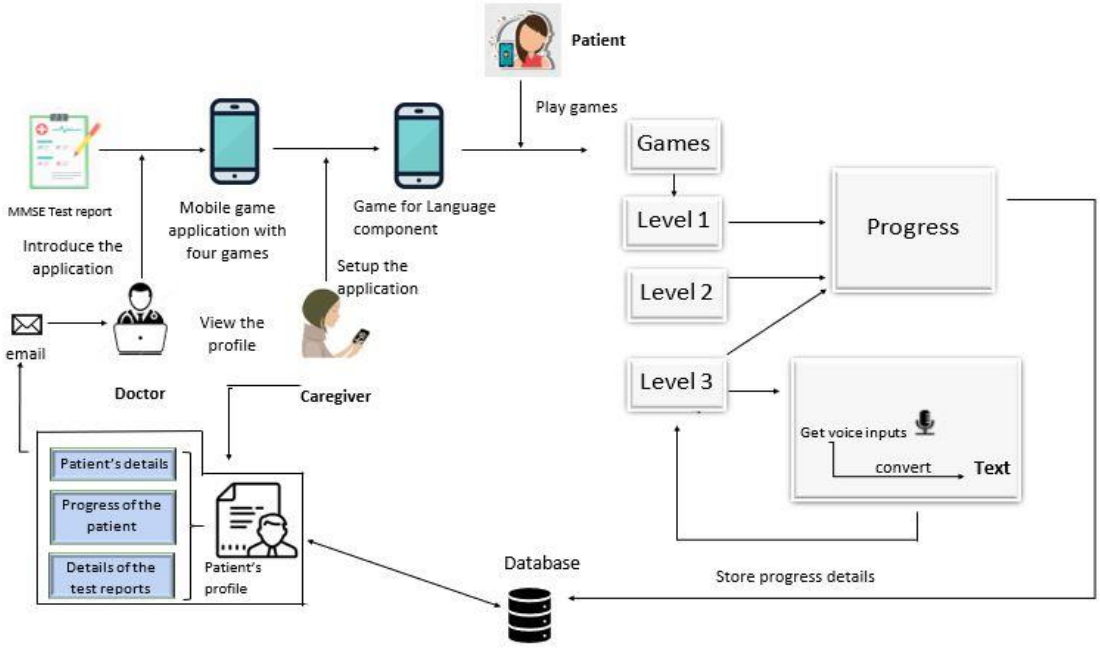

Figure 3: Language Component Overview

The reason is that patient's progress and all will be depended on these personal data. All the guidelines of using the application are provided in both Sinhala and English languages. After the basic preparation of the application, now patient can choose the game component and play the games starting from the basic initial level. With the progress patient can be move further.

This brain training mobile application used different technologies and platforms for developing it. For the game implementation of language component, C# programming language was used with the Unity game developing platform. Speech recognition was done using HMM and NLP technologies on DL. The speech recognition model for both Sinhala and English language was trained and created with CMUSphinx library. When considering about language component, patients who are suffering from speaking disabilities and comprehension problems. This component is included with three levels consisting three different games.

In the first level of the game, there are three parts. For each part there is a jumbled word list consisting with ten words to build up correctly. The words should be built up according to the given picture there.

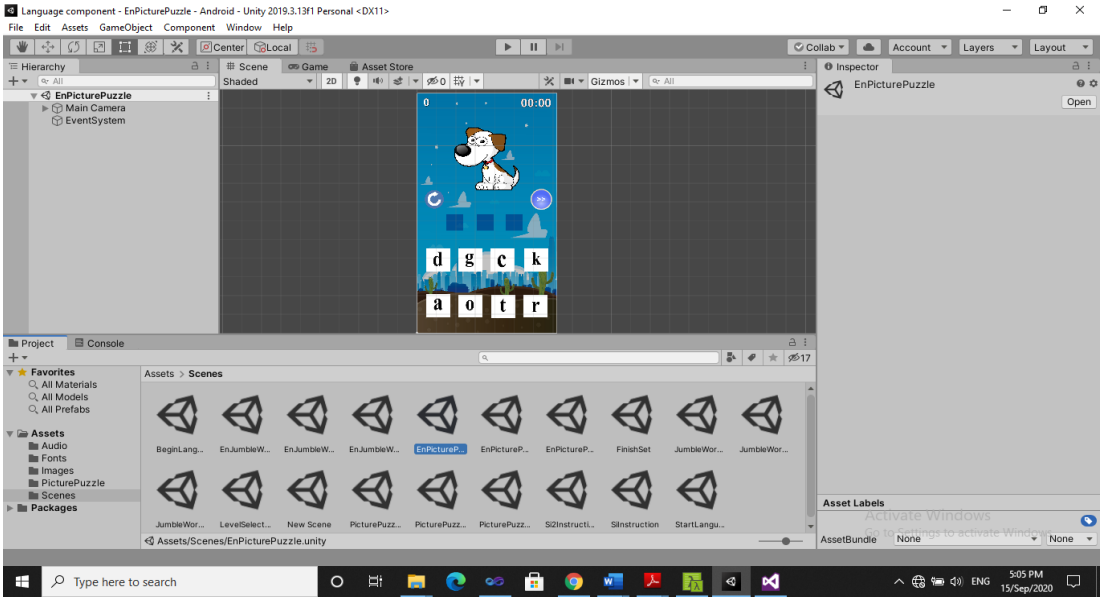

Figure 4: Game level 1 preparation with Unity game engine

These games should be done within the given time. And score will be added when the correct word is built up by the patient. When going to game part one, part two and part three, the number of the words are increased three letters, four letters, five letters consecutively to increase the complexity. According to that, all the given words are three letters words for the part one of the level one. In the part two, words are four letters and part three, words are five letters for the same level. On the game level two, there are no pictures to identify due to increase the complexity this level. There are only jumbled words to identify.

In third level of the game, it is an activity for the patients to practice the speaking words. In the display, it is shown the words. Then the patient has to speaking those words which are displayed for practicing. When the patient pronounces the words, those words are displayed on the screen as text. This scenario is speech to text process. Speech recognition system is done using acoustic model. Acoustic model is used for automatic speech recognition system to represent the relationship between an audio signal and the phonemes which makes the speech. This model is learned from a set of audio recordings and its corresponding transcripts. The acoustic model used in this brain training application is acoustic model trainer named CMUSphinx. This includes a series of speech recognizers. Because of that this acoustic model trainer can identify any language if we train number of voice recordings for the relevant language. The reason for selecting this trainer, it is compatible for both Sinhala and English languages according to our necessity of the application.

First of all, we need to set up the environment to train the CMUSphinx model. In there, it is set up the database to be used. Figure 5 shows how to set up that environment for the database. Python commands was given because this model is based on the Python programming language. Cmder command prompter have used to run commands for the acoustic model building.

Figure 5: Set up the database for training the model

The following Figure 6 shows how voice recording wav files of different people were trained using sphinx library using voice recordings.

