Journal of Theoretical and Applied Information Technology
29th February 2020. Vol.98. No 04

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

ARABIC DISORDERED SPEECH PHONETIC DICTIONARY GENERATOR FOR AUTOMATIC SPEECH RECOGNITION

[1]ASSAL A. M. ALQUDAH, [2]MOHAMMAD A. M. ALSHRAIDEH, [3]AHMAD A. S. SHARIEH
[1,2,3] Department of Computer Science, King Abdullah II School of Information Technology, The University of Jordan, Amman, Jordan.
E-mail: [1]assal.alqudah@yahoo.com, [2]mshridah@ju.edu.jo, [3]sharieh@ju.edu.jo

ABSTRACT

The phonetic dictionary, which is also known as pronunciation dictionary and lexicon, contains a mapping between the words of the intended language and their corresponding phoneme sequences. It is an essential component for developing an Automatic Speech Recognition (ASR) system. The phonetic dictionary acts as an intermediary component with other ASR components such as the acoustic model and the language model. This research aims to design and develop a phonetic dictionary generator (PDG) for Modern Standard Arabic (MSA) and Arabic disordered speech that can be used for ASR research and development. This rule-based PDG receives Arabic texts and transforms them into their corresponding phoneme sequences using pre-defined rules. Since ASR systems must accommodate different needs of speakers and users including the speech of normal speakers and speakers with speech and articulation disorders, this PDG will be able to produce phoneme sequences for both normal speech and disordered speech using pre-defined rules too. The input speech from speakers with speech and articulation disorders such as substitution and distortion articulation speech disorders can be different from the speech of normal speakers. In this release of the PDG, the substitution and distortion articulation speech disorders are considered for their importance and frequent recurrence. The PDG is evaluated using an Arabic text that contains 1,623 unique words. The output phonetic dictionary for normal speakers contains 2,473 phoneme sequences, whereas the output phonetic dictionary for speakers with disordered speech contains 62,997 phoneme sequences. This indicates that the output phonetic dictionary for speakers with disordered speech is more comprehensive and contains more possibilities and variations of the same unique word, which would ease the recognition task in ASR systems in a manner that suits different speakers with different pronunciation variations.

Keywords: *Arabic Language, Articulation Disorders, Automatic Speech Recognition, Disordered Speech, Phonetic Dictionary*

1. INTRODUCTION

Communication is vital for humanity in order to produce human to human interactions. Nowadays, rapidly changed technologies produced another type of communications, which is the human to machines communication. Therefore, people now speak not only to each other, but also to computers, smartphones, smart watches and many more. Consequently, speech technology changes our lives to another level where we cannot neglect anymore. Accordingly, to make all these technologies applicable, we are in need to have Automatic Speech Recognition (ASR) [1].

ASR has been an active research area for more than five decades, not only because it is important for human-human communications, but also to enable and improve human-machine interaction [1].

ASR aims to convert speech signal from a recorded audio to text. In order to do so, an ASR uses a probabilistic approach where the available speech signal corresponds to word or sequence of words with a probability. Therefore, this approach is considered to be a data driven approach where the developer or researcher has to collect speech and text data related to the research domain [2, 3].

In addition, ASR is a technology that transforms human speech signals into text in a given language. It is also known as Speech-To-Text (STT) technology. In the last decade, ASR research and development witnessed dramatic achievements due to advancements in software, hardware, tools,

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

algorithms, and language resources (text and speech) [4]. Many researchers have also worked on ASR for many languages worldwide including Arabic, English, Japanese, Mandarin, Finnish, and many other languages [4-22].

Generally, the ASR uses the collected speech and text to build statitical models of speech signals and text, and then applies a preselected search procedure in order to find the best word string that corresponds to the input speech signal. To optimize the recognition results, an objective function is given by the statistical models that enhance the search process [3].

