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Empowering Dementia Tele-Neurorehabilitation: AI-Enhanced Gamified Speech Therapy

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Pritish Pore[1], Prutha Rinke[1], Sharvari Bhagwat[1], Yash Desai[2]*, Arati Deshpande[1], Soubhik Das[3] and Pushkraj Marne[3]

[1]*Pune Institute of Computer Technology Pune, India*

[2]*Bachelor of Engineering (Computer) Pune Institute of Computer Technology Pune, India*

[3]*Manastik, Pune, India*

***Corresponding Author:** Yash Desai, Bachelor of Engineering (Computer) Pune Institute of Computer Technology Pune, India.

Abstract

Dementia, a neuro-degenerative disorder affecting various cognitive functions, including speech and language, presents significant challenges in rehabilitation. This research paper introduces a comprehensive tele-neurorehabilitation system designed for speech therapy in dementia patients, leveraging cutting-edge technology. The system incorporates nine distinct activities, employing text comparison models. Users engage in interactive exercises, where their spoken words are transcribed to text, fostering language engagement and cognitive stimulation. This application explores the dynamic correlation between dementia and speech therapy, analyzing advancements, challenges, and therapeutic applications. The outcomes of our study aim to deepen comprehension of this intricate relationship, providing a foundation for more precise and impactful speech therapy interventions, ultimately contributing to improved rehabilitation for those affected by dementia.

Keywords: Dementia; Speech Therapy; Tele-Neurorehabilitation; Gamification; Automated Speech and Language Therapy; Text Comparison; Cognitive Stimulation; Interactive Experience

Introduction

Dementia is an umbrella term referring to a cluster of conditions that impact different facets of cognition, such as memory, language, or learning, stemming from the degeneration of neurons in the brain (Alzheimer's Association, 2014) [1]. Dementia is a neurological disorder marked by a persistent decline in cognitive function, resulting from the loss or damage of neurons in the brain [2]. It covers a spectrum of cognitive challenges, hence it is extremely important to track dementia and thoroughly understand each patient's condition. The comprehensive assessment and diagnosis of dementia should encompass, at a minimum, the following four components:

1) A detailed clinical history 2) A neurological examination, placing emphasis on mental status evaluation 3) Targeted laboratory tests to screen for specific metabolic or physiological abnormalities 4) A structural brain scan, with a preference for MRI over CT when feasible [3]. The progression of dementia varies, and the severity and combination of symptoms depend on the underlying cause. It's important to note that dementia is a progressive condition, meaning that symptoms typically worsen over time. Early diagnosis and appropriate care can help manage symptoms and improve the quality of life for individuals with dementia and their caregivers.

Frontotemporal dementias involve neurodegenerative disorders affecting the frontal and temporal lobes, including clinical variants like behavioral and language-related forms. Primary progressive aphasia, a subtype, presents initial speech difficulties such as articulatory errors and word-finding challenges. Representing the third most common degenerative dementia, they rank second for those under 65, constituting about 20% of cases [3]. Speech and language impairments in dementia emphasize the vital role of speech therapy in enhancing communication skills and overall quality of life.

Speech disorders involve challenges in articulation, while language disorders compromise the language system, causing issues in word finding, retrieval, or anomia—the processing of linguistic information. Common dementia-related speech impairments include apraxia of speech and dysarthria. Apraxia, prevalent in Alzheimer's disease, is a motor speech disorder with symptoms like impaired rhythm and difficulty in sound pronunciation. Dysarthria, another motor speech disorder, coexists with apraxia, resulting in mumbled speech or altered speed. Language impairments in dementia lead to inappropriate word use, difficulty conveying ideas, and deficits in semantic and pragmatic functions [4].

The causes of speech and language impairment (SLI) in dementia are multifaceted. Neuro-degenerative processes associated with conditions like Alzheimer's disease, vascular dementia, or frontotemporal dementia lead to the deterioration of brain regions crucial for communication. The varied progression and symptoms linked to dementia highlight the importance of early diagnosis and the necessity for personalized care. Additionally, the progressive nature of dementia compounds these challenges, emphasizing the importance of early intervention and targeted speech therapy to support individuals and enhance their quality of life.

