

Speech Disabilities in Adults and the suitable Speech Recognition Software Tools – A Review

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Abstract— Speech impairment, though not a major obstacle, is still a problem for people who suffer from it, while they are making public presentations. This paper describes the different speech disabilities in adults and reviews the available software and other computer based tools that facilitate better communication for people with speech impairment. The motivation for this writing has been the fact that stuttering, one of the types of speech disability has affected about 1 percentage of the people worldwide. This fact was provided by the Stuttering Foundation of America, a Non-profit Organization, functioning since 1947. A solution to stuttering is expected to benefit a considerable population. Speech recognition software tools help people with disabilities use their computers and other hand held devices to satisfy their day-to-day needs which otherwise, require dedicated domestic help and also question the person's ability to be independent. ASR (Automatic Speech Recognition) systems are popular among the common people and people with motor disabilities, while using these techniques for the treatment of speech correction is a current research field and is of interest to SLPs/ SLTs (Speech Language Pathologist / Speech Language Therapist). On-going research also includes development of ASR based software to facilitate comfortable oral communication with people suffering from speech dysfunctions, i.e., in the domain of AAC (Augmentative and Alternative Communication).

Keywords—Automatic Speech Recognition (ASR), Disability, Speech Language Pathology/Pathologist (SLP), Speech Language Therapy/Therapist (SLT), Augmentative and Alternative Communication (AAC)

I. INTRODUCTION

Speech disabilities are a type of disorder in a person's communication because of which the "normal" words they say get disrupted, distorted and become unintelligible for the listener. Speech disabilities include but are not limited to stuttering, lisps, etc. People who find it difficult to speak due to a speech disorder are considered mute. The Canadian Association of Speech-Language Pathologists and Audiologists [www.caslpa.ca] published a fact sheet in 2005, where it is mentioned that "1 in 10 Canadians has a speech, language or hearing problem". It also mentions that stuttering (stammering) affects more population in the age group of 5 to 19.

As per the report by DIIR (Disability India Information Resources), there were 2.19 crore people with disabilities in

India who constituted 2.13% of the total population. This data was based on the Census India 2001. Out of this population, 7% were affected by speech disorders. This number had increased to 10% as per NSSO (National Sample Survey Organisation) 2002.

In their early stages of life, 4% to 10% of children worldwide are getting affected by Speech and language disorders [1][2]. Many of the fortunate kids are identified at the right time and with a regular training from SLPs, they are able to overcome the problem. However, others when they grow up, face various difficulties at many forums where communication is mandatory. Some of the affected people limit their participation in public activities and this behaviour is called "participation restrictions". The person thinks that others might react badly to disfluent speech and hence exhibits this kind of behaviour. Some others try to cover up their disfluent speech by changing the order of the words they use in their sentences (circumlocution), pretending to forget what they wanted to say, or simply abating to speak. Clearly, the impact of speech disorders on daily life can be influenced by how the impaired person and others react to the disorder.

Though there is no clear, known cause for these speech disabilities in children, SLPs/SLTs often employ a method based on the principles of motor learning in treating children with motor speech disorders such as Childhood Apraxia of Speech (CAS), also known as Developmental Verbal Dyspraxia (DVD) or dysarthria [3][4]. The pathologists suggest to identify the speech disorders in younger children by additional efforts of parents. There are guidelines published indicating the speech development of children against their ages in months. The degree of understanding of a child's speech by parents and strangers will decide the level of speech disability the child is prone to and this factor is used to measure the intelligibility of speech of the child.

II. SPEECH DISORDERS

There are different types of speech disabilities or dysfunctions observed in human beings and some of them are briefly described below:

A. Cluttering

A syndrome characterized by a speech delivery rate which is either abnormally fast, irregular, or both [5]. People affected

speak very fast which often becomes unintelligible to the listener. An example of the same is a speech like this: "Oh, I think I my speech is garbled. I speak too fast...Other people always say 'What did you say to me? Speak slower please'...I hear I hear myself. Uh my my words get garbled to myself I garble my words...". Many experienced clinicians have managed only to cure a few persons with this disorder.