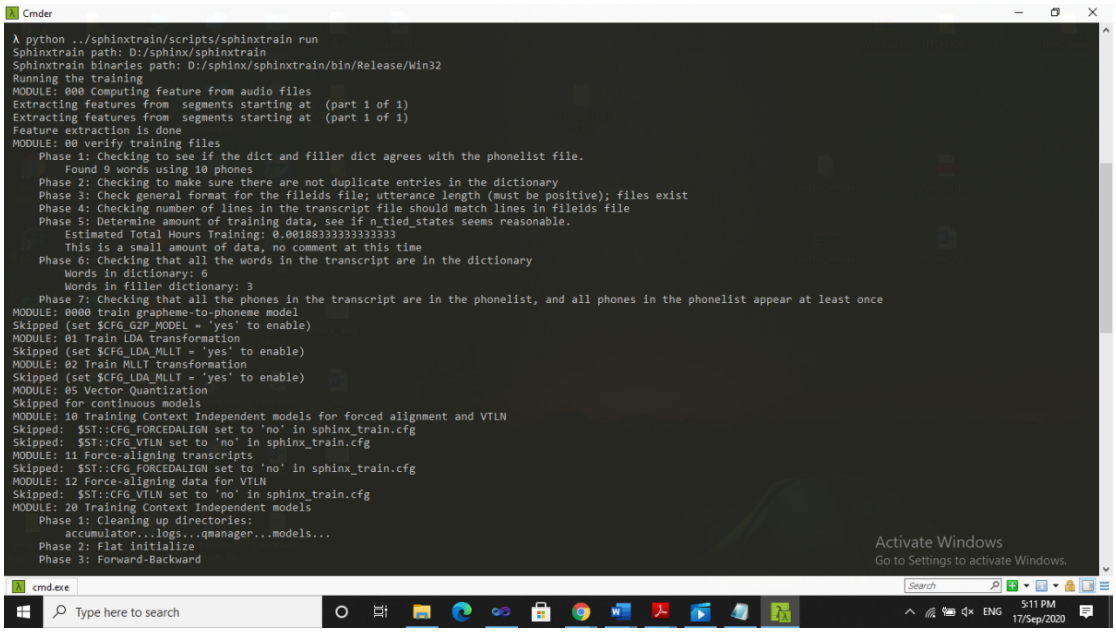

Figure 6: Training the acoustic model using CMUSphinx

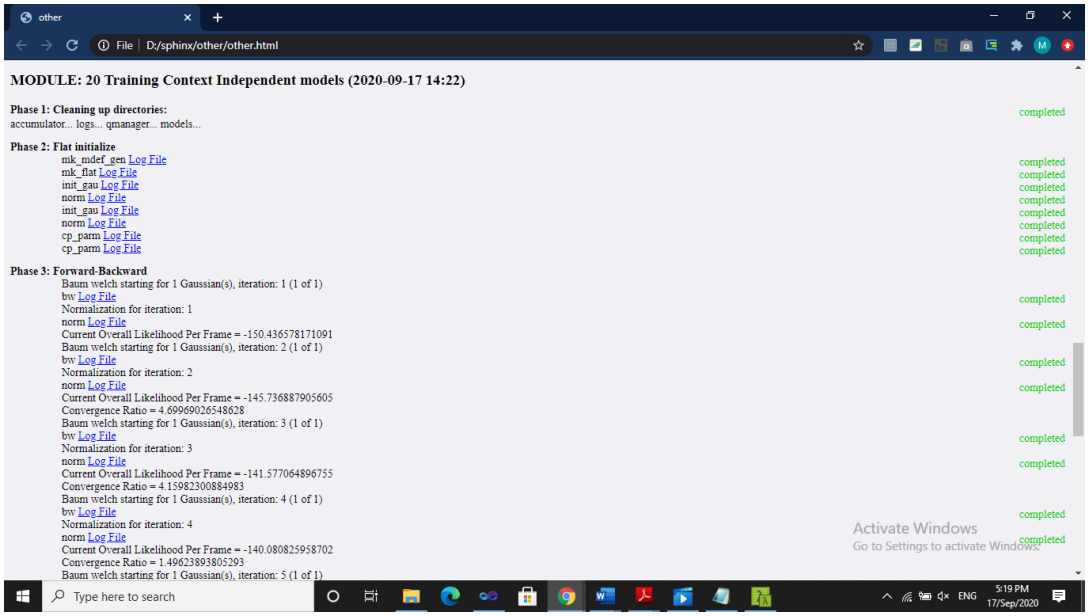

Figure 7: .html result file after training the model

After training the CMUSphinx model, it can be tested this trained model to check the speech to text process whether it works properly.

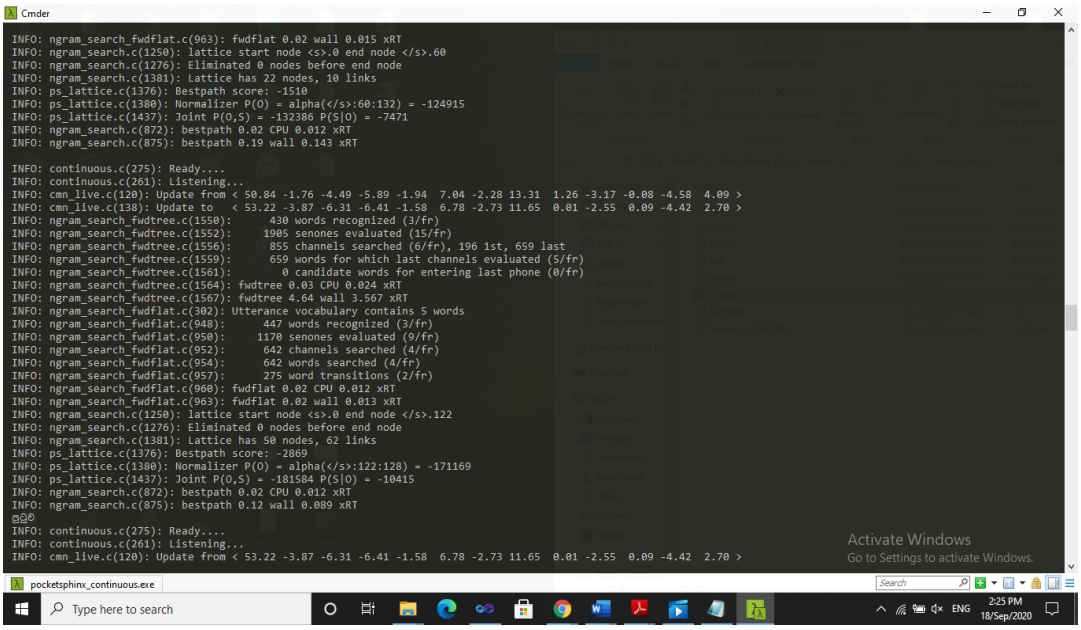

Figure 8: checking the created acoustic model

The progress of the Dementia patients should be seen by the doctor. Because if the patient needs more guidance from the doctor furthermore, the connection between doctor and the patient is a necessity. And then doctor can review the progress of the patient and give the relevant guidance. As the solution for that, at the end of every week of playing game, the doctor receives email containing the progress report of the patient for the relevant week through this brain training application. Among that doctor can see the progress of the patient weekly. For that, SMTP server was used to email sending process of this application. SMTP server which is known as Simple Mail Transfer Protocol for electronic mail transmission.

