# 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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Signature of supervisor: Date:

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## DEDICATION

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

We dedicate this to our supervisor, co-supervisor and external supervisor for their valuable support and guidance.

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

# ABSTRACT

Dementia is one of the most challenging health problems faced globally with the increase in the ageing population. The estimated current prevalence of dementia is 47.5 million worldwide. This number will nearly double in every 20 years globally [1]. Dementia is basically, a syndrome which cannot be cured by medicine [2], but non-pharmacological therapy can be used to treat Dementia patients, this is known as Cognitive Rehabilitation Therapy. According to the recommendations of the doctors, the use of a brain training application could be better than traditional approaches. There are number of Brain training mobile applications in the world that could be useful in improving human concentration, attention and all sorts of brain activities but there isn't any customized software solution that has games or activities. Patients can be in different stages of Dementia. So, for better cognitive rehabilitation they need the personalized therapies with the games and activities. Accordingly, developing this application is an actual global requirement for dementia patients. The world is evolving with new technologies and this application includes the mind games based on such technologies as Reinforcement Learning which predict the next level for patients based on user behavior. And there are some activities by using speech to text communication as well. Patients, caregivers and doctors can view the score and the progress reports. All the games have designed along with the supervision and recommendation from a Consultant Psychiatrist in Sri Lanka. The main objective is to help the Dementia patients in cognitive rehabilitation to improve the quality of life with best suited personalized games and activities.

## ACKNOWLEDGEMENT

The work described throughout this paper was on an outcome of a research project of four members group with the guidance assistance of few individuals. We would like to convey our thankfulness for our research project supervisor Dr. Dharshana Kasthurirathna (Senior Lecturer in Department of Software Engineering, Faculty of Computing, Sri Lanka Institute of Information Technology) for the great guidance and support throughout the whole research project for a successful end. We take this opportunity to express our gratitude to Dr.Chathurie Suraweera (Senior Consultant at National Hospital, Colombo/ Senior Lecturer in Department of Psychiatry, Faculty of Medicine, University of Colombo) for spending time and giving a good support to achieve this goal. Our gratitude goes to Mr.J.A.D.T.Jayawickrama (Lecturer, Department of Industrial Management, University of Kelaniya) for helping hand to success this research project. And we take this opportunity to express our gratitude to Dr. Janaka Wijekon, CDAP team and Sri Lanka Institute of Information Technology for providing all research materials and keeping a good educational environment to success this project. Finally, we would like to thank all the people who help building up this project even with a single word.

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| | |
|---|---|
| ML | Machine Learning |
| RL | Reinforcement Learning |
| NLP | Natural Language Processing |
| MMSE | Mini Mental State Examination |
| | |

# 1.INTRODUCTION

According to the World Health Organization, Dementia is a syndrome in which there is deterioration in memory, thinking, behavior and the ability to perform everyday activities. Although dementia mainly affects elderly people, it is not a normal part of ageing. Sri Lanka has one of the world's fastest ageing population [3]. Therefore, illness like Dementia will become more prevalent in the community. A syndrome like Dementia is a symptom of several underlying mental or brain disorders. There are number of Dementia categories. But there is no exact medication for those categories. Only the way is to assist the patients who is under the mild and moderate stages to keep their brain active using different activities by slowing down the stages one by one. Due to the frequent usage of smart devices in this present society, implementation of a mobile application including games or activities to increase the memory power of Dementia patients will be beneficial. There are wide range of mind exercises in the world. This system will be brought out the mobile application including different types games or activities under the cognitive functionalities like Attention and Concentration, Executive Functions, Language, and Memory. The games and activities have been implemented by using Machine Learning (ML) technologies like Reinforcement Learning (RL), Natural Language Processing (NLP), Hidden Markov Model (HMM). Next level of this games or activities will be predicted with the usage of RL by learning from the user. And some of the games which is included in this game will be implemented on speech to text communication by using NLP, HMM. The most important of the application is to follow the advancement during the time that they are spending at home. While the patient is away from the doctor, the patient can restore their subjective functionalities from their own by using this application. This will be an incredible assistant for the patients since there is not suitable cure to the Dementia.

## 1.1 Background

## 1.2 Background Literature

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 [1]. 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].

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].

RL is learning through interaction with the environment by taking different actions and experiencing failures and successes while trying to increase the receiving awards. The agent is not advised which action to take. RL is different from Supervised learning, an agent needs to be told what the correct action which is for every position it encounters. RL is different from other branches of ML and it is the third paradigm of ML. Basically, the main components of standard model in RL are policy, reward signal, value function and model [7]. In any step, the agent observes a state of the environment and receives a reward signal. Based on the current state and agent's behavior function at given time, which is called as policy, the agent chooses an action to take. This action is then sent to the environment which is updated and the loop repeats. This is how agent-environment interface works in RL [8].

Leslie Pack Kaelbling, Michael L. Littman, Andrew W. Moore mentioned that, RL is primarily concerned about the way it obtains the optimal policy. The agent should interact with its environment directly to obtain the information which can use appropriate algorithm to be processed to produce an optimal policy. At this point, there are two ways to proceed, model-based learning and model-free learning. Model-free learns a controller without learning a model. But, model-based learns a model and use it to derive a controller [9]. According to Ajay Subramanian, Sharad Chitlangia, Veeky Baths model-based learning and model-free learning are sub-categories of RL. In model-free methods, it updates value functions through data collection directly from the environment. Model-based methods build a model of the environment which can be used to generate more data by using the collected data [10]. In games, machine learning can be used for different purposes. RL has its several algorithms, for example Q-learning, SARSA, DQN, and DDPG. From those, Q-learning and SARSA are model-free algorithms [11]. Short-term cognitive training had positive effects on reasoning and speed of processing performance

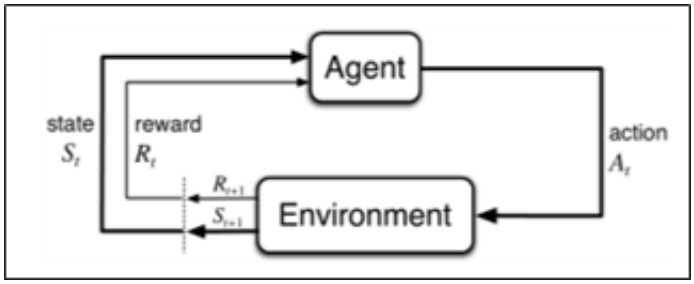



*Figure 1 : Interaction between agent and environment*

well. Performing that kind of activities continuously based on memory game against a software agent can be a preventive care approach for older adults to engage and entertain. RL agent attempts to acquire an appropriate policy based on observations, trial and error interactions with its environment [12].

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 [13].

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 [14]. 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, 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 [15].

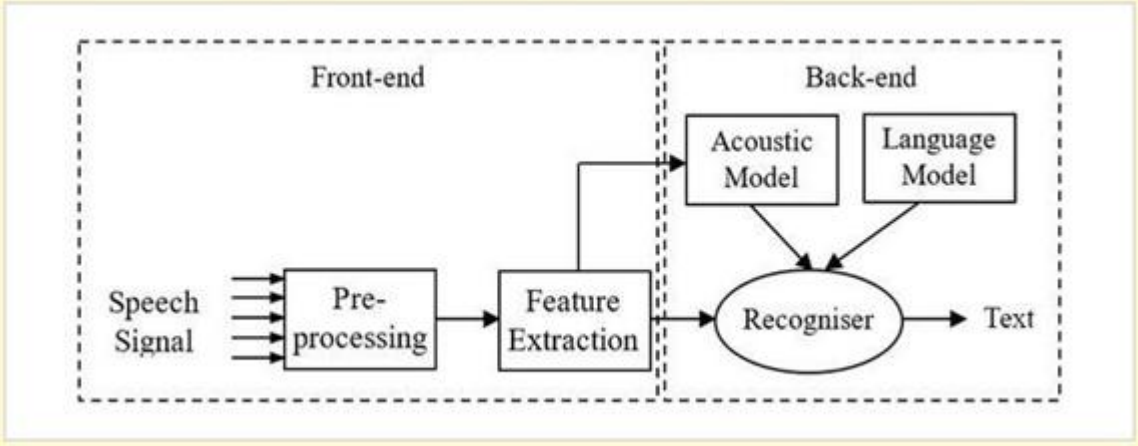



*Figure 2 : General framework of automatic speech recognition system*

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 [16].

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 [17].

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 [18]. 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.