B. Dysarthria

A condition that occurs when problems with the muscles that help a person to talk make it difficult to pronounce words [6]. This may be due to the paralyzing of the physiological function involving larynx, lips, tongue, palate and jaw. Dysarthria speech is characterized by poorly pronounced words. Other symptoms include:

- Creating tongue-ties sounds like mumbling
- Whispering or Speaking very softly – hearing is very difficult
- Nasal voice / Breathy voice or stuffy, hoarse, strained, voice – deciphering contents become difficult

Corrections for dysarthria include training by SLPs and also Surgery in some cases.

C. Lisp

This is a Functional Speech Disorder (FSD), a difficulty in creating one or more specific speech sounds, for example, /s/, /z/, /r/, /l/ and 'th'. This type of speech impediment with particular syllables was also called sigmatism. The cause of this problem is unknown, yet, it does not reduce the speaker's intelligibility very much. However, the impact of a lisp on adults' "image" may be a major factor for them to seek a therapy and correction.

D. Esophageal voice

The patient may swallow or inject some air into his/her esophagus. The air in the esophagus then vibrates a muscle and creates esophageal voice. It is often difficult to learn and understand esophageal voice and people with this problem can only talk in short sentences with a quiet voice.

E. Stuttering

Also called 'Stammering', a speech disorder in which sounds, syllables, or words are repeated or uttered for an extended duration than normal [7]. The speaker experiences a sudden break in the flow of speech, and because of these behaviours, stuttering is feared to be hindering in educational and working environment affecting performance, as well as blocking social communication.

In general, Speech Sound Disorders (SSD) is a category of speech problems which involves impairments in speech-sound production. SSD covers many sub-categories right from mild articulation issues to severe phonologic disorders involving multiple errors in speech-sound production and reduced intelligibility [9]. The other names used for SSD are "speech impairment" or "speech difficulties". The subcategories include

- Articulation disorder
- Phonological disorder

- Childhood apraxia of speech
- Dysarthria

Adults may also have developed speech sound disorders from childhood or after a stroke or head injury. Cerebral palsy is an injury to the brain, and affects the muscle control (palsy) making it sluggish. Cerebral palsy exhibits characteristics of muscle tightness, involuntary movement and impaired speech. However, the impaired people are able to use computers with some customization like, an adaptive keyboard (keyboards with raised areas in between the keys). They can use speech recognition tools trained specifically for their voice and accents [11].

III. AUTOMATIC SPEECH RECOGNITION

A process of getting the computer system to understand spoken language, Speech recognition is an inter-disciplinary research subject, which involves transformation of human speech signals to text, vectors and machine readable data [13]. Today's speech recognition systems combine various techniques from Signal Processing, Pattern Recognition, Linguistics and Natural Language Processing into a unified statistical framework and thus research in this domain is of interdisciplinary nature. The ASR systems have a wide range of applications especially in the domain of individual user based tools. There are 3 widely used approaches to speech recognition [14], which are,

- The Acoustic-Phonetic approach
- The Pattern Recognition approach
- The Artificial Intelligence approach

A. Components of an ASR System

A typical speech recognition system comprises the following:

- A large Corpora of speech data for training
- Suitable representation for input voice data and technique of extracting it from the medium
- Phonetic (Pronunciation) Model
- Acoustic Model (Learning Phase)
- Language Model (Learning Phase)
- Components to extract desired features
- Algorithms to search hypothesis space efficiently

For speech processing applications, both deterministic and stochastic models of signal processing have been performing well. The Hidden Markov Model (HMM) is a popular choice among the stochastic models.

B. The Hidden Markov Model

The basic theory of HMM was published by Baum, et al., in the late 1960s. These models were implemented for a variety of speech processing applications [14]. HMM is a popular method for characterizing the spectral properties of a speech frame. It is one of the most widely used and is based on the ideas of statistical signal modeling. HMM involves building a signal

model using the observed data/ symbols and after successfully building such a model, use it to predict or categorize the new input signal. This is useful in applications of speech recognition and speaker recognition.