Given the rise in the number of dementia cases, there is a pressing need to develop and expand effective treatments and prevention strategies. Exploring alternatives for dementia care, technology can be employed to connect patients and significantly personalize the care relationship between the patient and caregiver based on their unique needs [7]. Since rehabilitation typically denotes a personalized approach aimed at assisting individuals with cognitive impairments [4], this paper introduces a recommendation engine designed to aid Persons With Dementia (PWD) in creating personalized rehabilitation plans. Machine learning algorithms are widely utilized in the early detection of diseases, demonstrating notable accuracy, especially in identifying initial indications of dementia [8]. Kuo et al. [6], suggested an efficient classification model for early detection of dementia. By introducing a hybrid transfer-learning based model, Kuo et al. illustrated that the model exhibited significant predictive accuracy for this particular application. Tele-medicine, a broad term encompassing medical activities at a distance, enhances doctor-patient interactions via telecommunication, potentially improving information access for healthcare professionals, patients, and the general population [5, 6]. The evolving field of tele-rehabilitation shows promise in delivering comprehensive rehabilitation services remotely. In the specialized branch of tele-neurorehabilitation, these benefits extend to neurological rehabilitation, including conditions related to speech therapy [7]. Machine learning algorithms and speech therapy have gained extensive application in early disease detection, particularly showcasing high accuracy in identifying early signs of dementia [8]. Analyzing speech data proves valuable for identifying the early stages of dementia.

This paper focuses on the development of a tele-neurorehabilitation application designed to assist individuals with dementia in their speech therapy.

A Brief Background of Technology Assisted Speech Therapy

Speech therapy is a clinical program conducted by speech therapist or speech-language pathology (SLP) as a treatment program to help people with dementia (PWD). Speech-language pathologists (SLPs) are tasked with implementing speech therapy interventions to address communication challenges in dementia patients. SLP offers therapeutic interventions for individuals experiencing challeng-

es in speech sound production, resonance, voice, fluency, language, cognition, as well as feeding and swallowing disorders. In the context of dementia, SLP proves valuable by addressing communication difficulties, aiding in maintaining language skills, and addressing any issues related to swallowing and feeding that may arise during the course of the condition [9]. Horner et al. [10] estimated that up to 45% of institutionalized patients with dementia suffer from dysphagia or swallowing disorders. SLPs are key to helping patients overcome these challenges.

SLP intervention significantly enhances communication function and well-being for PWD. Strategies include focusing on specific units, selecting initial targets, measuring differences, and determining the intervention's delivery method. Patient-centered care, incorporating disease severity, personal strengths, and preferences, is crucial [1]. However, the shortage of SLPs relative to patient numbers makes treatment costs prohibitive for lower and middle-income individuals. Mobile device-based therapy offers a solution by providing direct access without the need for a physically present clinician [11]. Selecting the most suitable strategy for individual patients proves to be a complex task due to the limited attention given to evaluating speech treatment methods specifically tailored for dementia. Moreover, the imperative to customize therapy for distinct subgroups within developmental speech disorders in dementia has been largely overlooked [12]. SLPs have the flexibility to incorporate or modify these approaches based on their clinical judgment and the unique needs of dementia patients in their care [13].

AI has gained significant popularity in the healthcare domain in recent years, although its roots trace back much further [14]. In this paper, we introduce an AI assisted model for speech therapy for PWD where patients can practice a number of tasks and exercises widely accepted by the SLPs.

In summary, the contributions of our proposed system are as follows:

- A therapy app leveraging technology which proves beneficial for dementia patients by providing customized cognitive exercises, social exercises and memory-enhancing activities.
- Several interactive and gamified features to support mental agility, social connection, and emotional well-being while boosting motivation.
- Accessibility to allow patients to engage in therapeutic activities at their own pace, facilitating consistent monitoring of cognitive functions and progress.
- A technology-driven tele-neurorehabilitation approach that enhances dementia care by offering personalized support in a convenient and familiar environment.