2.1.2 Data Management

Every single application deal with the data. It can be small amount or large amount of data. But all these data should be maintained to a procedure. So, it is an administrative process to input, store, retrieve and delete data. Data management comprises all disciplines related to managing data as a valuable resource. When considering about the language skills component of this developed application, we have to handle some amount of data. The patients play the games and get some scores according their performance. This score is needed to be store securely in a database. Because these data are needed to send email to the doctor to show the progress of the patient. And also, caregiver and patient also want to see these data. And at the same time, to do all these things patients and doctor should register with this application and login through that accounts. When the registering someone for the it, the application stores the details of the patients and doctors. So, in there also the necessity is for having a datastore. For a secure data protection of this application, it is used PlayerPref which a local database inside the Unity game development engine. The data can be stored locally inside it. For running the application on different mobiles, the data cannot be stored in a local database. It is needed to store another external database server. For that, it is used Microsoft Azure PlayFab.

PlayFab is a serverless complete backend platform which is suitable for live game and it is owned by Microsoft. And it is a backend NoSQL database with a pre-structure for

games. This PlayFab has multiple services which are made for gaming applications. The services of PlayFab enable developers to use the cloud to build and operate games, analyze gaming data and improve the gaming experience. To the use of the PlayFab in this brain training application, it is created an account on Azure PlayFab and used the services.

2.2 Commercialization

We are surrounded by a world of electronic devices and it is an indispensable part of the daily life of people. And the demand of using mobile applications is an attentive fact nowadays. According to it, giving up a solution through game-based activities on a mobile application for Dementia disorder will be beneficial for the patients as well as every other people around those patients like family members, friends, caregivers, doctors etc.

We can introduce this application to psychiatrist doctors who are dealing with Dementia patients. Psychiatrists do relevant testing processes like MMSE testing for Dementia patients. And then psychiatrist can identify the necessary cognitive functionality or functionalities to be improved for the relevant patient. According to the recommendation of the doctor, patient plays the recommended activities to improve the impairment of necessary cognitive functionality or functionalities.

We can advert caregivers pointing out the benefits of using this brain training application for Dementia patients. Among that also we can inspirit the caregivers to give this application to play for Dementia patients with the recommendation of the doctor. Patients can have one month of trial period. After that doctors can monitor the progress of the patient and decide how the patients should play the games thenceforth. Patients can install this application to their smart phones and continue the with the games.

2.3 Testing and Implementation

2.3.1 Testing

Unit testing is some kind of a software testing where the individual units or component of a system software are tested. This unit testing is a WhiteBox testing technique. The purpose of doing unit testing is to validate the each of the unit in code perform as expected. This is done during the development of the software. In Unity game developing, it is used Test Runner for unit testing processing. The unit tests can be run programmatically from any script via the Test Runner API. This allows to retrieve a list of tests that will run in Edit Mode, Play Mode or both without running them. The unit testing example was given in the Figure 9.

The following tables Table 2, 3, 4 are some of the manual test cases which were used to check that the features and functionalities of the application working properly as expected.

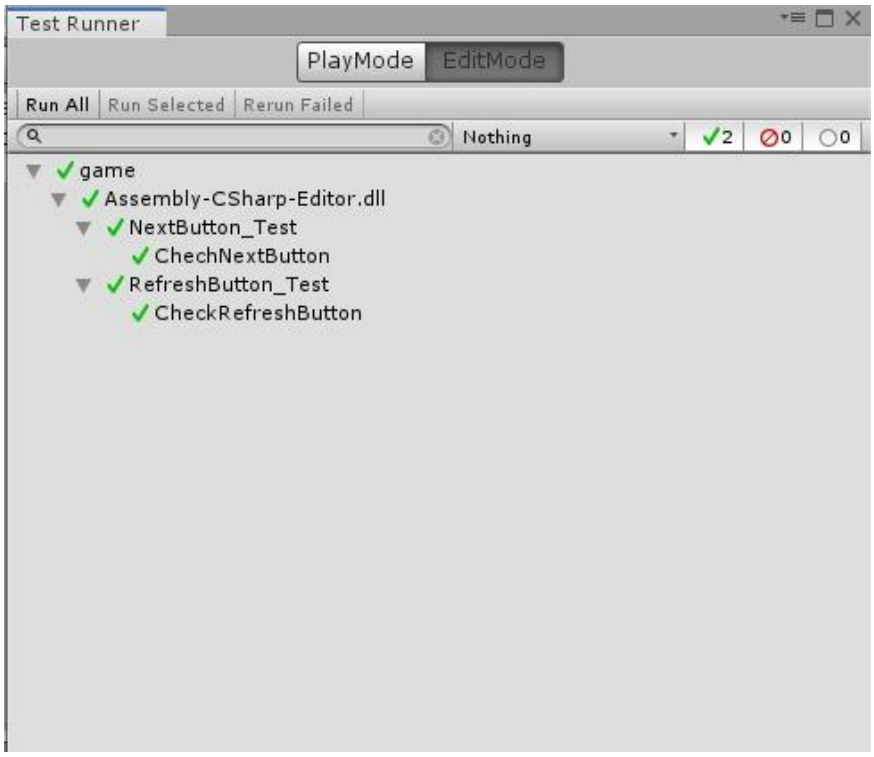

Figure 9: Unit Testing on Unity Game Development

Table 2: Test for next button

Test Case ID	01
Description	Go to next page to build the next word
Pre-Condition	Install the application to mobile phone
Steps	1. Open the application 2. Read the guidelines of playing the game 3. Selects the level “1” button or “2” button 4. Have a look into the given jumbled letters to build up the word 5. Drag the letters into the given boxes 6. Click the “next” button to load the next word page
Extensions	6.1. If the patient clicks next without dragging letters into boxes, application makes error sound
Expected Output	After clicking the next button, it is loaded the next page and score is added to correct built word
Actual Output	After clicking the next button, it is loaded the next page and score is added to correct built word
Pass/Fail	Pass

Table 3: Test for refresh button

Test Case ID	02
Description	Refresh the built word and build word again
Pre-Condition	Install the application to mobile phone
Steps	1. Open the application 2. Read the guidelines of playing the game 3. Selects the level “1” button or “2” button 4. Have a look into the given jumbled letters to build up the word 5. Drag the letters into the given boxes 6. Click the “refresh” button to refresh the built word
Extensions	7.1. If the patient clicks refresh without dragging letters into boxes, refresh does not work
Expected Output	After clicking the refresh button, it refreshes the built word and show the same word to build again
Actual Output	After clicking the refresh button, it refreshes the built word and show the same word to build again
Pass/Fail	Pass