C. ASR Lexicon – Markov Models for Pronunciation

The acoustic model is represented as Hidden Markov Model, where each state represents one phone or other sub word units. A few samples are shown in Fig. 1, where the probability of change in states is marked as numbers on the arrows.

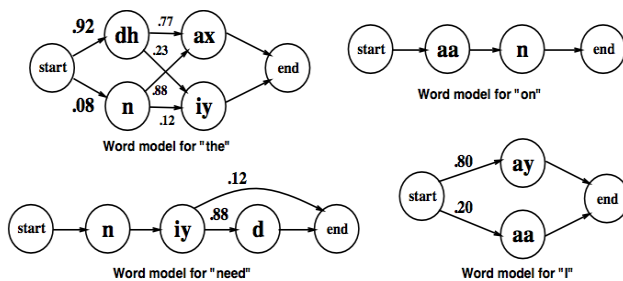


Fig. 1: Markov models for building 4 different words

Courtesy: Julia Hirschberg

IV. SPEECH PROCESSING RESEARCH

The research on Speech processing necessitates an understanding at three levels as depicted in Fig. 2. Speech processing theory involves the basic signal processing models, speech processing methodologies, techniques of analysis of the speech waveforms, the physics behind the production of speech and the mathematics of signal processing. The concepts include how the theory is applied in a practical scenario of analysis of speech, with techniques like wave form coding, etc. The 3rd step is to implement the theoretical concepts learnt using any programming tool like MATLAB. This also requires knowledge on machine learning algorithms and statistical tools for analysis of large volumes of speech data.

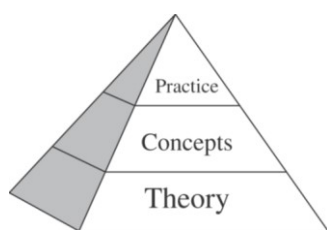


Fig. 2: Learning components of Speech Processing

Courtesy: MATLAB Central

1) *Practice Components:* Ability to implement theory and concepts in working code (MATLAB, C, C++); algorithms, applications

2) *Conceptual Components:* Basic understanding of how theory is applied; autocorrelation, waveform coding and others.

3) *Theoretical Components:* Mathematics, derivations, signal processing; e.g., STFT, cepstrum, LPC and others.

V. RESEARCH FOR SPEECH IMPAIREMENT PROBLEMS

Researches in Speech Recognition systems are useful to SLPs in such a way that the tools developed are employed before and after the treatment / training to measure the effectiveness of the same. There were attempts to use objective methods to evaluate patient's progress in speech therapy [17]; however a more personal level interaction is often effective to help patients recover faster and better.

The following techniques are also used to complement the speech disability of the user:

- A typical computer system to type or pick words that the user wants to say
- A set of flip cards which bear text or pictures of what the user wants to say
- Special computer programs that speak out the words / sentences which are input through keyboard / keypad / mouse / any other pointing device.

For the benefit of people with speech disorders, there are anti-stuttering devices like the following:

- Delayed Auditory Feedback based device (one such device has been named as DAF 1.0)
- Electronic fluency device

Delayed Auditory Feedback v.1.0 is a device that records user's voice and plays it back after a slight delay in time. This is the principle of DAF as applied to speech therapy for stuttering/stammering. Based on the same principle, there exists a software called axSoft Speech corrector which is developed for the following use:

- During the treatment of stuttering
- Improving the speech of people with speech impairments
- Improving the Public speaking skills by providing feedback
- Providing feedback on expressions while speaking
- Foreign languages training

Input to this program is a voice signal from a microphone. Necessary transformations for processing and a sound delay are applied to the signal and the processed audio is sent as output to the headphones. As the listener hears his/her own speech with a little delay, the feedback mechanism works effectively to reduce the stuttering. People with stuttering problem who have used this software regularly have been able to achieve significant reduction in stuttering.

Analysis of Speech signals has been done using various tools and techniques. The more commonly used features of speech in a real-time application are,

- How each word is stressed in a sentence

- The pattern of speech and the in-between pauses
- Prosodic features including Rate, Intonation, Nasality, Pitch and Loudness.

