Cognitive Rehabilitation based Customized Solution for Dementia Patients

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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.**

Keywords—Dementia,   Cognitive   Rehabilitation, Reinforcement Learning

I. 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.

Using the technologies of machine learning like RL, NLP and HMM the implementation of the games and activities will be done. 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.

II. Literature Review

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 [4]. 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 [5].

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 [6]. 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 [7].

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 [8]. 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 [9].
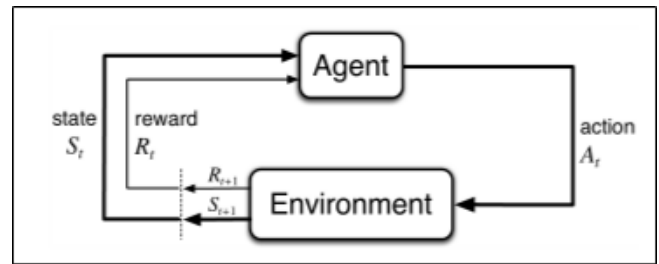

Fig. 1. Interaction between agent and environment [9]

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 [10]. 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 [11]. 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 [12]. Short-term cognitive training had positive effects on reasoning and speed of processing performance 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 [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 used 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 [15].

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 [16]. 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 since 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.

III. Methodology

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

A. 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.

1) 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.

2) 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.

3) 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 of the study, decided to use Python, TensorFlow, MySQL, Flask REST API, AWS Cloud, Unity and Q learning etc.

4) 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.

B. 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.
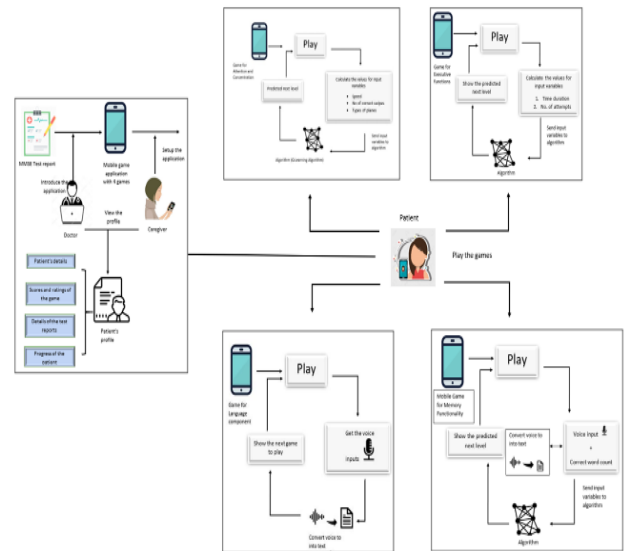
C. Implementation

Fig. 2: Overview of System

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. 2, 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, the doctor can continuously do a monitoring on patients at the required time. 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.

1) System Architecture
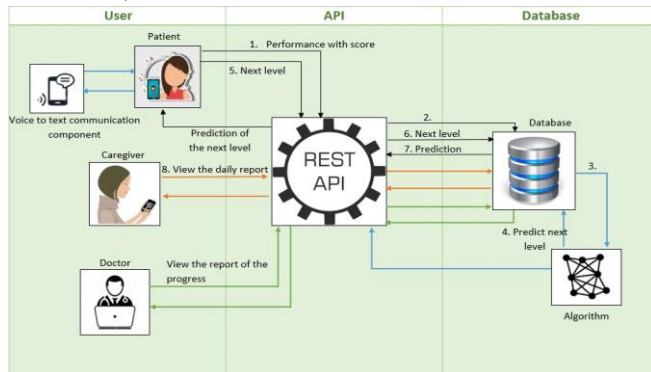
Fig. 3: High Level Diagram of System Architecture

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. Some of game interfaces are shown in Fig. 4, Fig. 5, and Fig. 6.

2) 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.

a) Attention and Concentration Component

Objective to develop this component was to improve Attention and Concentration of Dementia patients in personalized way by learn from the user and giving the most suited next level using RL algorithms.

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.
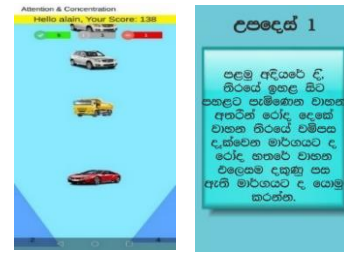

Fig. 4: Interfaces ofAttention and Concentration Component

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 number 3 'Q Learning'.

b) Executive Functions 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.
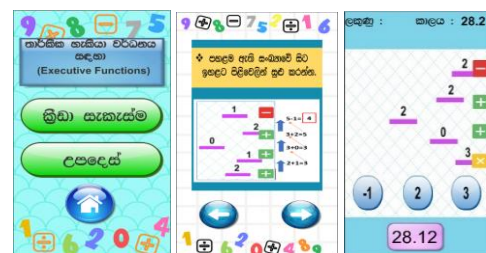

Fig. 5: Interfaces of Executive Functions Component

c) Language Skills 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.

d) 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).
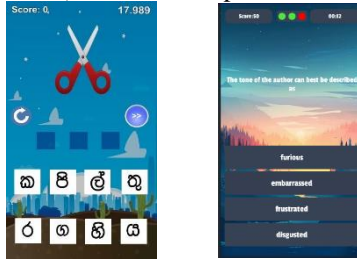

Fig. 6: Interfaces of Language and Memory Components

3) 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.

D. Evaluation

For the evaluation process of this application, the research team obtains two samples of patients with dementia. The most important feature of this application is that it predicts the next level of the game according to the performance of the previous game that the user has played. Hence, this application referred to as a personalized application. Furthermore, the main purpose of evaluating this application is the suitability of the personalized application over the average application. One sample of patients will use this personalized application for a period of one month. As mentioned earlier, the concept of the RL algorithm used for this personalization process. The second group will use the same game application that does not include a RL algorithm. One month after the timeline, the system evaluation process can be completed by observing the records of each patient group and estimating whether the system is acceptable or not.

IV. RESULTS AND DISCUSSION

The principle and the most significant result of making Personalized Application for Dementia patients is to help those patients by giving recovery in an intelligent manner utilizing various types of games and activities.

To obtain this result, the research team will analyze the progress reports of two samples of patients used in the evaluation process. This analytical process has been carried out with the assistance of Dr. Chathurie Suraweera, Psychiatrist, University of Colombo. Based on the results of both samples, the mobile game application with the Machine Learning concept has a high positive and success rate.

Patients with dementia show changes in each other's mood and personality, which can significantly affect their lives as well as their families. Also, not all dementia patients are in the same stage. Depending on the level of mentality, current stage or condition of the disease, cognitive impairments vary. Thus, this application will be a huge support to dementia patients as well as their families as it is implemented with a personalized approach.

Physician guidance is needed to use this application and to select the suitable game or games for the improvement in cognitive functioning. The custodian only must customize the application for the patient and then the patient can control the application due to user-friendly features such as visible font size, colorful images sweet soundtracks. Nowadays it is difficult to find a mobile application for dementia patients in Sinhala Language. For that reason, this developed method is great benefit to dementia patients as it is available in both Sinhala and English languages. A main reason for getting positive results is that the patient can choose the language of their choice.

V. CONCLUTION AND FUTURE WORK

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.

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