Table 4: Test for game level one

Test Case ID	03
Description	Play the game level 1
Pre-Condition	Install the application to mobile phone
Steps	1. Open the application 2. Read the guidelines of playing the game 3. Selects the level "1" button 4. Select the part "1" button 5. Have a look into the given picture and jumbled letters to build up the word 6. Drag the letters into the given boxes 7. Click the "next" button to load next page with word 8. Do the same procedure until the given words are finished. 9. After finishing the part 1, select part 2 and play the game as part 1 10. After finishing part 2 and play part 3
Extensions	8.1. If patient doesn't play the game part 1 within the given time, the game is redirected to the part 1 again 9.1. If patient doesn't play the game part 2 within the given time, the game is redirected to the part 2 again 10.1. If patient doesn't play the game part 3 within the given time, the game is redirected to the part 3 again
Expected Output	Play the game level 1 successfully
Actual Output	Play the game level 1 successfully
Pass/Fail	Pass

2.3.2 Implementation

Implementation is the most significant part of building up a project. This brain training application was built using Unity game development engine and speech to text model on acoustic model (CMUSphinx model).

The Figure 10 contains the code in the .cs class file which is created to drag the letters to the given boxes in the game level part 1 of both level 1 and 2. This is for the three letters words. According to the functionality created on this class, the given all eight letters can be dragged into any of three boxes given.