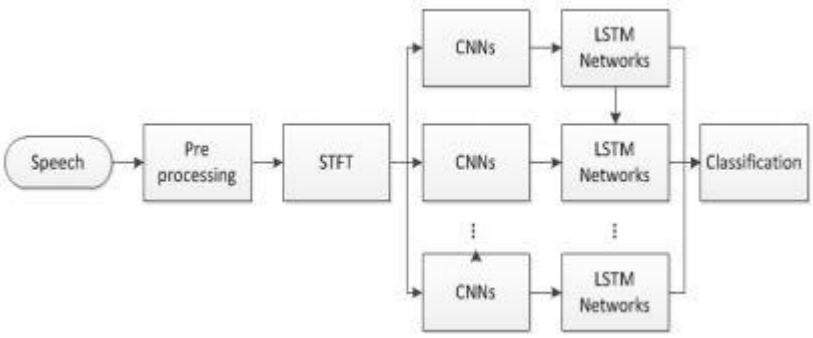



*Figure 3 : Block diagram of our time distributed network-based SER method*

### 1.3 Research Gap

In fact, moving on with mobile application which helps Dementia patients, take through about research gap is most vital for forthcoming researches. While in a conversation about mobile applications that were introduced for Dementia patients mainly supported for English Language, novelty of proposed system is supported both Sinhala and English language which can be mainly suited for elderly population of Dementia. And, to make interaction between patient and proposed system is used voice text component, nevertheless **Kiho kang et al.** has stated that Serious Game to Help Prevent Dementia is mainly played through finger tapping and touch [1].

| Features | Lumosity | Brain Games | Elevate | Eidetic | Proposed System |
|---|---|---|---|---|---|
| Learning from the user and personalize it | ✗ | ✗ | ✗ | ✗ | ✓ |
| View the daily report | ✓ | ✗ | ✓ | ✓ | ✓ |
| Doctor can view the progress of the patients | ✗ | ✗ | ✗ | ✗ | ✓ |
| Games in Sinhala language | ✗ | ✗ | ✗ | ✗ | ✓ |
| View the history | ✗ | ✓ | ✓ | ✓ | ✓ |
| Suitable for elderly people | ✓ | ✗ | ✓ | ✗ | ✓ |
| Take voice inputs | ✗ | ✗ | ✗ | ✗ | ✓ |
| Based on many functionalities | ✓ | ✗ | ✓ | ✓ | ✗ |

*Figure 4 : Compare Existing Mobile Game Applications*

### 1.4 Research Problem

Dementia is one of the most significant problems facing with the increase in the ageing population. The estimated current prevalence of dementia is 47.5 million worldwide [1]. This number will nearly double in every 20 years globally [1]. Just as a similar issue has happened in Sri Lanka. Dementia portrays a gathering of manifestations influencing memory, thinking and social abilities seriously enough to meddle with the everyday life. It isn't a specific disease, yet a few distinct illnesses may cause dementia. Dementia isn't just about memory loss. It can likewise influence the manner in which you talk, think, feel and carry on. It's additionally imperative to recall that dementia is not a characteristic piece of maturing.

Dementia is a disorder which can't be restored by drugs. That is the primary and significant issue accessible over the world. In any case, a few medications can assist with control indications for individuals living with Alzheimer's illness, dementia with Lewy bodies or Parkinson's infection dementia. Shockingly, there are as of now no medications that can improve the psychological manifestations of dementia. Drugs assume a key function in the lives of individuals with dementia, essentially to manage indications. Managing prescriptions is complex for individuals with dementia and their family and can bring about different issues prompting harm. The principle drugs used to treat psychological indications of dementia are called 'cholinesterase inhibitors'. These medications don't work for everybody, and the normal impact is fairly small. However, for the vast majority, they're despite everything great worth difficult. While numerous individuals can take dementia drugs with no issues, some may encounter disagreeable reactions. The most well-known reactions include, headaches, sleep problems, loss of appetite, vomiting, muscle pain, feeling tired, itching, dizziness etc. The impact of dementia drugs on the strength of an individual's heart and veins seems, by all accounts, to be commonly very sure [14].

In any case there are medications that help to slowdown the development of the disorder. There are medications just as mental and behavioral treatments that help. But a patient

could be performed that medications during their treatment sessions only. And, doctors can't get the history of treatments of each patient regularly.

The objectives of progressing treatment for dementia are to keep the individual securely at home for to the extent that this would be possible and to offer help and direction to the caregivers. The individual needs to routine follow-up visit each 3 to a half year [15]. The specialist needs to screen medications and the individual's level of functioning. Sooner or later, the family may need to consider setting the individual in a consideration office that has a dementia.

### 1.5 Research Objectives

Our proposed application has an ability to overcome those issues. It has games and activities to improve the cognitive functionalities for the Temporal lobe and Frontal lobe from the Cerebral cortex. There are four main subcategories under them as Attention and Concentration, Language, Executive functions and finally Memory. Each game consists of different levels. Reinforcement Learning is used in these games in order to predict the best level for the users. All these games are designed with user friendly interfaces specially for the elder people and in a way suitable for our culture. And the patients can view their progress with the score level as well as the doctor of the relevant patient via a report. Implementation of the application will take over throughout the year.

#### 1.5.2. Specific Objectives

- Implement a game to help to increase the Attention and Concentration level of patients.
- Implementation of an activity to improve Language skills.
- Implement a game to develop Executive Functionalities.
- Implementation of games to improve the Memory of the patients
- Only the patient, caregiver and the doctor can view the patient details and scores.

- Make both patients and caregivers life easier.
- Slow down the moving from one stage to another stage of Dementia.
- Giving rehabilitation with continuous monitoring.

# 3. METHODOLOGY

This segment helps to illustrate the paths how our research project teammates carry to succeed each task which are processed in successful manner.

## 3.1 Methodology

### 3.1.1 Feasibility study for proposed solution

As starting juncture of the project, project initiation was performed. Under project initiation phase several type of feasibility studies was overseen to discover any worthy of the project.

*A.* Economic Feasibility Study.

Prior to apportion our finacial resources, we did follow this economic feasibility study to ascertain cost and benefits which are correlated with our project. Our proposed soultion is benitifical to people who are undergoing from mild or moderate Dementia to recover through practice which is result in to descrease Dementia from the society. Further more, Dementia has economically impact to country/ world. Since our solution is capable to recover Dementia so that economy situation of the country will be increased.

B. Operational Feasibility Study

Undertake an operational feasibility, we were focused on whether our final product would be easily operated at side of end users. Since our proposed solution interacts with patient's care giver and doctor but not only the patient. Due to that point it will help patient to easily operate with the application and as well our application is proficient with understanding both English and Sinhala languages. Therefore, when we consider about Sri Lankan Dementia patient, this solution is more flexible to them.

C. Technical Feasibility Study

Covered technical feasibility study to focus on technical resources accessible for proposed solution and turned attention on assets that are obliged to activate, install, or obtain the system to develop the ultimate product. As a result

D. Scheduling Feasibility Study

This can be deemed as most important feasibility study area which can be conducted for project success. Under this assessment wrapped up and sketched out the project deadline is suitable for the project and this feasibility study estimated how much of time amount will take up to attain the definitive product containing testing stage.

### 3.1.2 Requirements gathering, data collection and analysis

For this research project mainly vise most of the important requirements gathered supervision under the Psychiatrist Dr. Chathurie Suraweera Senior Consultant at National Hospital, also conducted quantitative methods for requirements gathering and for the data collection. Therefore, we created a survey consisted of 4 multiple choice answers and 15 questions where responders had to answer with 5-point scale. There was no time limitation given to participant and it could fill anonymously. The aim was to carry out the survey is to get considerable responses with that X number of people will agree with our proposed solution for Dementia. In this case there were not all the surveys fully completed hence, considerable amount of fully completed results included in the analysis.

Based on the analysis and the requirement which came from the Psychiatrist doctor, research team decided to develop a one single personalize gaming application for both Sinhala and English languages which contain 4 different game components in it which are mainly focus on different skills on Dementia patients.

### 3.1.3 System overview

Immediately after developing our proposed system, doctor can recommend this application to Dementia patients and based on Mini Mental State Exam (MMSE)test report doctor can recommend the category of the game that patient should carry on. Referring to the Fig. 5, caregiver must set the application for patient and should provide all correct personal data into system. Reason for that is report of patient's progress and all depend on these personal data.

After the basic preparation of the application including login, patient can choose the game component which recommended by doctor. Furthermore, patient only allow to start with simple level which is an initial level and with the progress patient can be move further. Progress of the patient including game scoring can be sent as a report via an email. Hence, doctor can continuously do a monitoring on patients when the time needed. Also considering our proposed system level except the initial level, other levels behavior has been changing patient to patient. Nevertheless, this feature can be called as unique characteristic of our solution compared to other existing solution for Dementia patients.