Methodology

This paper presents a set of nine speech therapy activities tailored for dementia patients, integrating technology to deliver personalized and interactive interventions. The activities target specific facets of speech and language, encompassing mouth movement, reading, object recognition, tongue twisters, sentence completion, loudness and pitch variation, personal information recall, conversation practice, and category naming. A speech-to-text model transcribes user speech into text, allowing for evaluation by comparing it with database content. User advancement is monitored through a comprehensive dashboard, streamlining the creation of individualized therapy plans.

Mobile Application

In contemporary times, adults are increasingly familiar with and exposed to mobile technology at an advanced age. Beyond its utility for communication and entertainment consumption, mobile technology serves as a readily accessible resource for implementing user-friendly learning approaches for adults, including those grappling with dementia. Technology has the potential to enhance the quality of life for individuals grappling with cognitively debilitating diseases [15]. Given the widespread use of mobile technologies across diverse demographics, these devices hold the potential to assist adults with dementia in speech therapy. The ubiquity of mobile devices offers a promising avenue to incorporate supportive strategies tailored to the unique needs of individuals facing communica-

tion challenges associated with dementia [9]. Furthermore, apps with reminders and scheduling features aid in managing daily routines, enhancing a sense of structure and independence for those facing the challenges of dementia. Overall, mobile applications serve as versatile tools, addressing various aspects of care and support for adults navigating the complexities of dementia.

Gamification

Enhancing motivation stands as a primary objective when incorporating gamification into more serious contexts. Substantial empirical evidence supports the effectiveness of gamification and serious games. Findings from a survey high-light the correlation between utilitarian, hedonic, and social motivations and the intention to sustain usage. This suggests that the perceived benefit is influenced by the attitude towards gamification usage, with hedonic aspects showing a direct positive relationship. Conversely, social aspects impact attitude, underscoring their significance, particularly when addressing specific audiences such as individuals with dementia [16]. Hence, the gamification introduced in this paper incorporates a scoring system solely for the purpose of tracking patient progress within the system, intentionally not displayed to the user to prevent potential demotivation.

Current gamification strategies in the eHealth sector primarily target motivating younger populations, with a predominant focus on supporting physical exercise rather than addressing cognitive disorders [17]. Gamification proves to be notably important for dementia patients as it introduces a range of potential benefits tailored to enhance their overall well-being. One key advantage lies in its ability to provide cognitive stimulation, engaging individuals in activities that challenge memory, problem-solving, and decision-making skills. Beyond cognitive benefits, gamification contributes to emotional engagement by incorporating elements of fun, achievement, and positive reinforcement. This emotional connection fosters a more enjoyable and uplifting environment. Importantly, gamification introduces motivation and participation elements, encouraging individuals with dementia to actively engage in therapeutic activities, promoting a sense of accomplishment. Socially oriented games facilitate interaction among dementia patients, addressing feelings of isolation. Furthermore, the personalized nature of gamified therapy allows for tailored interventions that adapt to individual needs and abilities. Overall, gamification emerges as a holistic approach that not only addresses cognitive aspects but also contributes to emotional, social, and overall quality of life improvements for individuals living with dementia [15].

