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An Automated Speech-Language Therapy Tool with Interactive Virtual Agent and Peer-to-Peer Feedback

Maitraye Das
Technology and Social Behavior
Northwestern University
Evanston, IL, USA
maitraye@u.northwestern.edu

Abir Saha
Department of Electrical and Computer Engineering
Indiana University-Purdue University Indianapolis
Indianapolis, IN, USA
abirsaha@iupui.edu

***Abstract*—Widespread use of technology has brought about revolutionary changes in health domain. Treatment of speech and language disorders is one such field where computer-based techniques have the potential to provide readily available therapy at low cost by reducing the reliance on therapists and clinicians. Although significant research has been performed on computer-aided speech and language therapy, existing approaches do not focus on the nonverbal behavioral cues of a patient in a natural conversational scenario. In this paper, we propose an automated speech and language therapy tool with an intelligent and interactive virtual agent playing the role of a therapist. Besides giving feedback to the patient's response on various therapeutic tasks, the virtual therapist has the ability to carry out a conversation with the patient and give feedback on their non-verbal behavioral cues to help them improve their communicating ability. Additionally, our proposed system supports computerized peer-to-peer conversation in real-life scenarios which is also underrepresented in existing research concerning computer-assisted speech language therapy.**

***Keywords*—Automated speech and language therapy; virtual therapist; peer-to-peer feedback**

I. Introduction

Speech disorders are conditions in which people face difficulties with producing speech. Such conditions include problems with sound articulation, voice and fluency of speech. Among various types of speech disorders, stuttering, apraxia, dysarthria etc. are common. Stuttering or stammering means the disruption in the flow of speech due to involuntary repetitions and prolongations of sounds or syllables as well as involuntary pause or break in speech [1]. Apraxia is a motor speech disorder where the brain faces difficulty in controlling the lip and mouth muscles to form the desired words, resulting in sound distortions, substitutions and other problems. [2]. Dysarthria stems from impaired movement of muscles used to produce speech and results in slow speech, rapid mumbled speech and abnormal rhythm and pitch during speaking [3]. On the other hand, language disorders are associated with the inability to comprehend and process linguistic information [4]. Aphasia is a common multi-modal language disorder occurred due to degenerative processes (e.g. dementia) or sudden brain lesions (e.g. an ischemic stroke or a traumatic injury) [5]. Approximately 1% of adult population are affected by stuttering [6]. According to the World Health Organization, 15 million people suffer stroke worldwide each year [7]. Stroke often leads to chronic impairment of language abilities and severely limits a person's social interaction. Availability of Speech and Language Pathologists (SLP) compared to the number of patients is so low that the treatment cost often goes beyond reach for poor and middle-class patients. Therefore, computer and mobile device based therapy can be a feasible solution to the problem of limited staffing, because such therapy can be directly accessed by a person suffering from speech disorder without the need of a physically present clinician [8]. Following this need, significant research has been done to provide various computer-based speech and language therapy, such as alternative and augmentative communication (AAC), computer-assisted treatment (CAT) and computer-only treatment (COT). In AAC, typically a grid with symbols, pictures and sentences are pointed and vocalized. One problem with this approach is that it can be used for speech disorders like apraxia or dysarthria, but not with language disorders like aphasia [9]. In CAT, patient and SLP work side-by-side on the program, which has only a supportive function such as showing pictures. The SLP has to evaluate the answers himself. On the contrary, COT tasks can be evaluated automatically and patient can get graphical or audio-visual hints same as clues given by a human SLP for recalling words, or pronunciation of syllables. Research studies about computer-based therapy supports its use in clinical practice, as study participants have exhibited positive speech and language outcomes after using such programs [10].

In this paper, we present a COT type speech and language therapy tool that includes an autonomous interactive virtual agent playing the role of an SLP. Patients can practice a number of tasks and exercises widely accepted by the SLPs with the help of the virtual agent and receive feedback from the agent. Moreover, patients with speech and language disorders may be unable to express their thoughts properly in natural conversation due to problems in their nonverbal behaviors and thus lag behind in growing social skills. According to behavioral scientists, behavioral cues refer to patterns observed in a person's touch, facial expressions, hand and eye gestures, body posture, vocal behavior and so on [11]. Vinciarelli et al. [12] defines behavioral cue as a set of very short-lived (lasting from milliseconds to minutes) temporal changes in neuromuscular and physiological activity. Besides analyzing patient's performance on traditional speech and language therapy related tasks, the virtual therapist in our system takes into account nonverbal behavioral cues of the patients, such as pitch, volume, eye contact, smile intensity etc. in a natural conversational context and provides feedback to improve these nonverbal behaviors.