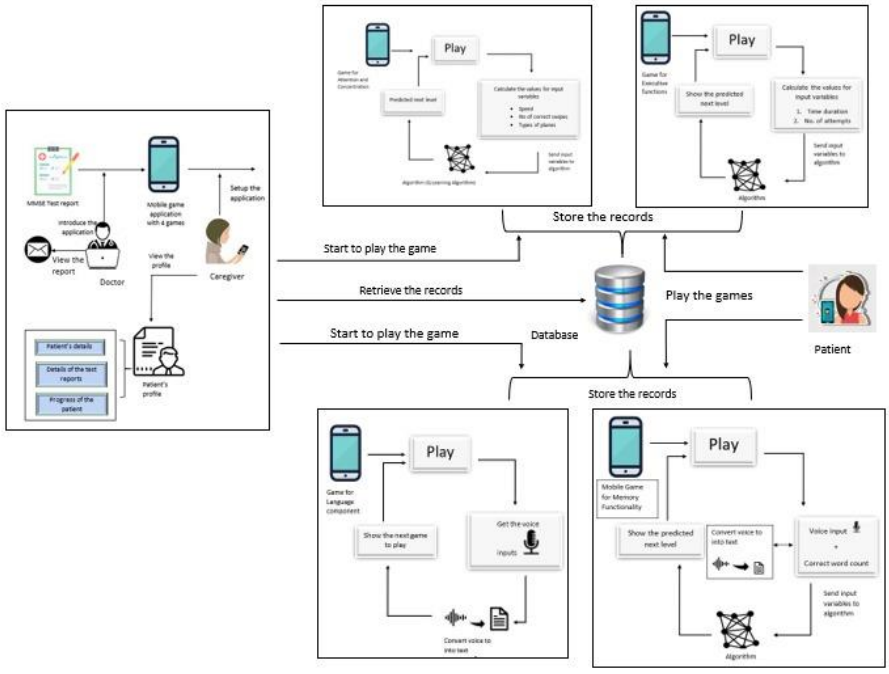



*Figure 5 : System Overview Diagram*

### 3.1.4 System architecture

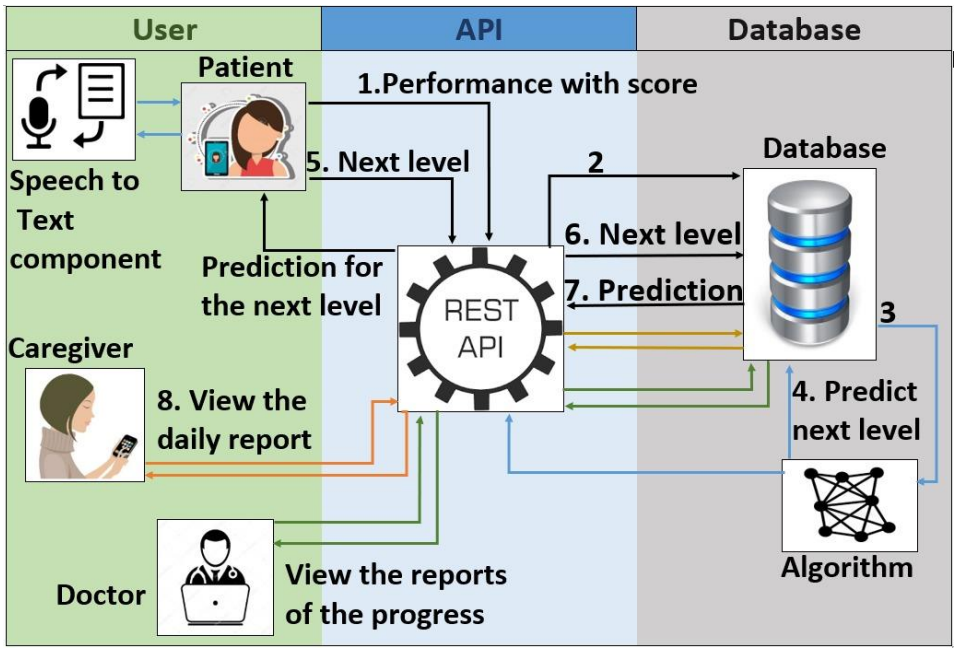



*Figure 6 : System Architecture*

This mobile gaming application mainly used technologies such as C# for games development, Python for machine learning algorithms implementation and SQL for designing, programing, and managing data into relational database management system. NLP, HMM and Q Learning algorithms used for this proposed system.

### 3.1.4 Game components

Consider about entire mobile gaming application, D-care contain registration and login process, reporting and mainly vise it contains 4 different game components which are aim for Dementia patient's different skills and areas. Per component includes one game with different personalized game levels.

#### 3.1.4.1 Attention and concentration component

Objective to develop this component was to improve Dementia patients' ability to focus on one thing at a time and controlling the focus of attention.

After registration and login process of the patient, caregiver must select the attention and concentration component based on doctor's recommendation. Research group implemented this component with both Sinhala and English Language and has given instruction to follow before attempt with game. Hence which is easy to manage by patient by their own. As in an initial level of the game patient is given a screen which displays set of vehicles coming top to bottom and need to slide that vehicles and should play according to the instructions given for this component. End of the initial level score and game related data will be stored to the database.


*Figure 7 : Interface for Attention and Concentration Component*

When consider about this game further we decided to implement this game with 3 levels. Except initial level other levels has personalized feature due to used Q learning algorithm which discussed under section 'Q Learning.

### 3.1.4.2 Executive function component

Until the login process steps are same as previous components. This area implemented to cover up small calculations, time management skills and ability of problem solving.

In the initial level of the game component patient gets set of numbers which are randomly changing with time and asked to perform with math operations. If patient success with initial level criteria can move on to other levels of the game. All data related to each level will be stored to the database. Base on patient's performance in the initial level used to predict the next level of the game via RL algorithm such as Q learning.


*Figure 8 : Interfaces for Executive Function Component*

### 3.1.4.3 Language skill component

Patients who are suffering reading, comprehension problem related to language either in English or Sinhala, doctors recommend this component. Same as the previous components process up to login is same. This game component developed with 3 levels. In the initial level patient ask to identify the given picture correctly and moving forward to other levels, we developed this to building up word and last level of this game included speech to text

converter which implemented using NLP and HMM model to improve speaking skill also by practice under this component can improve comprehension skill of the Dementia patients and records related to this also store to database. Further explain on speech to text converter, our research team decided and implemented that using HMM in DL.

We used NLP to understand human language. As mentioned above, last level of this component related game includes voice base activities. Last level of this game display word or sentence and patient need to respond for them using microphone. And we used NLP to capture this as an audio and we took a place to covert that captured audio into text. And after morphological, word segmentation, converted text is compared to text which stored in database. Once this comparison has done, system decide that patient has repeated the shown word or sentences correct or wrong. Based on this develop scoring for last level of the game on this component.


*Figure 9 : Interface for Language Skill Component*

### 3.1.4.4 Memory skill component

Research team implemented this component taking objective as to improve Dementia patients' memory which cover up stages such as registry and recall etc. Process until login is same as mentioned for above components. With the recommendation of doctor patient can go for memory component. This component implemented for both Sinhala and English languages so that patient can select one of language on their preferences. This component contains one game related to memory in it that we implemented 3 different game levels. In order to move with last two levels, patient need to perform with initial level with considerable amount of high performance. Based on their behavior on initial level next level will be predicted using Q learning algorithm. Furthermore, all records related to each level will be stored to the database. In this game each level given a passage with constant amount time and after that time become 0, he/ she will be given with set of questions to be answered. Except initial level other level overall complexity will be differ patient to patient (based on their performance).


*Figure 10 : Interface for Memory Skill Component*

### 3.1.5 Q – learning algorithm

When consider our proposed solution D-Care mobile gaming application, components such as attention and concentration, executive function and memory, except initial level of the game other levels are differing from patient to patient. Hence our D-Care acts as personalized mobile gaming application for Dementia patients.

Research team decided to implement this application using RL which is a main branch of ML. According to the RL concept Dementia patient acts as agent of the gaming environment and based on the action performed by agent rewards will be given to the agent. RL contain two type of algorithm named model-base and model-free. For our solution we used Q- Learning algorithm which is a model-free algorithm for RL. Under Q-learning algorithm process we followed few steps. As the first step we initialized our Q-table. There were X number of rows and Y number of columns which represented actions. And then chose to perform with an action. We ran this step up until the time we stop off the training. Later all we stepped with evaluation of algorithm for our game levels. From there we performed with serval actions and noted an outcome and rewards. So for the attention and concentration we took speed, number of correct swipes and type of vehicle, for executive function took time duration and for memory skill component we took complexity of the paragraph in word and time taken to answer for quiz as inputs for algorithm. After result of the algorithm process, it was able to predict the next levels of the games related to their components. Finally scoring or reward gave based on actions at one stage. Since performance or actions performed by patient is vary compared to another, inputs values are changed. Due to is result in prediction of levels in a various manner.

## 3.2 Commercialization Aspect of the Product

As a commercialization of our implemented application for Dementia patients, be able to publish this application to psychiatrist who are dealing with Dementia patients. Psychiatrists do stick to up the relevant testing processes like MMSE testing for Dementia patients. Later all psychiatrist doctor can find out the essential cognitive functionality or

spiritual functionalities to be improved for the applicable patient. Allowing to the approval of the doctor, patient completes the recommended activities or games to expand the weakening of needed intellectual functionality or functionalities.