Figure 1 shows components of an ASR system [4]. Language resources (text and speech), feature vectors that are produced through a suitable features extraction technique, phonetic dictionary also known as pronunciation dictionary, language model, acoustic model, and decoder are required for an ASR. Figure 2 shows the role of pronunciation dictionaries in ASR systems in specific [5].

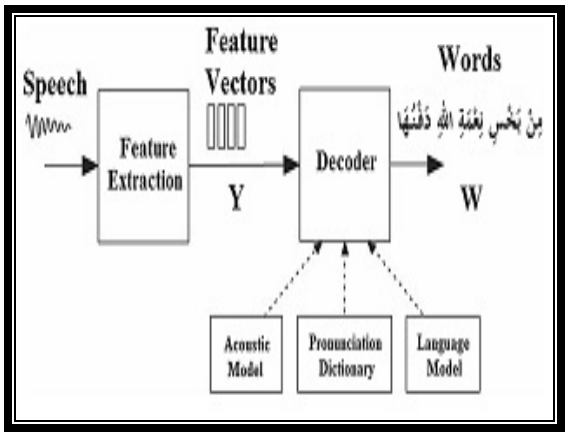

Figure 1: Components of ASR Systems [4]

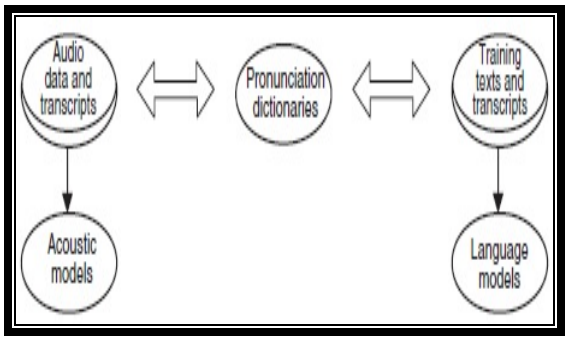

Figure 2: Language-Dependent Resources for ASR [5]

Based on Figure 1 and Figure 2, the pronunciation dictionary is a very crucial component for developing ASR systems. It acts as the mediator and the intermediary link between the acoustic model and the language model in ASR systems [4, 5, 20, 21, 22]. Therefore, having an accurate and comprehensive pronunciation dictionary that covers vocabularies of a language and their pronunciation variations would have positive impact on the overall performance of ASR systems. Figure 2 also shows that ASR system development typically requires three primary language resources including the texts for training the language model, the audio or speech data for training the acoustic model, and the pronunciation dictionary, which have close links between them [5].

This research aims to design and develop a rule-based phonetic dictionary generator (PDG) that receives Arabic texts, transforms them into their corresponding phoneme sequences using pre-defined rules, and produces a machine readable pronunciation dictionary that can be used mainly for ASR research. The pre-defined rules in our PDG represent direct grapheme-to-phoneme conversion rules, Arabic phonological and pronunciation rules. Wide pronunciation variations for all Arabic phonemes including variations related to both normal speech, and disordered speech. Modern Standard Arabic (MSA) text are used to evaluate the performance of the PDG depending on the type of the phonetic dictionary the user wishes to generate, which can either be a phonetic dictionary for MSA that can be used for ASR systems for normal speakers or a phonetic dictionary for Arabic disordered speech that can be used for ASR systems that are expected to be used by not only normal speakers, but also by speakers suffering from speech and articulation disorders. The latter is more comprehensive than the former in terms of coverage of the pronunciation variations for the same input Arabic text.

The rest of the paper is organized as follows: Section 2, highlights some research background and related works on fundamentals of speech disorders and Arabic pronunciation dictionaries. Section 3 presents development activities for the Arabic disordered speech phonetic dictionary generator. Section 4 provides an evaluation of the Arabic disordered speech phonetic dictionary generator. Conclusion is finally presented in Section 5.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

2. RESEARCH BACKGROUND AND RELATED WORKS

This section provides a research background in general and fundamentals of speech disorders in specific in Section 2.1. It also highlights the related work pertaining the production of the pronunciation dictionary for Arabic language in Section 2.2.