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In addition to individual therapy, group therapy has also proven to be a viable alternative for people with speech and language disorders [13]. Group intervention facilitates interactions with different members of the group, and thus promotes generalization of language skills and exerts a positive effect on the quality of life [14]. Participants of a group gain experiences regarding coping with and solving problems, and receives both peer and professional support. It has been found that group therapy improves both cognitive function in patients and their management of psychiatric conditions [15]. Considering these positive aspects of group therapy, our proposed system includes provision for the patients to practice therapeutic tasks in a collaborative environment with peers, where both parties can give feedback to each other and also receive feedback from the system to improve their speaking and communicating ability.

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

- We propose an automated speech and language therapy tool with an intelligent and interactive virtual therapist.
- We consider a patient's nonverbal behavioral cues in a natural conversational context with the virtual therapist and provide feedback to improve both speaking and communicating ability of the patient.
- We include peer practice in real-life conversational scenario along with peer-to-peer and system-to-patient feedbacks to enhance conversational skills of the patients.

II. Related Work

Thanks to the rapid rise of technology in health domain, computer-based speech and language therapy has experienced an immense growth in popularity, and people suffering from speech and language disorder have experienced vast improvement after using these techniques. A study in 2014 found 128 apps in App Store (Apple, Inc.) and 95 in Google Play Store with the keyword 'Aphasia' [16]. Besides, various ACC, CAT and COT type software and subscription based web services are in use for speech and language therapy, and a considerable amount of literature can be found about these [16]. In [17], Parnandi et al. proposed a remote monitoring system for apraxia where a therapist assigns speech production tasks through web interface and patient practices the tasks on mobile device. This system includes an automated speech analysis engine that provides quantitative speech assessment results to the therapists for further review. Stark et al. modeled ELA Virtual House [18] and developed three language tasks (discovery, structured discovery, and memory tasks) [19] for training on the word and sentence level within the virtual house based on the ELA Syntax program. However, this virtual house application does not have any provision for conversational speaking practice. In [20]-[23], Cherney et al. have incorporated their Oral Reading for Language in Aphasia (ORLA) treatment technique into a virtual reality setting. By means of script training, the setting uses a virtual assistant to support a patient in a conversational context. The virtual assistant replicates the actions and suggestions a real therapist may use during a face-to-face session. However, the authors collected response from the patients in typed form and measured performance in terms of key strokes and response time only. Thus this method cannot detect the mispronunciation of the words or sentences by the patient and is feasible only for language therapy (not speech therapy). Theodoro et al. conducted a Wizard of Oz pilot study to test the interactions between a human and virtual avatar of a clinician in conversational scenario [24]. The virtual avatar was driven by a human support worker using pre-arranged scripts.

None of these above-mentioned approaches consider nonverbal behavioral cues of the patients in a natural conversational context. Our system is inspired by LISSA [25] and Aging & Engaging framework [26] which enhance social skills of teenagers with Autism Spectrum Disorder and older adults respectively by providing feedback on nonverbal cues. Real-time feedback by intelligent interface on nonverbal cues is also explored in a public speaking scenario in [27, 28].

Peer collaboration has been studied for computer-based pronunciation training in [29]. Houlihan et al. assessed the effects a peer-led telephone-based technique in [30] to help adults with spinal cord injury improve their self-management behaviors. In [31], a dyadic computerized Maze Task was designed to guide peer interaction among children with social communication disorders, where the task required substantial high-level collaboration and perspective taking than typical conversations. Marshall et al. evaluated the effects of a virtual reality platform on people with aphasia in [32]. The platform, named EVA Park, consisted of several functional and fictional locations and scenarios that created opportunities of interactive communication between multiple users based on goals set by human therapists or support workers. To the best of our knowledge, no previous work adopts the computerized peer-collaboration technique in natural conversation and/or provides feedback on nonverbal cues in the context of speech and language therapy.