Proposed Approach

- Speech-To-Text Model
  Speech to text conversion finds applications in various scenarios. An effective method to gain fluency in English language that enhances the user's way of speech through correctness of pronunciation following the English phonetics was developed by Jose et al [18]. In Speech-to-Text (STT) conversion, the system identifies and converts spoken words and phrases from audio input, facilitating efficient communication between humans and machines. This conversion proves especially beneficial when individuals with different languages or dialects interact. Without an STT system, language barriers may hinder mutual understanding. The STT converter addresses this by detecting words spoken in various accents or dialects, converting them into easily readable text. To achieve this functionality, various methods have been proposed. Fig. 1 illustrates the basic steps of the STT process, involving the extraction of key features from input speech, word and sentence matching using acoustic models and defined syntax, and semantic analysis for sentences. This process, performed in parallel, concludes with language modeling using the selected method [19]. The speech captured from the source is recorded through a microphone, and its features are extracted into text format.
- Text-to-Speech Model
  In the process of Text-To-Speech (TTS) conversion, the provided text undergoes analysis and is then transformed into its audio counterpart for playback. This functionality proves advantageous for individuals who comprehend a language but may not be proficient in reading or writing it. Additionally, it holds utility for those who are visually impaired, enabling them to grasp messages through auditory means. Fig. 2 illustrates the fundamental steps of the TTS process. Initially, the text undergoes preparation for audio conversion through pre-processing and text normalization. Subsequently, linguistic analysis and prosodic prediction are sequentially performed to generate the waveform of the text message [19]. Implementing a TTS feature in a mobile app tailored for dementia patients holds tremendous potential in improving their overall user experience. For individuals grappling

with cognitive challenges, particularly in reading and comprehending written text, TTS becomes a crucial tool. Dementia patients can effortlessly listen to information, messages, or instructions, reducing the barriers posed by written language difficulties. By fostering a user-friendly interface that accommodates auditory communication, the app enhances the independence of dementia patients, promoting engagement and usability in their daily interactions with the mobile platform.

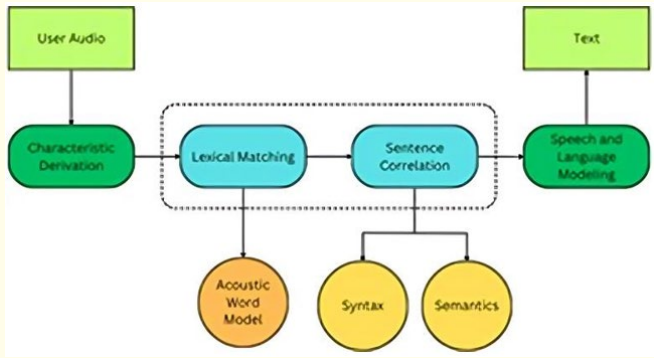

Figure 1: Speech-to-Text Model.

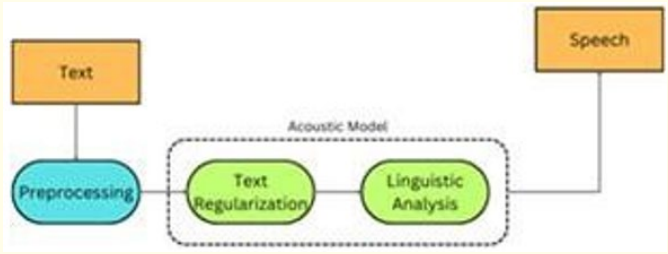

Figure 2: Text-to-Speech Model.

- Text Comparison Model

  Text comparison plays a pivotal role in various applications, ranging from content similarity assessment to language processing tasks. It involves analyzing the accuracy and coherence between the original input (either spoken or written) and the processed output (either text or speech). For Speech-to-Text, the comparison may focus on the precision of transcribing spoken words into text, ensuring that the app accurately captures and represents user input. In Text-to-Speech, text comparison evaluates how faithfully the app renders written content into spoken words, considering factors such as pronunciation, tone, and naturalness. The initial findings from a text matching task show promising results when compared to more sophisticated state-of-the-art approximate string matching techniques [20]. Text comparison can contribute to the creation of customized communication profiles for users and also assist in identifying inconsistencies or ambiguities. It can be utilized to provide memory aids by presenting previously entered text alongside newly inputted text. This supports users in recalling recent information and aids reminiscence, helping them connect with past interactions. By analyzing their preferred language usage and communication style, the app can adapt to individual needs, providing a more personalized and supportive experience. Fig. 3 illustrates the fundamental steps of the Text Comparison Model.

Considering the processing approach mentioned earlier, a program was devised using these models to autonomously conduct the entire speech therapy activity for PWD.