Further than, this solution can commercial caregivers be suggesting out the improvements of drumming this brain training mobile game application for patients who are slumped to disorder called Dementia. We can denote the caregivers to make available this application or solution to play a part for Dementia patients in combination with the encouragement of the relevant psychiatrist doctor. Patients who have Dementia, can have one month of trial time period. After one month of trial period patients can install this cognitive rehabilitation based personalized solution which was implemented for Dementia patient using reinforcement learning to their smart phones and continue the with the games.

### 3.3 Testing and Implementation

#### 3.3.1 Testing

Unit testing is WhiteBox software testing where the individual units or component of a system software are tested. The purpose of unit testing is to validate the each of the unit in code perform as we expected. In Unity game developing, it is used TestRunner 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.

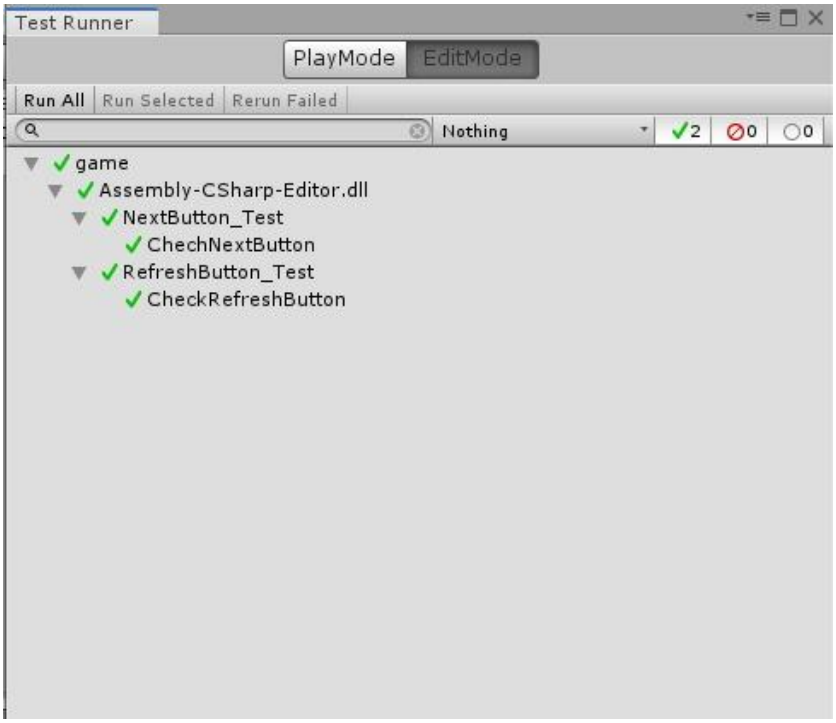



*Figure 11: Test cases are running on Unity test Runner(Language Component)*

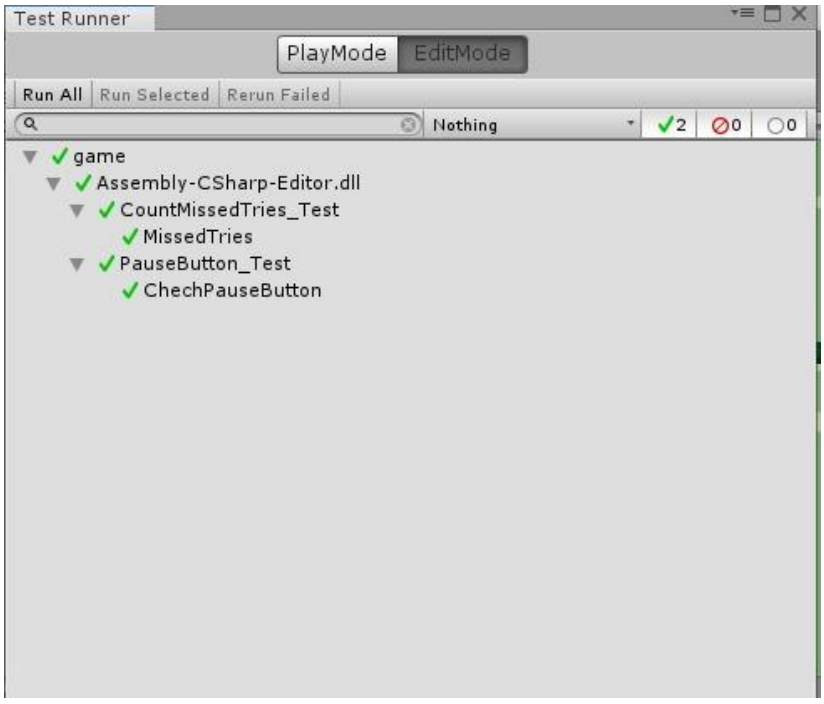



*Figure 12: Test cases are running on Unity test Runner(Attention and Concentration)*

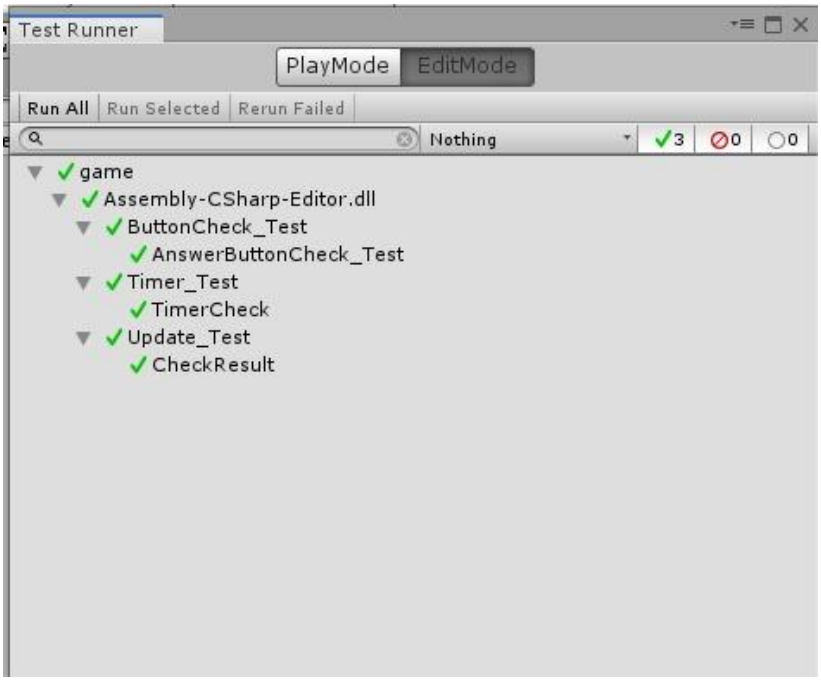



*Figure 13: Test cases are running on Unity test Runner(Executive Functions)*

The following tables are shown of the manual test cases which were used to check that the features and functionalities of the application working properly as expected.

*Table 1: The patient selects an answer for a mathematical problem of Executive Functions Component*

| **Test ID** | **01** |
|---|---|
| **Description** | The patient selects an answer for a mathematical problem. |
| **Pre-condition** | A number set should be displayed. |
| **Steps** | 1. "Start" the game.<br>2. Select the correct answer from the three multiple choices. |

| | |
|---|---|
| **Extensions** | If the patient selects a wrong answer, the button turns red and the score will increase otherwise it turns green. |
| **Expected output** | The button turned green and score increased. |
| **Actual output** | The button turned green and score increased. |

*Table 2 : Test case for checking the timer for changing number set s of Executive Functions Component*

| | |
|---|---|
| **Test ID** | **02** |
| **Description** | Once the patient answer is selected, the timer for changing the number sets is recalculated from 0. |
| **Pre-condition** | The patient should be selected an answer. |
| **Steps** | 1. "Start" the game.<br>2. First time select an answer from the three multiple choices.<br>3. The second time an answer is not selected. |
| **Extensions** | If the patient selects an answer, the timer goes back to 0 and starts again. |
| **Expected output** | The first time, after selecting an answer the timer starts again from 0.<br>The second time, after the full fixed time is over, start again from 0. |
| **Actual output** | The first time, after selecting an answer the timer starts again from 0.<br>The second time, after the full fixed time is over, start again from 0. |

*Table 3 : Test for next button of Language Skills Component*

| | |
|---|---|
| **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<br>2. Read the guidelines of playing the game<br>3. Selects the level “1” button or “2” button<br>4. Have a look into the given jumbled letters to build up the word<br>5. Drag the letters into the given boxes<br>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 4: Test for correct attempt count of Attention and Concentration component*