III. System Overview

In this section, we give an overview of our system which offers twofold practice option for a patient with speech and language disorders- 1) individual practice 2) peer practice. At first, a patient creates account into the system and enters necessary login credentials. The application allows for testing without the need of entering any login details; however, a guest account will be created automatically in the background.

A. Individual Practice

After logging in, a patient can practice several tasks related to the type of her disorder and its stage or severity level. The unique profile ID of the patient stores his/her improvement in performing the tasks, which denotes the current stage of her disorder. Tasks are categorized into two sections; one for speech disorder (apraxia, dysarthria, stuttering etc.) and the other for language disorder (aphasia). All tasks are well accepted by the SLPs and used in regular therapy.

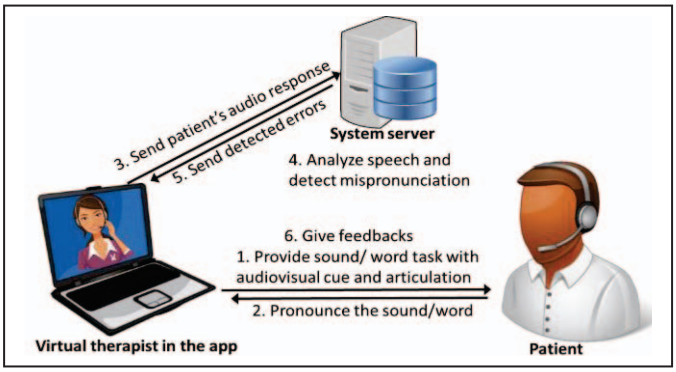

Figure 1. System overview of speech disorder related task execution

1) Tasks related to speech disorders: Similar to existing approaches [17], we follow the Nuffield Dyspraxia Program (NDP3) to mitigate the effects of speech disorders, including articulation of individual sounds, sequencing sounds together, and retaining prosodic accuracy [33]. In the NDP3 protocol, patient's current speech skills are measured by an initial assessment and the therapy is designed afterwards based on the patient's skills. Both the assessment and therapy are directed in a multi-layer bottom-up approach where the bottom layer consists of single speech sounds, the next layer contains CV words (C: consonants, V: vowels), followed by CVC, CVCV and multisyllabic words, consonants cluster words, and finally phrases and sentences to form connected speech. The therapeutic tasks include the production of 1) all the single consonants, vowels, and diphthongs, 2) a set of single words at each phonotactic structure (CV/VC, CVCV, CVC, CCV and multi-syllabics) through picture naming, and 3) phrases and sentences through imitation with pictures. The NDP3 protocol necessitates regular therapy sessions under the guidance of a speech therapist. In our system, an autonomous interactive virtual agent plays the role of the speech therapist. Our virtual therapist has a distinct visible avatar in the screen with high quality voice.

A set of picture cues are presented to the patient as stimuli to denote single consonants, vowels, diphthongs, and words at each of the phonotactic levels. At the same time, virtual therapist reads aloud the sounds or words carefully and shows the articulation by lip and tongue movement. The patient produces specific sounds, syllables, or words accordingly. The pronunciation of the patients are recorded using microphone and sent back to the system for analyzing the accuracy of the patient's response. There is option to listen to the recording and practice again. System overview of the execution of speech order related tasks is shown in Fig. 1.

Errors made by the patient in pronunciation are identified according to the recommendation by ASHA which validates three segmental and suprasegmental features of speech disorders- (1) inconsistency on consonants and vowels in repeated productions of syllables or words and altered use of a particular sound class in different word positions [34], (2) elongated and disrupted coarticulatory shifts or struggle between sounds and syllables (i.e. articulatory struggle) [35], and (3) indecent prosody, which occurs most commonly during lexical stress realization [36].