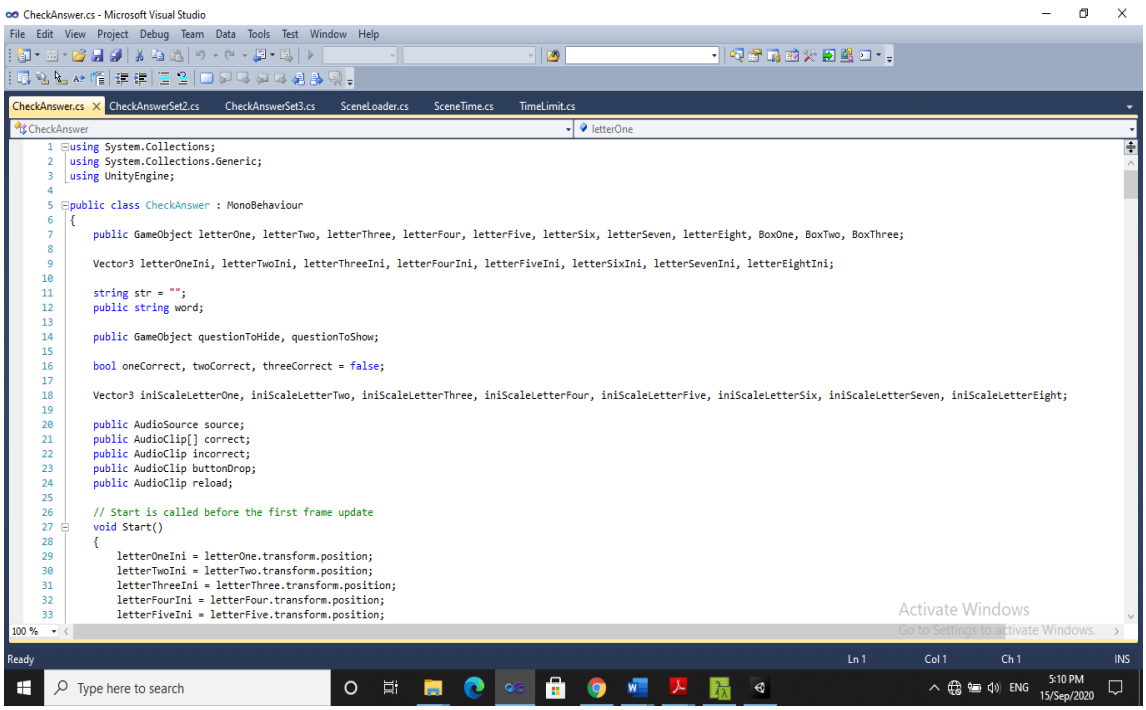

Figure 10: Process of dragging letters to the given boxes

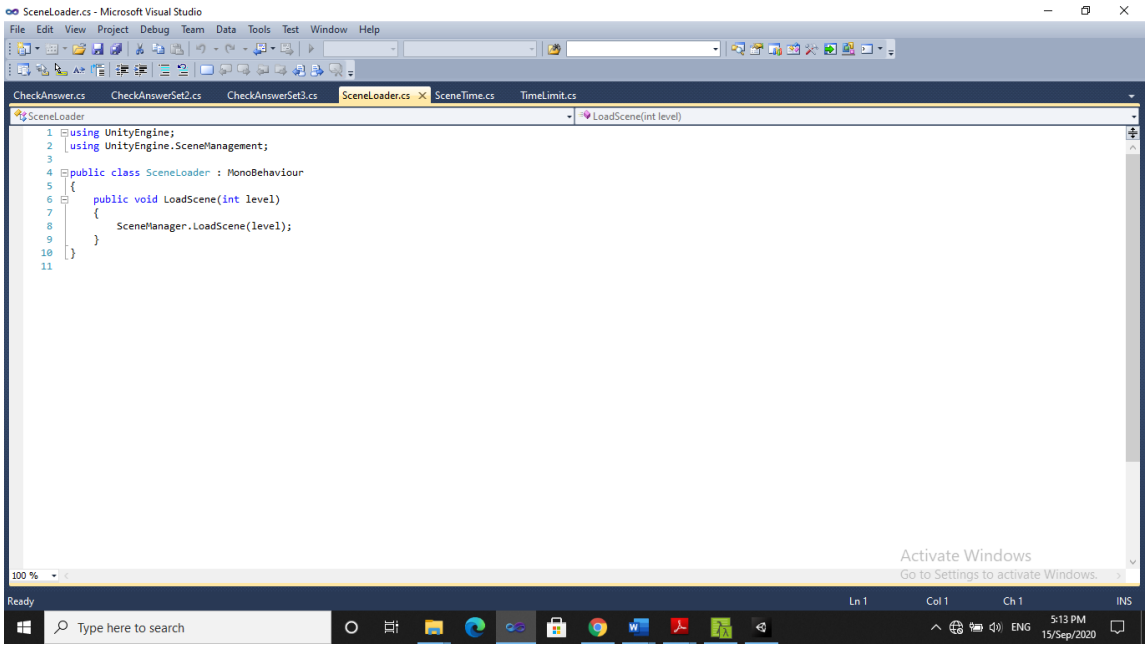

Figure 11: Next scene loader

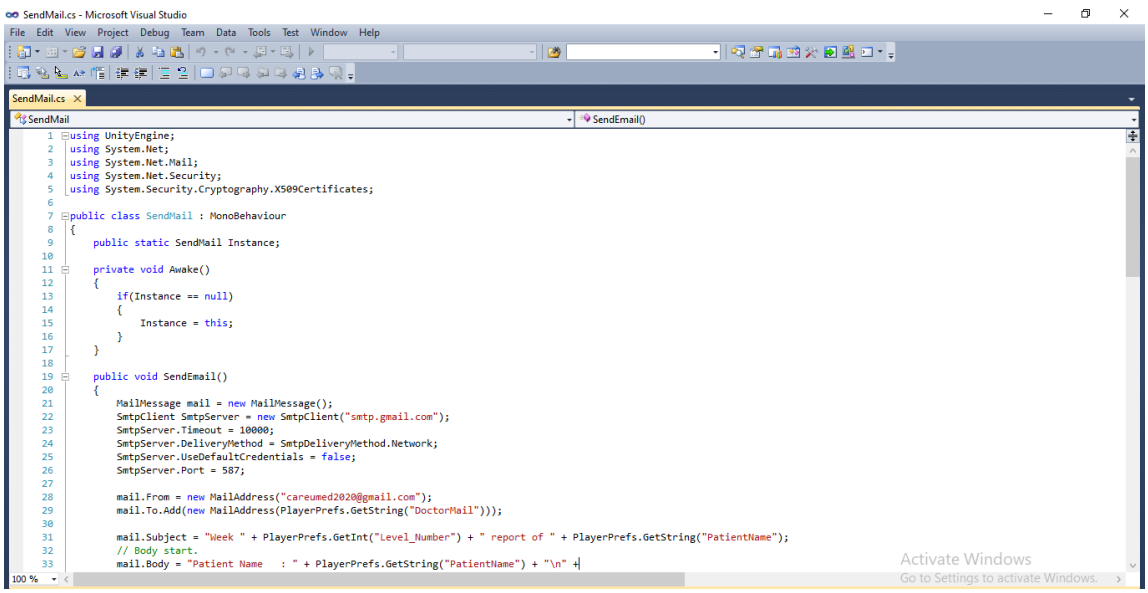

Figure 12 : Sending Mails using SMTP server

The implementation for sending mails to the doctor was created as the above Figure 13 using SMTP service.

At the same time, weekly progress of the Language component was done. This progress shows using a bar chart and the calculation for the progress as following Figure. This calculation and progress were created using an iteration according to the Figure13 shows. And it is used PlayerPref for storing data inside the databases locally and also PlayFab to store data in the database server.

Sending weekly report is another advantage of this created system. The Figure 14 shows the structure of the email that is sent to the doctor containing the progress up to seventh week of the patient who plays the games under language component.