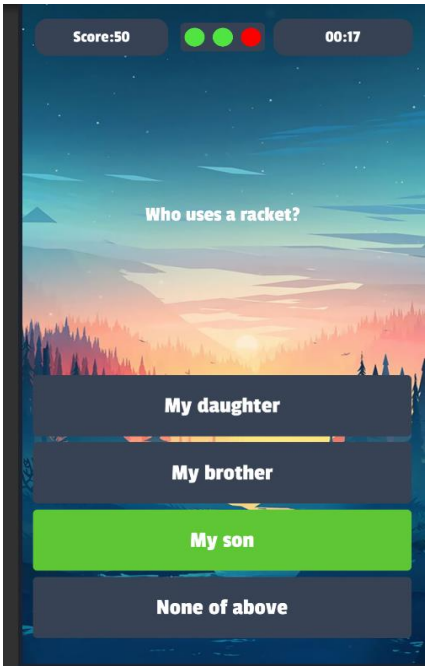
| | |
|---|---|
| **Test ID** | **01** |
| **Description** | Display the count of correct attempts |
| **Pre-condition** | The patient should login to the game |
| **Steps** | 1. Go to home page.<br>2. Navigate to Attention and Concentration game. |

| | |
|---|---|
| | 3. Click the play button.<br>4. Swipe the vehicle images towards the correct sides. |
| **Extensions** | If the patient clicks the pause button, the game will pause. |
| **Expected output** | Display the correct no of attempts |
| **Actual output** | Display the correct no of attempts |
| **Pass/Fail** | Pass |

*Table 5: Test case for correct answer button function in Memory Component*

| | |
|---|---|
| **Test ID** | 001 |
| **Test Priority (Low, Medium, High)** | Medium |
| **Module Name** | Quiz panel in memory game |
| **Test Designed By** | Roshni Silva |
| **Test Executed By** | Roshni Silva |
| **Test Description** | Patient selects a correct answer for given question in the quiz panel based on passage displayed. |
| **Pre- condition** | Install D-Care application to patient mobile device and join with memory game component |
| **Test Step/s** | 1. Open the application<br>2. Join with memory section<br>3. Read the instruction given for memory game<br>4. Select the level “1” or “2” button |

| | |
|---|---|
| | 5. Select the preferred language<br>6. Get started with the game<br>7. Try to memorize the given passage<br>8. Attend with the quiz<br>9. Among the answer buttons given for the question, choose the correct answer without exceeding the time limit for entire quiz |
| **Expected output** | The correct answer button turn into green color and the score will increased by 50 |
| **Actual output** | The correct answer button turned into green color and the score increased by 50 |
| **Status (Pass/ Fail)** | pass |

| Note |  <br>Figure 14: Result of actual output for selecting correct answer |
|---|---|

### 3.3.2 Implementation

#### 3.3.2.1 Implementation for attention and concentration

- **Game Implementation**

The game has three mail levels and sub steps for each level. First implemented the first level of the game and then implemented the steps of it. Then the same way followed to implement the second and the third level of the game. For the data management use playerPref locally and used playFab to save in the cloud.

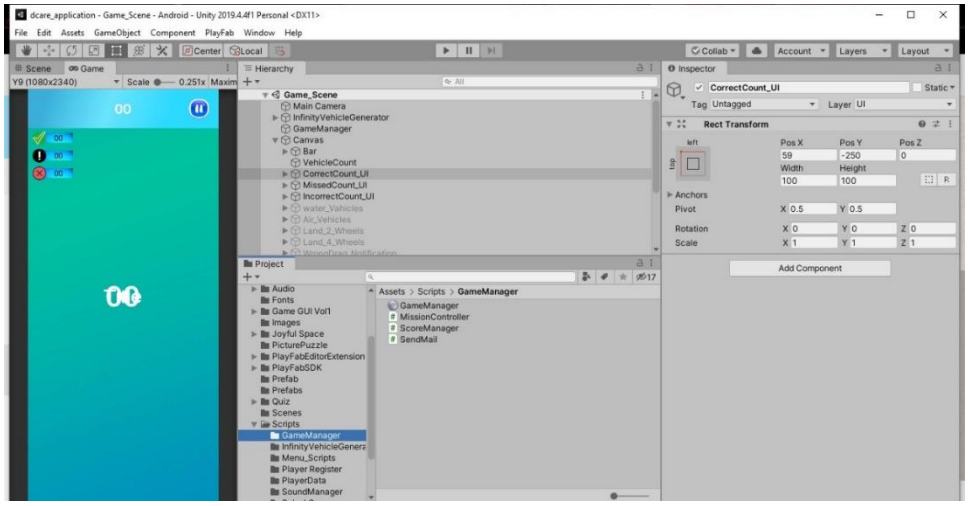
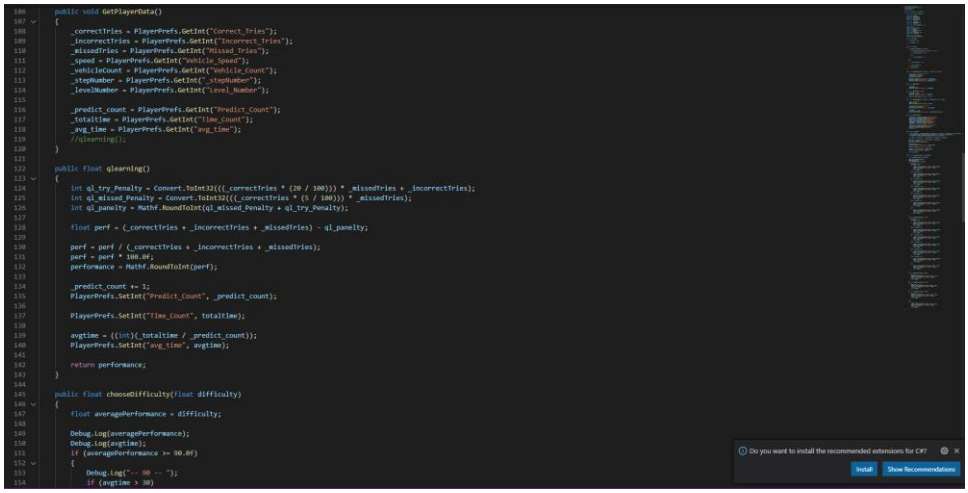


*Figure 15: Game implementation of Attention and Concentration*

- Algorithm Implementation



### 3.3.2.2 Implementation for executive functions

This game has four levels, and it will be more complicated level by level. The game consists with five numbers which are moving, and player has to calculate those numbers from bottom to up according to the math operation. These numbers will change every 30 seconds (It can be changed). In every round user has fixed time duration to play the game. The user has to solve as much as he can within that time duration. There is only one math operation in first level and level by level it will be adding one more math operation (addition, multiplication, subtraction and division) one by one. And there are two timers

in this game. One timer for changing numbers appears in here. The user has 30 seconds to solve one number set. After the user clicks an answer a new number set will appear. The game will stop after second timer became 0. This timer is fixed time duration in every game level.

As mentioned earlier, there are five numbers in this game, and they are moving horizontally, and the five numbers are randomly appearing on the screen after fixed time duration or after selecting an answer. Math knowledge of the elderly people might be not in quiet good situation therefore all these five numbers are less than five. Three multiple choices are given to the player and player has to choose the correct answer. Multiple choices are also appearing in random format.

```
        if (time <= 0)
        {
            time = roundLength;
            randomNums();
            result = numbers[0] + numbers[1] + numbers[2] + numbers[3] + numbers[4];
            displayResults();

            Answers[0] = result;
            Answers[1] = result + Random.Range(1, 6);
            Answers[2] = result - Random.Range(1, 6);
            ShuffleArray(Answers);

            for (int i = 0; i < buttons.Length; i++)
            {
                buttons[i].image.color = Color.white;
            }
        }
    }
}
1 reference
void randomNums()
{
    if (GMS.counterDownDone == true)
    {
        for (int i = 0; i < numbers.Length; i++)
        {
            numbers[i] = Random.Range(0, 5);
            numbersText[i].text = numbers[i].ToString();
        }
    }

}
```

*Figure 16: Appearing numbers randomly and formatting answers for the calculation (Executive Functions)*

Next step is check whether the answer which is given by the player is correct or wrong. If the answer is correct it will appear in green color otherwise it will be red color. And also, for every correct answer there will be adding a score and it is based on the time.