We follow the approach presented in [17] for analysis of patient's response captured by microphone and presented to the system server. At first, DC part is removed using preprocessing filter, the speech signal is segmented into small frames and necessary features are extracted for each frame. By analyzing the average energy and zero crossing rate of input sound, a voice activity detector detects both speech and non-speech parts that represent silence during articulatory struggle on a frame by frame basis. A lexical stress analyzer operates on the speech to classify strong-weak (SW) and weak-strong (WS) stress patterns. The classifier is based on a multilayer perceptron, and its input feature vector includes the mean and maximum energy, mean and maximum pitch, peak-to-peak amplitude, and syllable durations. Patient's pronunciation errors are detected by means of Hidden Markov Model (HMM). A grammar lattice that includes the correct phoneme sequence and expected mispronunciations of each phoneme (known from experimental training data) is used by an HMM decoder in conjuncton with acoustic models to generate a phoneme sequence from the patient's verbal response. The patient's phoneme sequence generated using this method is then compared to the target phoneme sequence through a dynamic-programming string alignment procedure. Three kinds of mispronunciations (insertion, deletion and substitution) are identified to detect inconsistent and variable speech produced by the patient. After completing speech analysis, the virtual therapist provides feedback to the patient in terms of the number of mispronunciations, articulatory struggle and indecent prosody.

The tasks related to speech disorders also include creating word by joining sounds or syllables. The picture cues are repeated based on the speech level of the patient and his/her performance on the tasks. The virtual therapist also shows lip and tongue exercises to increase muscle movement of the patient and monitors his/her response. This is especially helpful for the people with acquired speech disorder after brain injury.

2) Tasks related to language disorders: We design the tasks related to language disorder considering three linguistic levels – form of language (phonology i.e., sound combinations in a word, morphology i.e., structure of words, syntax i.e., order of words in sentences and relationships among elements within a sentence), content of language (semantics, i.e., meanings of words and sentences) and function of language (pragmatics, i.e., contribution of context to meaning). The tasks in our system related to language disorders are as categorized into two types based on the bias of the tasks.

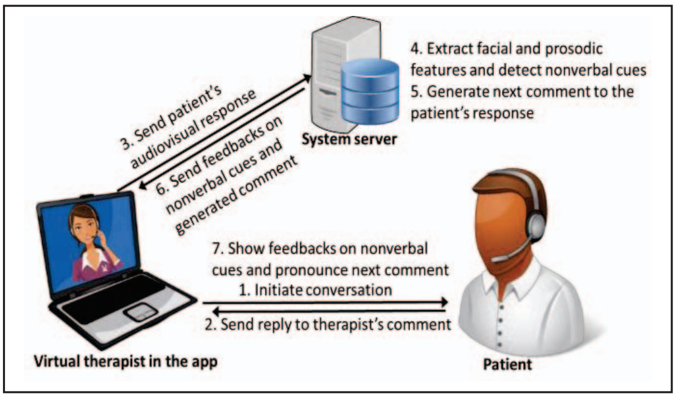

Figure 2. System overview of patient-to-vitual therapist conversation

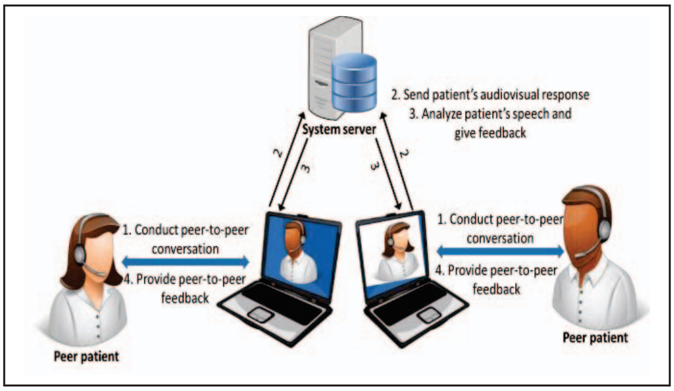

Figure 3. System overview of peer-to-peer conversation

a) Objective task: A number of objective tasks are presented to improve phonological, morphological, syntactical and semantical skills of the patients. Such tasks include – 1) relating images to a word and words to an image, 2) completing a word with missing letters and a sentence with missing words, and 3) ordering letters in a word and words in a sentence in the correct position. For objective tasks, picture cues are provided and the words are read aloud by the virtual therapist along with visual articulation. Patients selects her answer among the given choices (letters, words, or images) or provides typed input (letters, or words). Thus the accuracy of these tasks can be calculated by simply checking whether the patient's response equals to the correct answer or not.

b) Subjective task: Subjective task includes conversation with the virtual therapist. A patient may have problems in basic sentence making level during natural conversation. For this reason, we follow the script training approach which can improve participation in personally relevant conversational activities [20, 21]. We prepare scripts of some real-life conversational scenario between the patient and the virtual therapist, such as booking a flight, ordering food in a restaurant etc. Each spoken word by the therapist is highlighted automatically with each written word in the screen. At the beginners' level, script contains written cues in the screen for the patient. As the patient learns the scripts, he/ she can remove the cues sequentially, so that practice simulates real conversation at the final stage.