2.1 FUNDAMENTALS OF SPEECH DISORDERS

In order to develop pronunciation dictionaries, three considerations must be tackled including the definition of words in the given target language, selection of a finite set of words, and determining how the pronunciation of these words look like, which are shown in Figure 3 [5].

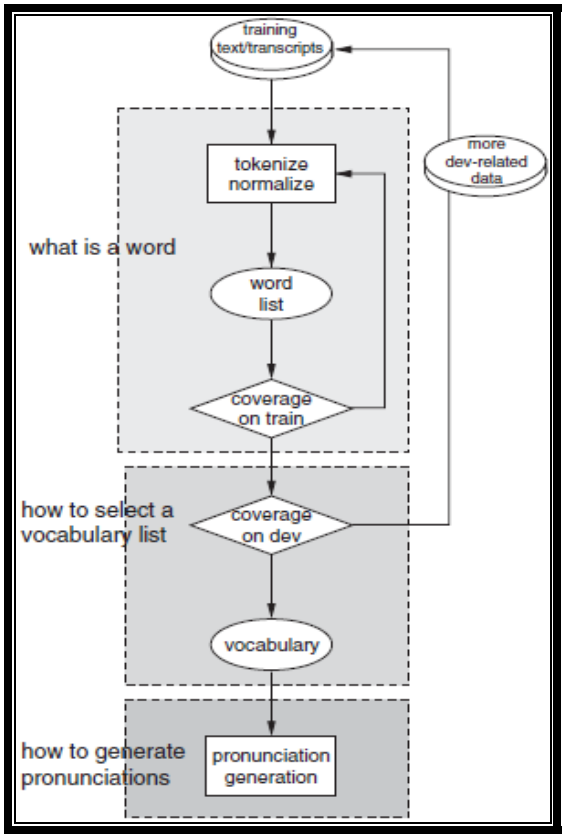

Figure 3: Language Independent Processing Steps for Pronunciation Dictionary Generation [5]

A word is defined in many languages as the sequence of alphabetic characters separated by a space or some other specified markers [5]. However, word definition is dependent on the target language. Like many other languages, a word in the case of Arabic language has a clear boundary that is separated by clear spaces. In addition, a trade-off between the amount of available training text, the vocabulary size limit, and the data's speaking style must be sought. Finally, the pronunciation generation can either be completely manual, manually supervised, grapheme-to-phoneme rules, and/or manually supervised grapheme-to-phoneme rules [5]. For Arabic language, if the available training texts are vowelized, the pronunciation generation task becomes straightforward using grapheme-to-phoneme rules or the so called letter-to-sound rules together with relevant phonological rules. However, if the texts are not vowelized or semi-vowelized, the pronunciations generation task becomes challenging. For instance, if the following Arabic text is given without diacritical marks [6]:

/علم رائد بالخبر متأخرا/ /Raed knew the news late/

This Arabic sentence contains four words, where each word is expected to be pronounced differently due to the absence of diacritical marks. Possible pronunciations for each word can be:

/**علم**/: عَلَمُ، عَلَمَ، عَلَمِ، عَلِمَ، عَلِمَ، عُلِمَ، عَلَّمَ، عُلِّمَ، عِلْمُ، عِلْمَ، عِلْمِ، عِلْمٌ، عِلْمٍ، عِلْمً (13 possible pronunciations)

/**رائد**/: رَائِدُ، رَائِدٌ، رَائِدِ، رَائِدَ، رَائِدً، رَائِدٍ (6 possible pronunciations)

/**بالخبر**/: بالخَبَرِ، بالخَبَرَ، بالخَبَرُ، بالخُبَرِ، بالخُبَرَ، بالخُبَرُ (6 possible pronunciations)

/**متأخرا**/: مُتَأَخِرَاً (1 possible pronunciation)

Therefore, the above mentioned possible pronunciations can be concatenated to form Arabic sentences, where it is possible to produce 13*6*6*1 = 468 sentences [6].