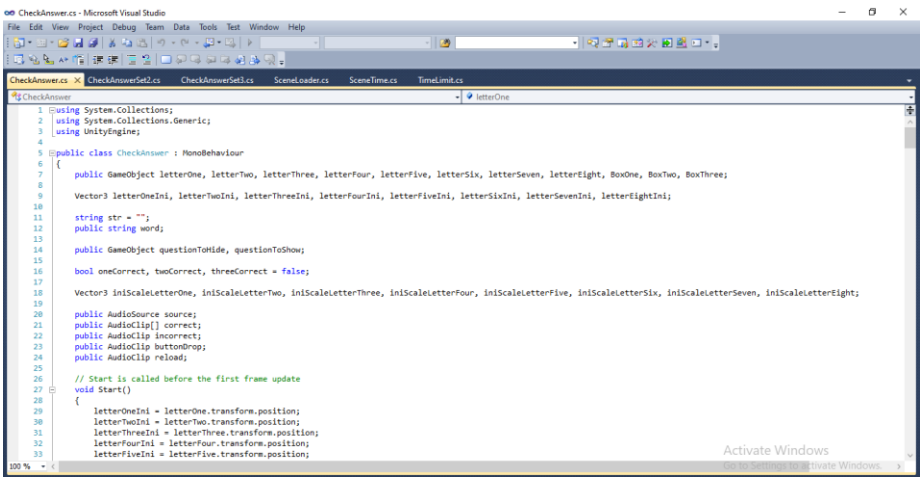
```
public void ButtonCheck(int buttonNum)
{
    if (buttons[buttonNum].transform.GetChild(0).GetComponent<Text>().text == result.ToString())
    {
        Debug.Log("Correct  !");
        buttons[buttonNum].image.color = Color.green;
        score += 2 * time;
        scoreText.text =  score.ToString("0");
        source.PlayOneShot(clips[0]);

    }
    else
    {
        Debug.Log("Wrong  !");
        buttons[buttonNum].image.color = Color.red;
        //score -= 15;
        scoreText.text =  score.ToString("0");
        source.PlayOneShot(clips[1]);
    }
```

*Figure 17: Checking Answers (Executive Functions)*

### 3.3.2.3 Implementation for language skills

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 figures contain 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 18: Process of dragging letters to the given boxes*

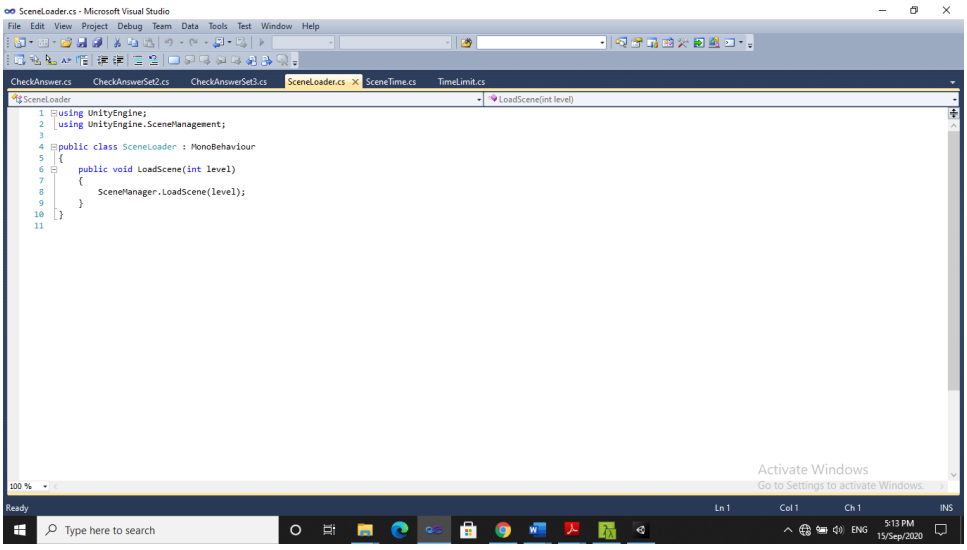



*Figure 19: Next scene loader*

It was set up the environment to train the CMUSphinx model. Python commands was given because this model is based on the Python programming language

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. And it is used PlayerPref for storing data inside the databases locally and also PlayFab to store data in the database server.

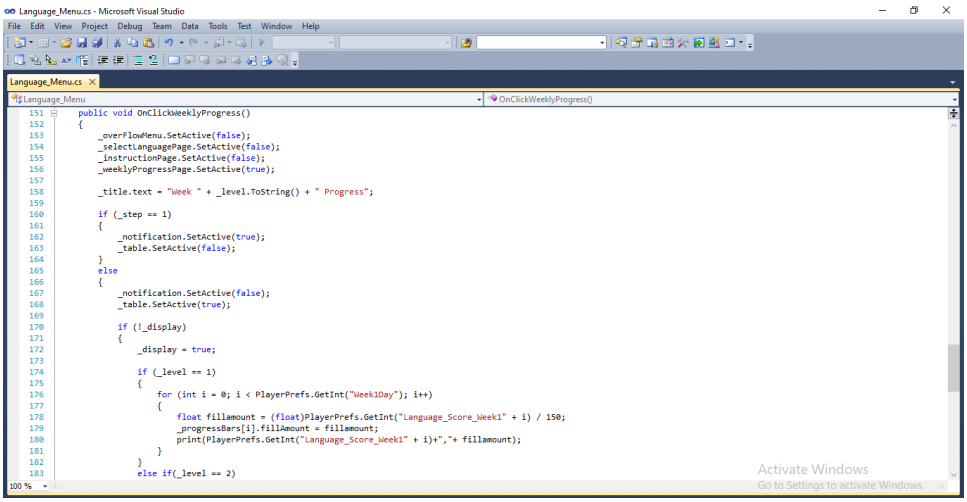



*Figure 20: Weekly progress calculation of language component*

### 3.3.2.4 Implementation for memory

Basic Game UIs

The development of the user interfaces for memory game were done using the Unity engine based on the C# programming language. Below figures are indicated level and language selection, and passage displaying UIs that were implemented.

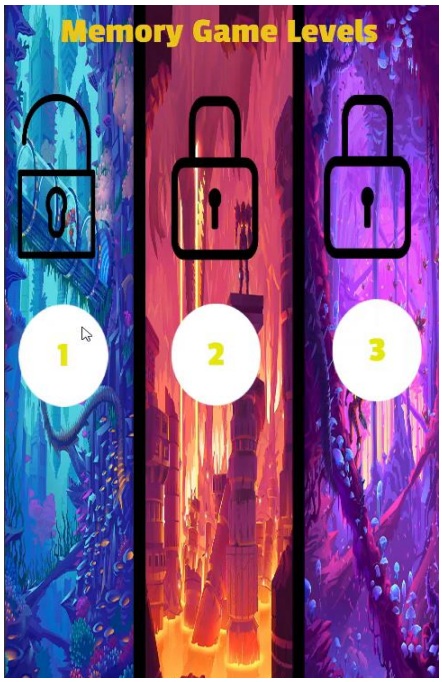
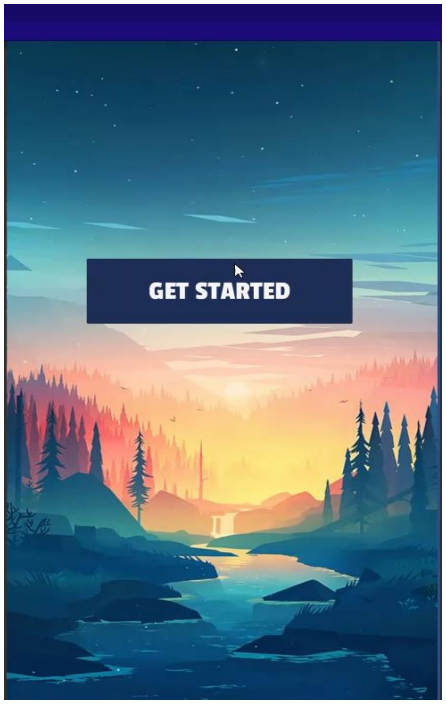




Figure 21: Basic Memory Game UIs



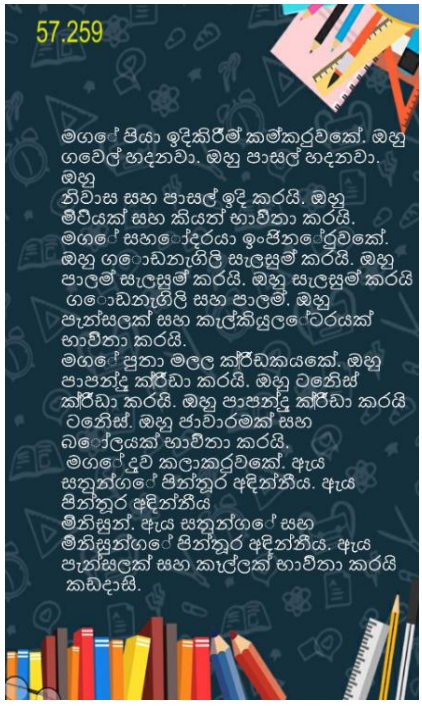




Figure 22: Basic Memory Game UIs

## Implementation of UI functionalities

```
public void NavigateToPage()
{
    switch (gameObject.tag)
    {
        case "English":  // If the menu selection is English this will redirect to to Starting page of the game in English
            //SceneManager.LoadScene("Estarted");
            Application.LoadLevel(levelToLoad);
            break;
        case "Sinhala":  // If the menu selection is Sinhala this will redirect to Starting page of the game in Sinhala
            //SceneManager.LoadScene("Sstarted"); // put scene name which should navigate when press this
            Application.LoadLevel(levelToLoad);
            break;
        case "Estarted": // Get Started with English
            //SceneManager.LoadScene("EP1");
            Application.LoadLevel(levelToLoad);
            break;
        case "Sstarted": // Get Started with Sinhala
            //SceneManager.LoadScene("SP1");
            Application.LoadLevel(levelToLoad);
            break;
        case "L2Estarted": // Get Started with English
            //SceneManager.LoadScene("L2EP1");
            Application.LoadLevel(levelToLoad);
            break;
        default: break;
    }
}
```

Figure 23: Implementation of Page Navigation Function

Above code segment in figure 12 was implemented to navigate among few of pages. According to that it used simple switch statement along with public C# function called NavigaeToPage(). As in this image there is a parameter which is called levelToLoad, is declared as in below figure. That parameter should be the name of scene where to navigate.