Patient's responses to the scripts are captured via microphone and camera and uploaded to the system server in real-time for analyzing and providing feedback to the patient. At the advanced level of the conversational practice, patient's nonverbal behavioral cues are also analyzed according to the approach in [26]. From the audiovisual files, several facial and prosodic features are extracted, including smile intensity, pitch, frequency, volume and difference in pixels between consecutive frames. A face tracker finds out eye-gaze direction along with 2-D and 3-D coordinates of the patient's pupils. The system overview of the conversation between the patient and the virtual therapist is shown in Fig. 2.

Feedbacks are provided on the patient's performance both in real-time and after conversation. The real-time feedback uses flashing icons to recommend changes in the user's eye contact and gazing direction, smile, volume of voice, body posture and movement. Hidden Markov Model (HMM) is used to predict the appropriate timing of icon flashing in order to suggest timely adjustment of a patient's non-verbal behavior. Post-session feedback shows the number of reminders received by the patient during the conversation, the amount of time the patient could continue conversation without getting any reminder, and the time taken to adjust their behavior. The virtual therapist also provides suggestions for continued improvement.

In a natural conversational scenario, the virtual therapist cannot follow the prepared scripts like the script training session. For this reason, our system dynamically modifies plans to lead a dialogue. Following the technique in [25], patient's inputs are mapped to explicit, context-independent clauses, where the preceding therapist output is considered as the context. The mapped clauses are used to produce a suitable therapist reaction to the patient's input using a vigorous but flexible hierarchical pattern transduction method.

B. Peer Practice

In our system, multiple patients can remotely participate with each other in conversation on real-life context, such as making a doctor's appointment, enquiring about swimming classes, making purchases etc. The topic of the conversation is generally motivated by experiences in patient's lives or specific aspects of language, such as asking questions, initiating conversation, and improving word finding. Peers can provide feedback to each other's performance in terms of understandability of speech, pause between words or sentences to find appropriate word in the context, groping errors i.e., struggle to pronounce a word and non-verbal cues such as smile, pitch, volume etc. Peer-to-peer conversation is also captured by the system and analyzed to provide feedbacks on the individual performance of the patients. The overview of the peer-to-peer conversation is shown in Fig. 3.

IV. Discussion and Future Work

We note that speech and language disorders are highly subjective. For this reason, the level of the difficulty and contents of the tasks have to be continuously adjusted and new tasks should be included by consulting SLPs. We note that our proposed automated speech-language therapy cannot substitute conventional face-to-face session with human SLPs and patients completely. For this reason, time-to-time conversation with an SLP in the form of peer support may increase the authenticity of the system to the users and increase their interest to use the therapy.

As future work, we are planning to implement our proposed system and evaluate its practicality to help individuals with speech and language disorders increase their speaking and communicating ability. The evaluation also involves optimization of the performance by friendly user interface accessible to particular age groups and additional features like rewards, minimal button-pressing, bigger texts etc. Another direction is to include augmented reality based features in our framework to make the therapy more engaging and speed up the learning process.

V. Conclusion

In this paper, we present the design of a computer-based speech and language therapy tool which includes an autonomous and interactive virtual therapist. The virtual therapist sets tasks widely accepted in regular face-to-face therapy to the patients, captures audiovisual response of the patients to the tasks and provides feedback on their performance. Moreover, our system works as a stand-alone intelligent application that can carry out conversation with the patient without any outside help from human and suggest improvements on the patient's non-verbal behavioral cues during conversation. Furthermore, multiple users can practice conversational skills with each other in our system and get real-time feedback from both the system and other peers.

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