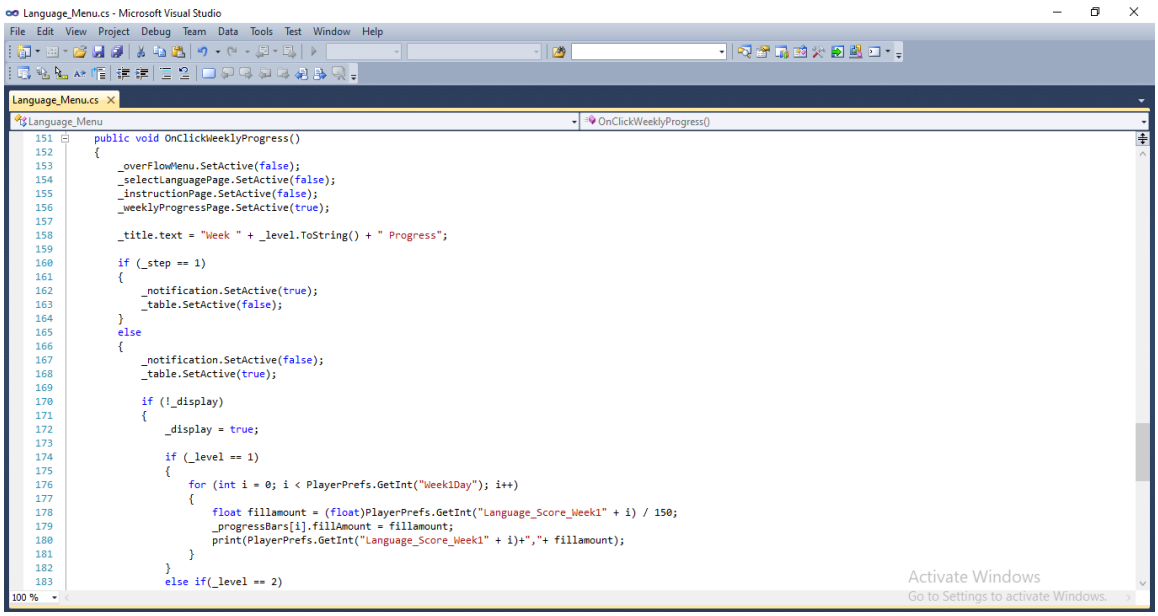

Figure 13 : Weekly Progress Calculation of Language Component

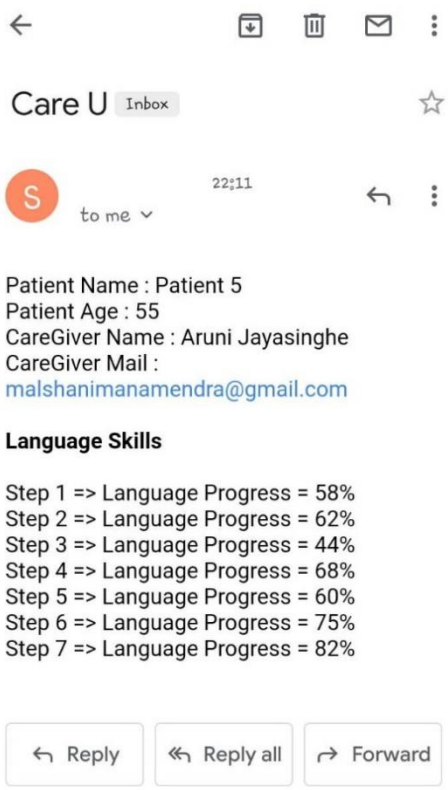

Figure 14 : Progress Email of the patient

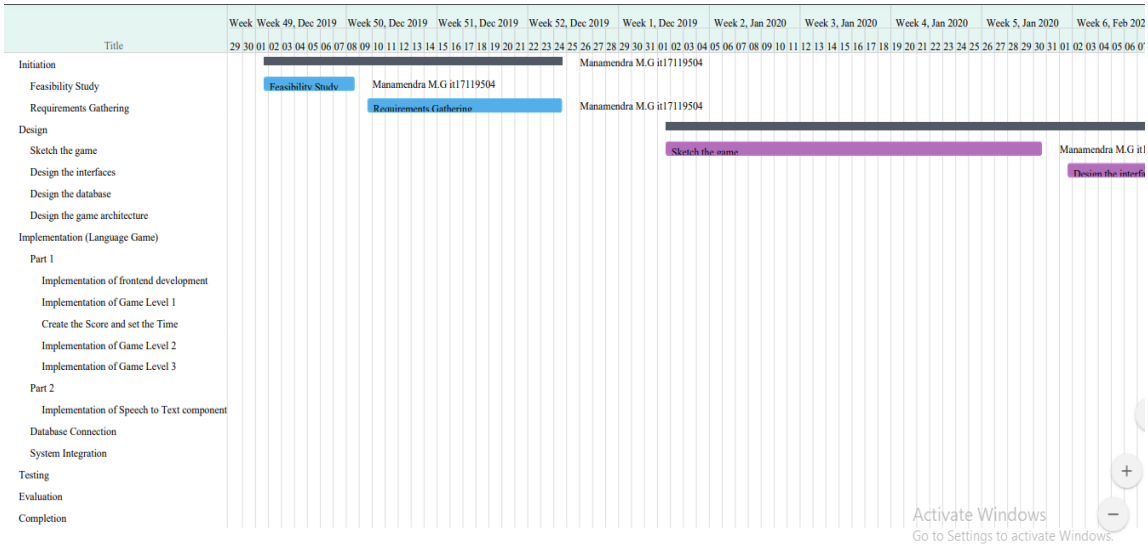

Figure 15 : Gantt Chart of the Language Skills Component

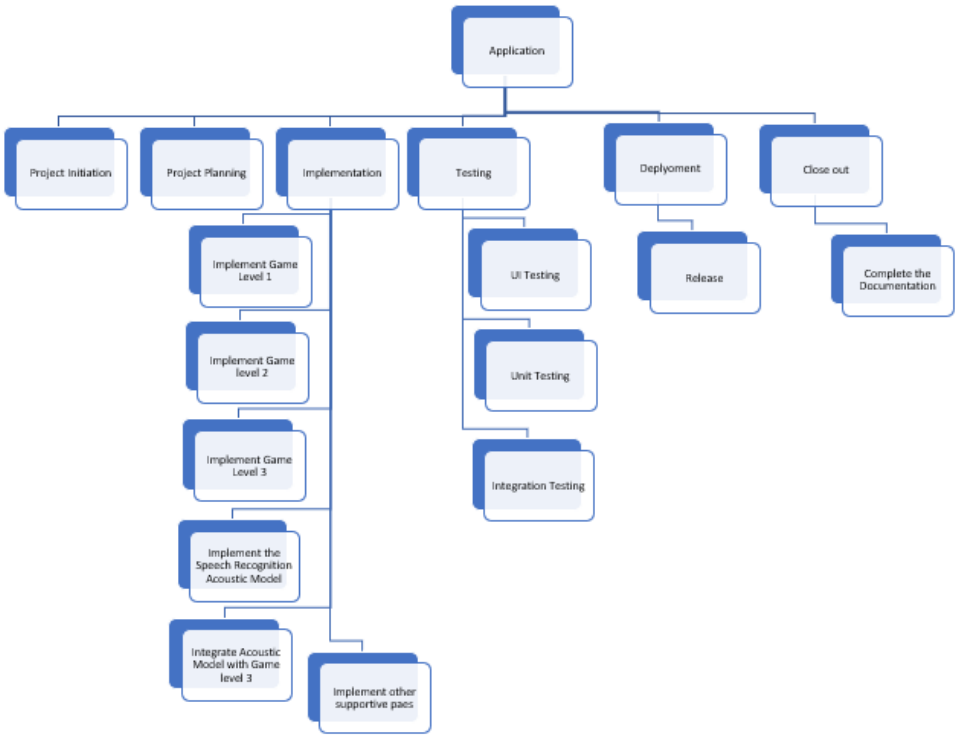

Figure 16 : Work Breakdown Structure of Language Skills Component

The Figure 15 Gantt chart and Figure 15 Work Breakdown Structure shows all the details about the language component throughout the whole research study. The Figure 16 Gantt Chart shows the days of the months and stages that we completed during that time period very clearly. And at the same time Figure 15 Work Breakdown Structure shows the steps that finished the language component from the project initiation.

3. RESULTS AND DISCUSSION

3.1 Results

When considering about the results, it is the most important finalized outcome after creating a system. The interfaces of the applications are the first appearance of any system which any user is first looking for. Figure shows some sample interfaces for language component.

Figure 17 : Interface for English Language Game

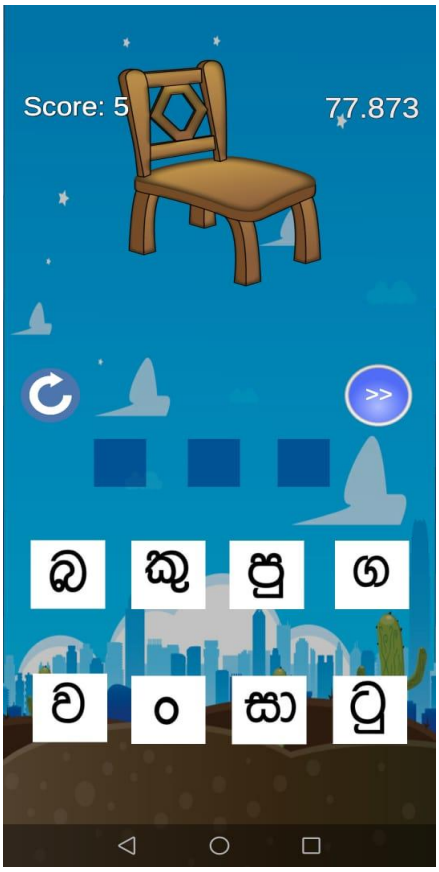

Figure 18 : Interface for Sinhala Language Game

And the progress representation of the most valuable outcome of this research study. Because that representation shows the progress of the Dementia patients using graphs and that progress goes to the doctor and caregiver as email. The calculation to get the progress was done as follows.

The patient plays one level of the game and each level has three parts. For each part, there are ten questions. If patient answer correctly, he or she can get 5 marks for each question. Altogether 50 mark for each level. There are three parts like that. So, 150 total marks have for each level. This one level should be played 14 days or else two weeks by the patient.

progress percentage = (marks got by the patient) / (total marks for the level) * 100%

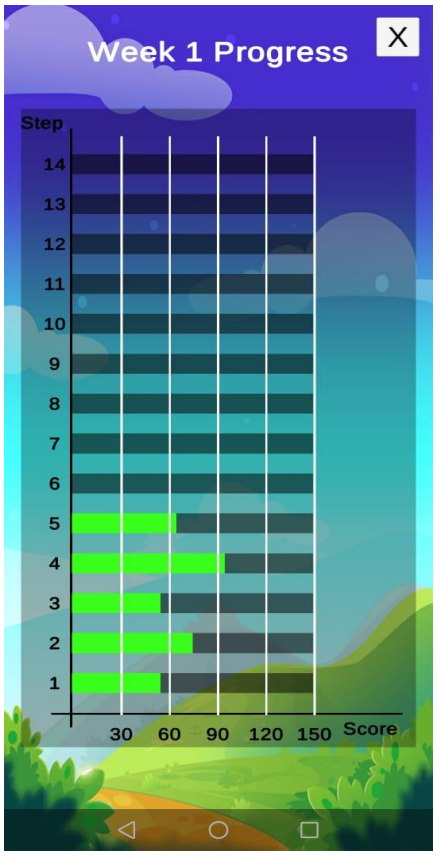

Figure 19 : Weekly Progress Representation

3.2 Research Findings

This research study was performed to provide a solution for rehabilitating Dementia patients in a cognitive way through an electronic device using Reinforcement Learning and Speech Recognition in Deep Neural Network. The main object of the whole research study was to give a consolation to Dementia patients and their families. For this study, reinforcement learning algorithms like Q-learning, Deep Q-Learning algorithms were used as the technologies to personalize the games and activities according to the patient level by level. And at the same time, speech recognition (speech to text) model was created using Hidden Markov Model using Natural language Processing in Deep Neural Network.