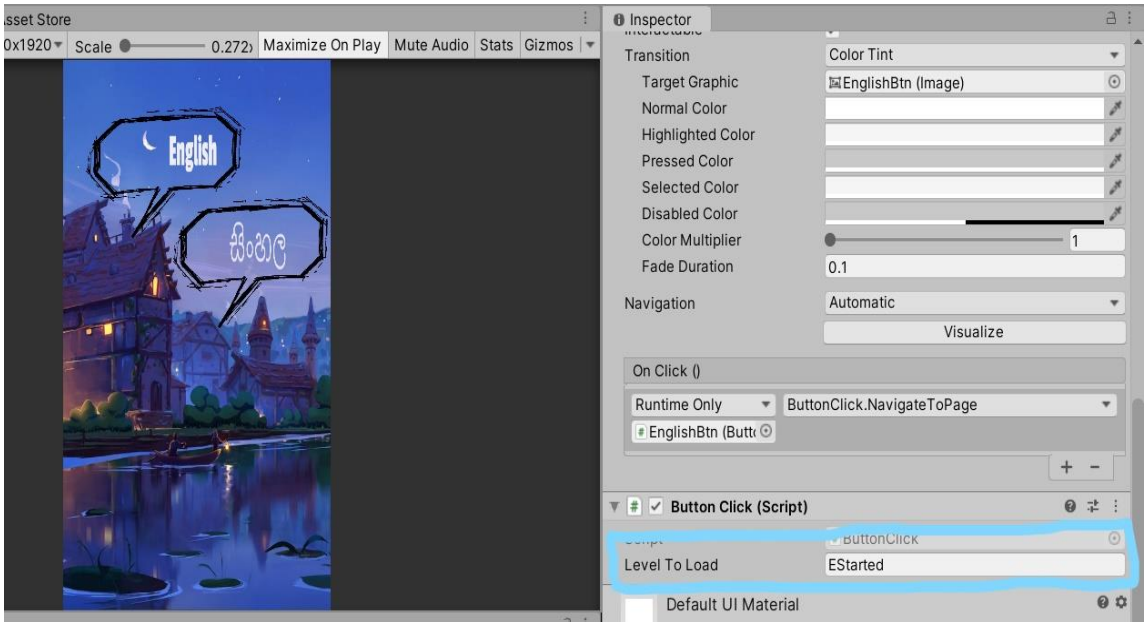



Figure 24: Unity Game Engine Inspector Section for UI

# 4. RESULTS AND DISCUSSION

## 4.1. Results

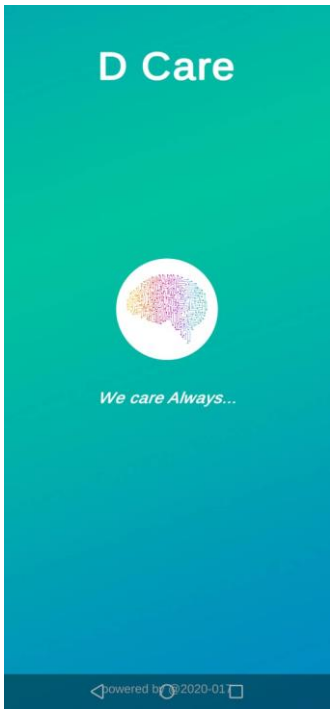



*Figure 26: Home Page*


*Figure 27: Sign-In Page*

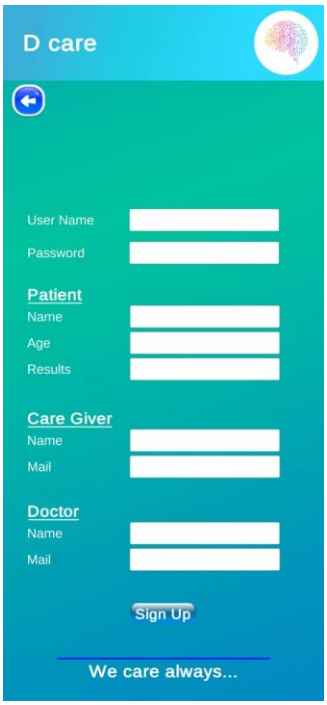



*Figure 25: Sign-Up Page*

The principle and the hugest consequence of making Customized Application for Dementia patients is to help those patients by giving recovery in an insightful way using different kinds of games and exercises. The first thing that catches your eye when you look at any application is its appearance.

The equations and calculations used to make the weekly progress report vary from game to game. Below are some weekly progress reports generated for the games for each of the patient's cognitive functions (Figure 27).

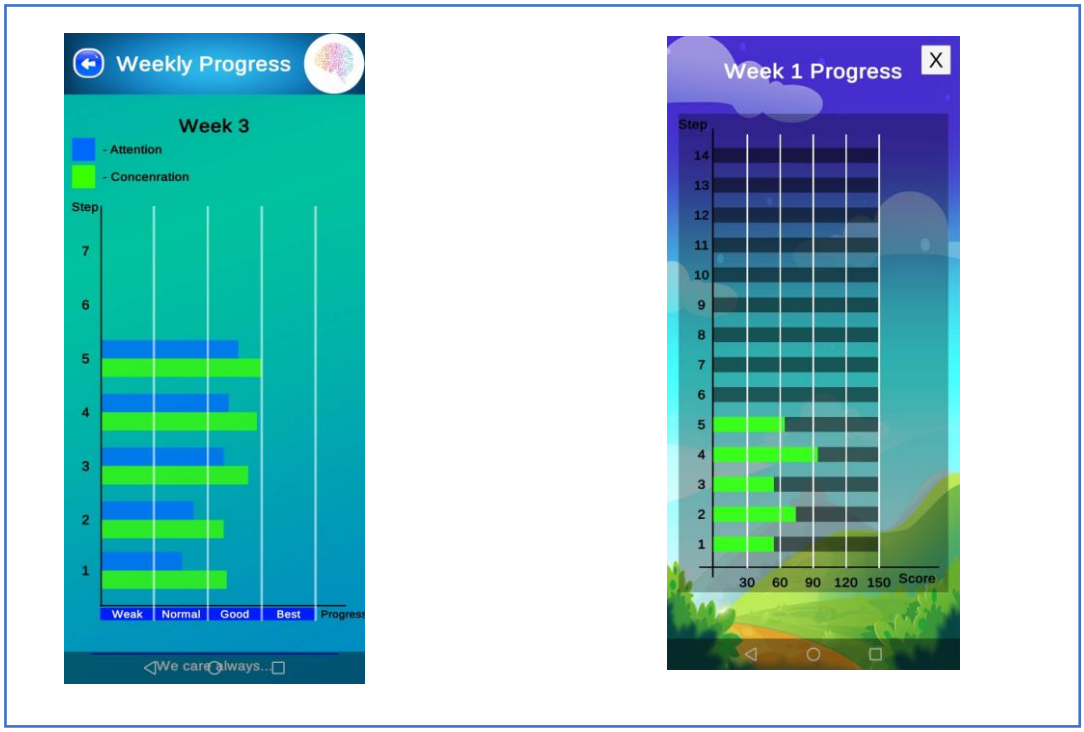



*Figure 28: Weekly Progress Reports*

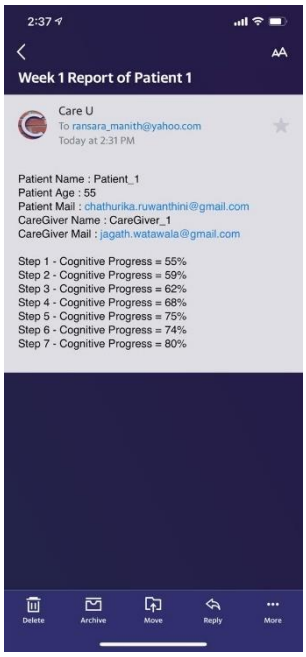



*Figure 29: Sample test of sending*

*progress report to doctor.(Executive Function)*

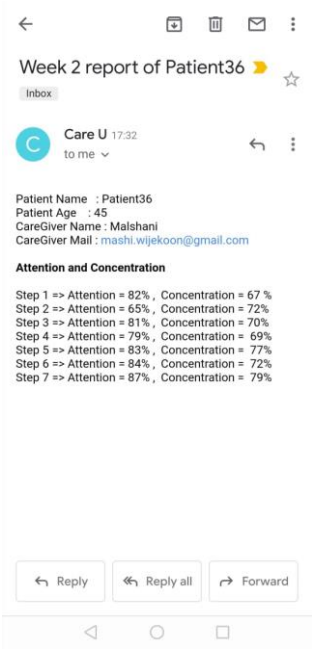



*Figure 30: Sample test of sending progress report to doctor(Attention and Concentration)*

Then, we achieved a special result of this application which is the feature of connection between the Patient's doctor and this application. End of every week, a report of weekly progress will send to the doctor via an email (Figure 28,29).