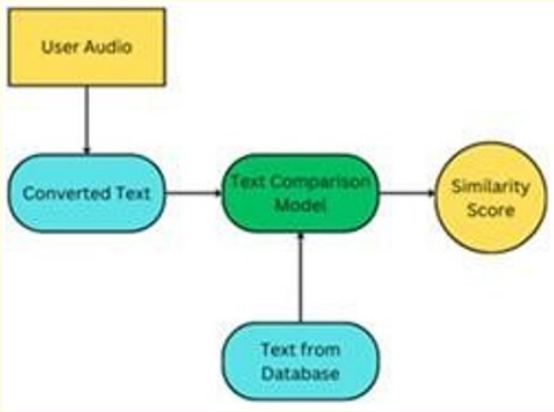

Figure 3: Text Comparison Model.

Implementation

This research paper introduces nine activities for dementia patients to help assist with their speech and language therapy. These handpicked activities are meticulously designed to target various aspects of speech and language, promoting engagement and cognitive stimulation for an effective and personalized therapeutic approach.

Each activity integrates crucial features for vocalization, recording, and speech evaluation. A text-to-speech model articulates necessary text and hints, while a speech-to-text model transcribes user speech for comparison with the database, assigning scores. Notably, these scores remain backend data, guiding adjustments to activity difficulty based on individual performance.

Users access a comprehensive dashboard for overall progress and individual dashboards per activity, aiding in pinpointing areas for improvement. The feature allowing users to listen to responses and re-record if desired enhances the learning experience. Step-wise hints are thoughtfully embedded, providing incremental assistance during speech therapy sessions.

The activities implemented and introduced by this paper are as follows:

1. *Mouth movement*: This activity is designed to assist patients in practicing diverse mouth movements, addressing potential challenges faced by PWD. It includes a brief visual demonstration illustrating the proper mouth movements during speech, accompanied by audio cues for users' reference.
2. *Reading activity*: This activity incorporates sentences and brief paragraphs for users to read aloud, with their performance recorded and evaluated. In instances where users encounter challenges, helpful hints are available by clicking on the specific word or sentence, which is then audibly presented to assist them. This exercise assists patients in articulating complete sentences, thereby enhancing their reading and speaking abilities.
3. *Object Recognition*: In this activity, users are presented with an image of an object on the screen and are tasked with verbalizing the name of the object. This exercise not only hones their speech skills but also engages and sustains cognitive abilities by encouraging associations between objects and corresponding words or speech. To aid users, hints are initially offered through on-screen text naming the object, and if challenges persist, the object is verbally pronounced for further assistance.

4. *Tongue Twister*: This straightforward activity involves providing users with tongue twisters, targeting specific syllable groups to improve their verbal skills. Users can access helpful hints by clicking on specific words or the entire sentence, with audible presentations for assistance.
5. *Sentence Completion*: As part of this engaging activity, users are presented with an incomplete sentence and are tasked with appropriately completing it by uttering a fitting word or phrase. Hints are available in the form of images representing suitable answers, which can be further vocalized if desired. This game serves as a dual-purpose exercise, promoting the engagement of both cognitive abilities and speech skills.
6. *Loudness and Pitch*: This activity focuses on helping users emphasize specific words within sentences. Text displayed on the screen, which requires variations in loudness or pitch, is highlighted. This exercise assists users in speaking clearly and conveying emotions like surprise, joy, sorrow, and more. For additional guidance, the sentence is audibly presented with all the intended changes in loudness and pitch for certain words.
7. *Address and Name*: This straightforward activity prompts PWD to verbally share personal information, including their name, address, and the names of caregivers or relatives. This exercise aims to reinforce the practice of essential details, aiding in memory retention. Additionally, it serves as a valuable test of their ability to communicate vital information, potentially crucial in situations where they may need assistance in finding their way back home. If users struggle to recall this information, it is provided to them to assist in memory recall and reinforce their ability to remember essential details.
8. *Conversation*: This activity is a little different as it involves the active participation of a caregiver, and the recording of the patient's speech is optional. The user is given a specific topic to engage in a brief conversation with their caregiver. Hints are provided to the caregiver, suggesting thought-provoking and open-ended questions to encourage meaningful dialogue. Caregivers are equipped with a set of guidelines and parameters to assess the conversation, and at the conclusion, they enter a rating along with the duration of conversation, facilitating the tracking of patient progress.
9. *Category*: This activity too requires a caregiver. Users receive a category prompt and are tasked with naming as many items from that category as possible, such as fruits or animals. To aid users, initial hints include displaying images of items belonging to the category, followed by captions. If needed, the hint is vocalized for the user. The caregiver plays a key role in recording the number of correct items listed by the patient in the system, facilitating the tracking of progress.