Moreover, go beyond from this research, another research function can be done through it. In the speech to text activity (speech recognition), the category of the text like noun, pronoun, verb, adjective etc. can be showed to patients to remember it. And also, as speech to text (speech recognition), text to speech (text recognition) can be done as dictionary for Dementia patients. This text recognition can be done also deep learning technologies.

3.3 Discussion

This section is mainly focused on the problems and obstacles that faced during design and implementation and how those issues were solved and succeed this study. And this section discusses about how to improve this application and gaining the upcoming achievements.

The research study “Cognitive Rehabilitation based Personalized Solution for Dementia Patients using Reinforcement Learning” was started on November 2019 to find out a best personalized solution for rehabilitation of Dementia patient through an electronic device. The solution was identified as a mobile application with games and activities using modern technologies like Reinforcement Learning and Deep Neural Network.

A literature survey was carried out to identify the similar types of software products that are available and used by the Dementia patients. It was identified limitations to be done this research study and an analysis was done to identify alternative solutions for those limitations. The literature survey was done on Dementia, mobile applications for Dementia and at the same time to identify the technologies like Reinforcement Learning, Q-Learning, Deep Q-Learning, Deep Neural Network, Hidden Markov Model, Natural Language Processing that was to be done on the project also identified through the literature survey. And the problems and defects of the existing applications and the advantages of proposed system were identified among the literature survey study.

There were some obstacles when creating speech recognition model in the language component of the application. Voice recordings of different people had been used and for all those recordings, phonetics was analyzed.

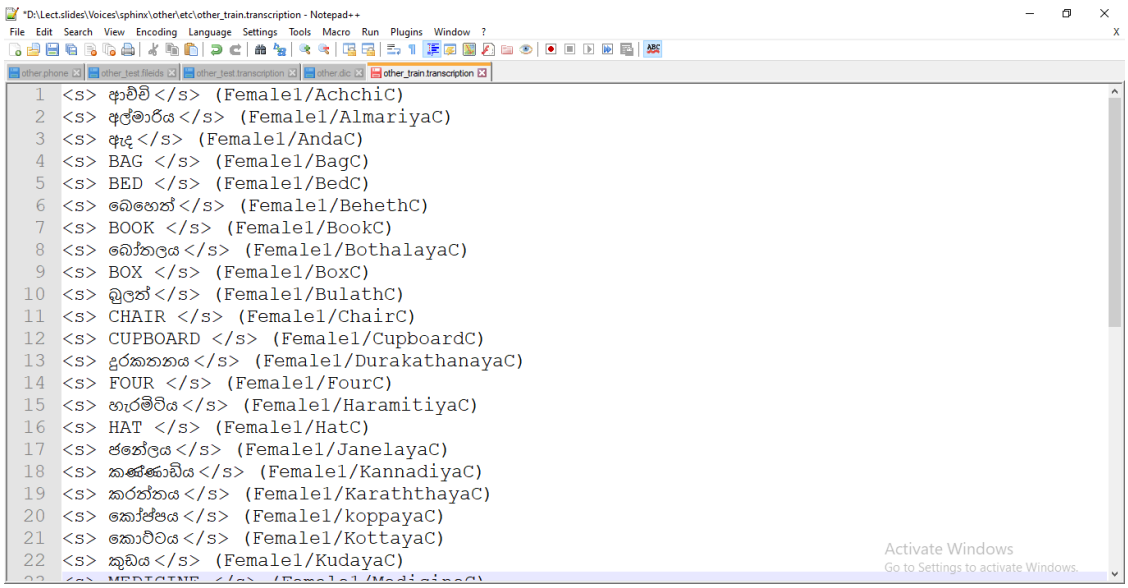

Figure 20 : Trained Voice Recordings Transcription

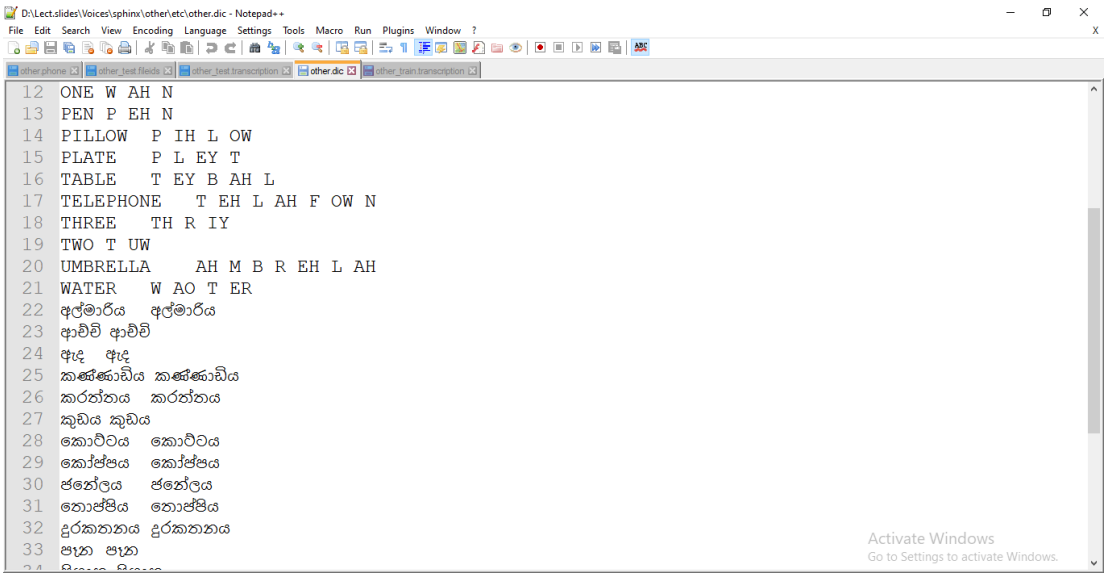

Figure 21 : Phonetic Dictionary

When integrating four components which were implemented separately, there were many bugs. The biggest issue was system crashing. In there, after integrating components, the email system using SMTP was crashed. So, we had to implemented it again because of it.