The following figure shows how voice recording wav files of different people were trained using sphinx library using voice recordings (Figure 30).

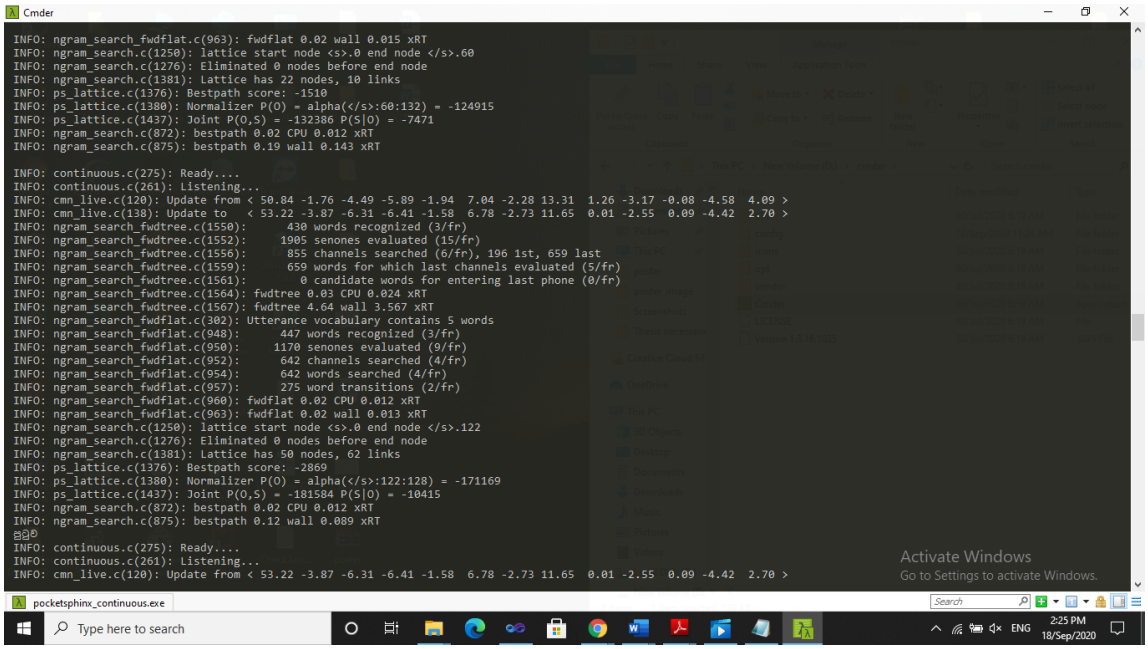



*Figure 31: results of the speech recognition acoustic model*

## 4.2. Research Finding

Dementia patients can use the D-Care application to improve their cognitive skills with best suited personalized games and activities. These games and activities are focussed on four main functional areas related to Frontal lobe and Temporal lobe of the Cerebral cortex. Attention and Concentration, Executive functions, Language and memory are those functionalities.

We used reinforcement learning algorithms such as Q-Learning, Deep Q-Learning to get the predictions for the next level game variables to give users a customized game. In some

games had to implement the algorithm using more than one algorithm because of the limitations they had.

We gathered and analysed the progress results of the users using same application with and with using machine learning technologies. With the results we can say the personalized application shows good results than the other.

So, finally to get the good and best suited customized levels in games reinforcement learning is good approach and needs model free algorithm. Among the model free algorithms, the Q-Learning and Deep Q-Learning algorithms gives the good results.

### 4.3 Discussion

This section mainly focuses on discussing the problems that faced during design and implementation and how those issues were resolved. In addition, this section discusses how to improve the system and succeed in gaining the achievements.

The research study " Cognitive Rehabilitation based Personalized Solution for Dementia Patients utilizing Reinforcement Learning " was begun on November 2019 to discover a best customized answer for recovery of Dementia tolerant through an electronic gadget. The arrangement was recognized as a versatile application with games and activities utilizing present day technologies like Reinforcement Learning and Deep Neural Network.

The first question we face is to which cognitive functions to choose for this application. Then we arranged several meetings with the external supervisor and talked about it and made a final decision. Various problems arose in designing games and activities to suit selected cognitive functions. This is because each of the cognitive functions must be designed in the same way as the treatments given by the doctor. When implementing the

algorithms for predicting next steps of some games there were some issues came up because the selected ML area. According to the Q learning algorithm it was hard to apply without fixed number of actions. Therefore, as a solution for that used the Deep Q learning algorithm also.

When integrating four parts which were executed independently, there were numerous bugs. The greatest issue was framework smashing. In there, in the wake of incorporating parts, the email framework utilizing SMTP was crashed. In this way, we needed to actualize it again as a result of it.

### 4.4 Summary of Individual Contribution

| Student | Contribution |
|---|---|
| Rathnayaka M.H.K.R. | Implemented mobile game to increase the attention and concentration of the patients, bit at a time to a considerable level. Carrying out simple tasks will be increased in complexity, will be introduced to the patients with the game. The game will be very simple at the initial stage and level by level game will be started to change. This game was implemented by using the reinforcement learning, which helps to make the game more specific to each patient. Referred Q-Learning and Deep Q-Learning algorithms. Implemented help |

| | |
|---|---|
| | page, instruction page, daily reports, weekly reports and report history according to the Attention and concentration game. And implemented email functionality that sends email to doctor automatically every week and send carbon copy to the caregiver. Some needed pages implemented in both Sinhala and English (E.g. Instructions, Daily progress). And finally implemented Sign in, Sign Up, user profile and home pages. |
| Watawala W.K.C.R | Implemented game for executive functions which will be helped to improve the effectiveness and speed process of executive functions the game for Executive Functions component is based on simple math calculation process. This game has four levels, and it will be more complicated level by level. This game was implemented using the reinforcement learning, which helps to continue the game more specific to each patient. Implemented reports which displaying patient progress. And the email functionality to send mail to doctor and caregiver. Implemented help page and other needed pages for the game. |

| | |
|---|---|
| Manamendra M.G. | Implemented game to improve the Language based on the reading, writing, comprehension and communication skills of the Dementia patients for both Sinhala and English languages due to the impairment of these skills will be caused to different kinds of Language problems in their day-to-day life including three level of games. Implemented speech to text component using Acoustic Model. This Acoustic Model was created using Hidden Markov Model in Deep Neural Network with the help of CMUSphinx library. Implemented calculation for progress and generate weekly progress reports which displaying patient progress. And the email functionality to automatically send mails to doctor and caregiver at the end of every week. Implemented help page, instruction pages and other needed pages for the game component. |
| Silva S.R.R.M | Implemented memory game for Dementia patients to principally enhance their memory and ability to improve. Considering about the memory of the Dementia patients, implementation of the activities of this component is chiefly aim at above mention aspects such as |

| | |
|---|---|
| | registration, recall and recognition. The game will have two or multiple levels in it and in each level, patient should be covering all the aspects of the memory and this game will be implemented using the reinforcement learning. Reinforcement Learning is using to predict the next level of the game for memory. Based on the performance of the patient that level will be predicted. Implemented reports which displaying patient progress. And the email functionality to send mail to doctor and caregiver. Implemented help page and other needed pages for the game. |

# 5. CONCLUSIONS AND RECOMMENDATIONS

Dementia patients need activities for Cognitive rehabilitation. To provide the patients personalized therapies, a user-friendly application was developed in a very interactive way including games and activities.

These games and activities are under four main functional areas from Frontal and Temporal lobes of Cerebral cortex such as Attention & Concentration, Executive functions, Language and Memory. The main objective of each game or activity is to improve the relevant cogitative functionalities of the patients in personalized way. The games are executed in touch screen and all the necessary places both Sinhala and English languages are used eliminating the gap between Sinhala and English and the technology gap for the elderly people. In three games QL and DQL algorithms of RL is used to learn from the user and predict the user specific next level for each user. This will help the patients to receive customized and most suited rehabilitation for the Dementia patients. And two of the games and activities have used Speech to text communication get the necessary user inputs. For the implementation CNN is used. Progress reports are generated for each functional area separately and both the caregiver and doctor can view the progress of the patient continuously. The new games introduced by D-care application improves the cognitive functionalities of the Dementia patients with continuous monitoring.

As for the future work, the application can be improved by increasing the accuracy of predicting the next level of the games. And in the Language game and Memory related activities, improve the speech to text communication by using the voice inputs after removing the background noise. We hope to introduce more games covering the other functional areas related to Frontal lobe and Temporal lobes of the Cerebral cortex. And to include the test to detect the Dementia patients using ML.

# 6. REFERENCES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