The general conclusion reached by many researchers engaged in the work of providing ASR based solution to the disabled community is that the available technology is mature enough to handle the requirements. However, there are human factors, e.g., feeling of enslavement to the technology, which are impeding the developments in this field. An improvement in the reliability of present day speech recognisers will be a major milestone if we want them to be used effectively and confidently by the disabled persons.

VI. EARLIER WORK IN SPEECH DYSFUNCTIONS AND SOLUTIONS

A category based review of the Speech Recognition Techniques used in earlier researches has been conducted and the results are presented in this paper. They are compared on parameters like, the method / algorithm used, description of their database, accuracy of the results, category of speech dysfunction of the beneficiary, etc. The techniques used are briefly explained in the following section and the comparison and the author's view on the technique are provided in the subsequent sections. A commonality observed across the different articles is that they adopt a "User-centered methodology" for their development and/or prototypes. This shall be attributed to the fact that the work is aimed at people with speech disability and the degree of disability varies from one user to another. Hence the level of customization / training required for each user may vary greatly from others.

a) Communication aids for people with disabilities using Speech Recognition Techniques [18] – A Speaker-dependent automatic speech recognizer has been built for recognizing the unintelligible words of the user, convert it to a predefined sentence format and output it in a synthesized form.

b) Mouse Movement using Speech and Non-Speech Characteristics of Human Voice [19] – voice controlled mouse operation has been achieved using a defined set of words (up, down, left, right) and four sounds (aaaaa, iiiiii, eeeee, ooooo and uuuuuu).

c) Performing Computer Operations with Voice Controlled Mouse [20] – uses continuous speech and very short vowel pronunciations to control the mouse movements for the benefit of people with general physical disabilities such motor disability.

d) MFCC based Recognition of Repetitions and Prolongations in Stuttered Speech using KNN and LDA [24] – The main objective of this paper is to analyse the effectiveness of MFCC features for the recognition of prolongations and repetitions in stuttered speech.

e) Automatic generation of conversational utterances and narrative for Augmentative and Alternative Communication: a prototype system [25] – This article describes an Augmentative and Alternative Communication (AAC) software which encourages rapid conversational interaction.

f) STARDUST – Speech Training And Recognition for Dysarthric Users of Assistive Technology [27] – The recogniser uses isolated words which are easier for dysarthric users and forms compounded sentences on its own.

g) Speech Technology for e-Inclusion of People with Physical Disabilities and Disordered Speech [28] – This paper examines areas for e-inclusion of people with speech disabilities who can benefit from advances in speech processing. The identified areas are access, control, communication, rehabilitation and therapy.

<i>First Author</i>	<i>Database & Results</i>	<i>Features</i>	<i>Technique Used / Classifier</i>	<i>Type of Disability addressed</i>
Mark S. Hawley [18]	9 participants' live data – 96% accuracy achieved	Mel-frequency cepstral coefficients (MFCCs)	HMMs with 11 states	Moderate to severe Dysarthria
Sandeep Kaur [19]	Not Specified	MFCC, Normalized cross-correlation coefficients (NCCC), Gain	Minimum Feature Distance Technique	Stuttering and difficulty in saying full words
Sarita [20]	Not Specified	Extraction using LPC, Pitch, Energy & Vowel quality	ANN (Artificial Neural Networks)	Motor disabilities
Lim Sin Chee [24]	10 (8 male and 2 female) samples from UCLASS database – 90% accuracy achieved	Mel-frequency cepstral coefficients (MFCCs)	K Nearest Neighbours (KNN) & Linear discriminant analysis (LDA)	Stuttering
Martin Dempster [25]	3 users from the disabled community using AAC	Not Specified	Natural Language Generation (NLG) technology used to automatically generate conversational utterances	Cerebral palsy & Dysarthria
Mark Hawley [27]	5 users' live data – 92% accuracy achieved	MFCC	Continuous Density Hidden Markov Models (HMM)	Severe Dysarthria
Mark Hawley [28]	Not Specified	Not Specified	Application of the STARDUST [27] project analysed and representations made.	Physical Disabilities and Speech Disorders – All sub categories

VII. PROPOSED METHODOLOGY AND IMPLEMENTATION

A sample speech recognizer has been developed using JSAPI (Java Speech Application Programming Interface) to

recognize words in a fixed dictionary. Input has been live speech with normal and impaired person's voice samples.