And also, there were many issues after integrating speech recognition model with the games. Because the games were developed using C# programming language using Unity game development engine. But speech recognition model was created in Python programming language using CMUSphinx library. When combining the two systems on different programming languages, system gets many errors. To solve that problem, it is used Swig which is a software development tool for connecting two systems into one.

4. CONCLUSION

The Dementia disorder is a very dangerous deterioration in the memory of a human brain. Dementia patients need activities for rehabilitating their cognitive functionalities. A personalized therapy can be done as a solution for this. A user-friendly brain training mobile application for cognitive functionalities was implemented in an interactive and effective way including games and activities.

These games are based on the main cognitive functionality called Language skills of the Frontal Lobe and Temporal Lobe of Cerebral Cortex. The main objective of this component was to give a solution for reducing the impairments of the Language skills in an effective way to make the Dementia patients life easier. The speech recognition acoustic model was used in this component for speech to text-based activity. For that, Hidden Markov Model of Deep Neural Network was used as Deep Learning technique.

As for the future work under the language component, the application can be improved increasing the functionality activity based on text to speech using Deep Learning technique. And moreover, we can improve the personalizing process increasing the success. We hope to introduce more games covering other functional areas related to Frontal and Temporal Lobes of the Cerebral Cortex for make Dementia patients life more comfortable.

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6. GLOSSARY

Dementia	A syndrome in which there is a deterioration in memory, thinking, behavior and the ability to perform everyday activities
Reinforcement Learning	An area of machine learning concerned with how software agents ought to take actions in an environment in order to creation of cumulative reward
Deep Neural Network	An artificial neural network with multiple layers among input and output layers
Hidden Markov Model	A statistical representative model which can be used to describe the evolution of observable events that depend on internal factors, which cannot be directly observable
Acoustic Model	A file which contains statistical representations of each of the distinct sounds that makes up a word

7. APPENDICES

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;
using UnityEngine.SceneManagement;
using TMPro;

public class Language_Menu : MonoBehaviour
{
    public GameObject _overFlowMenu;
    public GameObject _selectLanguagePage;
    public GameObject _instructionPage;
    public GameObject _instructionsLevel_1;
    public GameObject _instructionsLevel_2;

    public TextMeshProUGUI _levelNumber;
    public TextMeshProUGUI _stepNumber;

    [Header("Weekly Progress")]
    public GameObject _weeklyProgressPage;
    public GameObject _table;
    public GameObject _notification;
    public List<Image> _progressBars;
    public TextMeshProUGUI _title;
    public bool _display = false;

    private int _level;
    private int _step;

    private void Start()
    {
        if (PlayerPrefs.HasKey("Language_Level"))
        {
            _level = PlayerPrefs.GetInt("Language_Level");
            _step = PlayerPrefs.GetInt("Language_Step");
            print("111");
        }
        else
        {
            PlayerPrefs.SetString("Language","Sinhala"); // Set language as sinhala.
            _level = 1;
```

```
            _step = 1;

            PlayerPrefs.SetInt("Language_Level", _level);
            PlayerPrefs.SetInt("Language_Step", _step);
        }

        _levelNumber.text = _level.ToString();
        _stepNumber.text = _step.ToString();
    }

    #region Button Clicks

    public void OnClickOverFlowMenu()
    {
        _overFlowMenu.SetActive(true);
    }

    public void OnClickBack()
    {
        _selectLanguagePage.SetActive(false);
        _instructionPage.SetActive(false);
        _weeklyProgressPage.SetActive(false);
    }

    public void OnClickBackToMainMenu()
    {

    }

    public void OnClickBackGround()
    {
        if (_overFlowMenu.activeInHierarchy)
        {
            _overFlowMenu.SetActive(false);
        }
    }

    public void OnClickLanguage()
    {
        _overFlowMenu.SetActive(false);
        _selectLanguagePage.SetActive(true);
        _instructionPage.SetActive(false);
    }
```

```
public void OnClickInstruction()
{
   _overFlowMenu.SetActive(false);
   _selectLanguagePage.SetActive(false);
   _instructionPage.SetActive(true);
}

public void OnClick_SwitchInstructions()
{
   if (_instructionsLevel_1.activeInHierarchy)
   {
      _instructionsLevel_1.SetActive(false);
      _instructionsLevel_2.SetActive(true);
   }
   else
   {
      _instructionsLevel_1.SetActive(true);
      _instructionsLevel_2.SetActive(false);
   }
}

public void OnClickSelect_Sinhala()
{
   PlayerPrefs.SetString("Language","Sinhala");
}

public void OnClickSelect_English()
{
   PlayerPrefs.SetString("Language", "English");
}

public void OnClickPlayGame()
{
   if(PlayerPrefs.GetString("Language") == "Sinhala")
   {
      if(_level == 1)
      {
         SceneManager.LoadScene("PicturePuzzle");
      }
      else if(_level == 2)
      {
         SceneManager.LoadScene("JumbleWords");
      }
      else if(_level == 3)
```

```
            {
                SceneManager.LoadScene("");
            }
        }
        else if (PlayerPrefs.GetString("Language") == "English")
        {
            if (_level == 1)
            {
                SceneManager.LoadScene("EnPicturePuzzle");
            }
            else if (_level == 2)
            {
                SceneManager.LoadScene("EnPicturePuzzle");
            }
            else if (_level == 3)
            {
                SceneManager.LoadScene("");
            }
        }
    }

    public void OnClickWeeklyProgress()
    {
        _overFlowMenu.SetActive(false);
        _selectLanguagePage.SetActive(false);
        _instructionPage.SetActive(false);
        _weeklyProgressPage.SetActive(true);

        _title.text = "Week " + _level.ToString() + " Progress";

        if (_step == 1)
        {
            _notification.SetActive(true);
            _table.SetActive(false);
        }
        else
        {
            _notification.SetActive(false);
            _table.SetActive(true);

            if (!_display)
            {
                _display = true;
```

```
            if (_level == 1)
            {
                for (int i = 0; i < PlayerPrefs.GetInt("Week1Day"); i++)
                {
                    float fillamount = (float)PlayerPrefs.GetInt("Language_Score_Week1" +
i) / 150;
                    _progressBars[i].fillAmount = fillamount;
                    print(PlayerPrefs.GetInt("Language_Score_Week1" + i)+","+
fillamount);
                }
            }
            else if(_level == 2)
            {
                for (int i = 0; i < PlayerPrefs.GetInt("Week2Day"); i++)
                {
                    float fillamount = (float)PlayerPrefs.GetInt("Language_Score_Week2" +
i) / 150;
                    _progressBars[i].fillAmount = fillamount;
                }
            }
            else if(_level == 3)
            {
                for (int i = 0; i < PlayerPrefs.GetInt("Week3Day"); i++)
                {
                    float fillamount = (float)PlayerPrefs.GetInt("Language_Score_Week3" +
i) / 150;
                    _progressBars[i].fillAmount = fillamount;
                }
            }
        }
    }

    #endregion
}
```