Results and Discussion

The gamification of speech therapy exercises for dementia patients is pioneering and by integrating game elements into therapeutic activities, patients are more likely to stay engaged and motivated throughout their sessions. The interactive and rewarding nature of gamified exercises serves to make the rehabilitation process enjoyable, encouraging consistent participation.

The implemented games in this research project are designed to strategically target crucial aspects such as memory retention, cognitive abilities, social abilities and vocal abilities. This holistic approach is anticipated to result in a tangible enhancement of these abilities for individuals, particularly those undergoing speech therapy.

The project incorporates tailor-made games, including activities like recalling names and addresses to target memory functions. Sentence completion exercises empower users to formulate their own sentences, stimulating creativity and cognitive abilities. Additionally, games focused on category correlation and image recognition serve to activate and engage the patients' minds. Furthermore, activities centered around mouth movement, loudness, and pitch aim to enhance vocal performance and provide a platform for effective vocal practice. The inclusion of real-person conversation is expected to foster social interaction, providing patients with a practical platform to refine their speech skills in everyday scenarios. Overall, the project is poised to serve as a transformative tool in the realm of speech therapy, bringing about comprehensive improvements in memory, cognitive abilities, vocal skills, and real-world conversational engagement due to the integration of advanced technology.

Future Scope

This research project centers on the efficacy of employing speech therapy exercises to aid individuals with dementia, with a particular emphasis on refining these exercises to enhance user adaptability to technology and expedite the curative process. In the future, this project aims to introduce Spectogram analysis to improve the results of this research.

A Spectrogram visually represents signal strength evolution over time, showcasing various frequencies within a waveform in a two-dimensional format. Time is plotted on the horizontal axis, frequency on the vertical axis, and intensity or color denotes the amplitude of frequency components at a specific time [21]. Spectrogram analysis transforms audio signals into a graphical representation based on frequency, amplitude, and time. This visual representation can be converted into an image, enabling a matrix-based comparison to determine the percentage similarity between two signals. Therapists can interpret this similarity percentage without requiring specialized technical knowledge [22].

Moreover, Spectrogram analysis plays a crucial role in distinguishing between speech, music, and pitch variations, assisting patients with dementia in perceiving changes in their pitch and facilitating targeted practice. The spectra of speech encompass source harmonics overlaid by vocal tract formants, with spectral peak trajectories providing valuable insights for sound segment evaluation [23]. This detailed analysis will enhance the effectiveness of Spectrogram in the realm of speech therapy for individuals with dementia.

Conclusion

Speech therapy is crucial for individuals with dementia, addressing their communication challenges. Utilizing AI-assisted tele-neurorehabilitation, personalized speech therapy sessions are delivered remotely, overcoming geographical barriers. This integrated approach extends the reach of speech therapy, creating a dynamic and accessible framework for addressing the unique needs of dementia patients, providing consistent monitoring and personalized care in the comfort of their homes.

Integrating gamification into dementia therapy adds an enjoyable dimension, stimulating cognitive functions. Automated speech and language therapy use technology for personalized interventions, adapting to evolving patient needs. Together, they create a dynamic environment for engaging dementia therapy. Text comparison tools track progress systematically, fine-tuning interventions based on individual responses. Targeted cognitive stimulation activities challenge the brain, promoting mental acuity and delaying decline. In summary, interactive experiences, virtual simulations, and multimedia content significantly enhance dementia therapy, providing a more engaging and enjoyable therapeutic approach.

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