A. Experimental Setup

The development has been done on a MS Windows-10 stand-alone system with voice input capability. The speech input has been provided through a microphone and output has been a transcribed text file. The vocabulary contained a moderate number of words and JSGF style grammar was adopted. Speech input was about 4 minutes duration without break.

B. Results and Observations

The study has been conducted in 2 ways:

1. Experiments have been carried out with normal person's voice sample using Microsoft speech engine, Google Transcribe web page and the newly developed module. The parameters used to compare the results were: Time taken for the input (Speed of decoder), Accuracy in terms of number of words correctly recognized, Word Error Rate (WER) and Prior training requirement. Accuracy is calculated as the below mentioned ratio and expressed as a percentage.

$$\text{Accuracy} = \frac{\text{Total Number of words} - \text{Deletions} - \text{Substitutions}}{\text{Total Number of words}}$$

This parameter ignores the number of new words inserted and hence the WER is calculated as,

$$\text{WER} = \frac{\text{Insertions} + \text{Deletions} + \text{Substitutions}}{\text{Total Number of words}}$$

The accuracy obtained has been 77% compared to 80% using Google Transcribe. However, the commonly misinterpreted slang words like "r" for "are", "b" for "be", etc., have been correctly recognized in the new method. Also, a sample paragraph that took 3 minutes 40 seconds on Google Transcribe could be decoded within 2 minutes 20 seconds.

Following table summarizes the observations:

Benchmark	Accuracy for a sample speech (in numbers)	Time For Decoding(RT) (in minutes)	Prior Training Requirement
Google Transcribe	60/75	3:40	No
MS word	27/75	3:50	Preferred but NOT used
Proposed System	58/75	2:20	Yes

2. Experiments have been repeated with speech impaired person's voice sample. The program's accuracy has been very low when the voice sample of a speech impaired person was used as input. This indicates that the processing requires more scientific and machine learning techniques to effectively and correctly decode the distorted speech.

The results of this pilot program reveal that establishing a system for the use of an impaired person to facilitate free conversation in formal / casual environments is necessary and has growing needs. This research area needs to take leaps forward to be used by the community at large.

VIII. SUMMARY AND CONCLUSIONS

Surveys indicate that the population of speech disabled human beings are increasing and as the world moves forward with technological aids, the requirement of customizable, user-specific communication tools are also increasing. The demands of the disabled community pose challenges to the researchers to develop new tools which will serve as an effective communication aid to bridge the gap between them and rest of the world. Earlier researchers have indicated that there is a potential to combine the best methods proposed in the past, to produce good systems that will facilitate the people with speech dysfunctions overcome their disabilities [28]. Through this review, it is proposed to implement a software tool that will perform like a human interpreter for a speech disabled person when he/she wants to have a direct oral discussion with others.

Making effective progress in this domain requires knowledge of the disabled user community, difficulties faced by them, procedures of assistive technology and speech technology. Thus, this kind of research necessitates a multidisciplinary team approach and will take smaller leaps.

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ORGANIZATIONS INVOLVED IN THE TREATMENT AND RESEARCH ON SPEECH IMPAIRMENT IN CHILDREN

1. "The Stuttering Foundation" Since 1947 – A non-profit Organization Helping those who Stutter <http://www.stutteringhelp.org/>
2. Royal College of Speech and Language Therapists (RCSLT) <http://www.rcslt.org/>
3. The website of American Speech-Language-Hearing Association <http://www.asha.org/>
4. Dr. Caroline Bowen's www.speech-language-therapy.com
5. Canadian Association of Speech-Language Pathologists and Audiologists (CASLPA). <http://www.caslpa.ca>