In ASR, pronunciation variation can cause high recognition errors normally in the form of insertions, deletions, or substitutions of phoneme(s) that are related to the phonemic transcription in the phonetic dictionary. Therefore, pronunciation variations usually reduce the recognition performance of ASR systems, which normally occurs cross-word and within-word variations [11].

ASR systems must accommodate to different needs of any sort of speakers and users including users with normal speech, users with speech and articulation disorders, and others. This indicates that

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

the generated pronunciation dictionaries must accommodate to this need too by including pronunciation variation entries related to pronunciations of normal speech users, disordered speech users, and others.

Good speech and language skills are vital for human in order to convey clear and understandable messages. Without these skills, the human will suffer from bad communication with others, and may face negative attitude from them. Furthermore, he/she may have problems with interacting with new technologies such as cell phones, smart phones, computers and many more [23, 24].

Therefore, speech is considered defective, disordered or impairment "when it deviates so far from the speech of other people that it calls attention to itself, interferes with communication, or causes its possessor to be maladjusted" [25].

The American Speech-Language-Hearing Association (ASHA) defined speech disorders as the inability to produce the correct speech sound when speaking, or having any problem with the voice [26]. Moreover, any effect on a speech that leads to degrading a person's role in society, or making him/her dissuading from interacting in social activities in a way that exploits their potential is considered as a speech disorder [24].

Children from infants to 6.4 years old continuously learn how to speak correctly. Furthermore, this age is considered the normal age for language acquisition [27]. After this age, if the child has any difficulty in speaking, he/she is considered to have a speech disorder problem. Therefore, speech disorders can appear from the age of 7 years or 8 years to adult's age [28, 29].

Speech disorders can be classified into four major categories as follows: articulation, time, voice, and symbolization [25]. The articulation speech disorders refer to any failure in developing a speech sound/s of a particular language (English, Arabic, etc…) in any age, because of motoric problem/s [30]. Furthermore, this type of disorders encompasses four main categories, which are substitution, omission, distortion, and addition [30, 31].

The second type of speech disorders is time speech disorders. Time is an important dimension of speech, whereas human speak words sequentially in order to produce a sentence. Therefore, any problem in producing words in the correct timing leads to a defective speech. [25] Stuttering is considered a serious timing problem, where the speaker repeats word or part of word during the speaking process, prolongation, or even suffering from a silent block [32, 33].

The third type of speech disorders is voice speech disorders. According to ASHA, a person has a voice disorder if 1) he/she suffers from organic problem that results from physical changes in the voice mechanism or even from problems with the central or peripheral nervous system innervation to the larynx that affect functioning of the vocal mechanism, or 2) he/she has a functional problem where the person does not have any problem with physical structure, but still suffers from inefficient of the vocal mechanisms [34].

Finally, symbolization disorders (dysphasia) is a mild form of problems where the person suffers from speaking, writing, or even reading disabilities. In such cases, the person has difficulties in using or comprehending linguistic symbols (written or spoken). This problem could be formulative, expressive, or receptive [25, 35].

The problem of speech disorder is not related to a specific community. This problem is common; therefore, the prevalence of speech disorders has been investigated by several studies and associations around the world. The National Institute on Deafness and Other Communication Disorders (NIDCD) in [36] stated that almost 18.5 million in the United States of America (USA) have a speech, voice, or language disorder. In addition, 8 to 9 % of young children suffer from a speech disorder such as articulation disorder. Moreover, more than one million Americans from children to adults have stuttering speech disorder. Another study was conducted by the Canadian Association of Speech- Language Pathologists and Audiologists (CASLPA) stated that 10% of the Canadians have a speech, hearing, or language problem [37]. A study was also conducted to measure the prevalence of articulation disorders between Dutch adults in 2007. This study found that 23.3 % of 748 adults suffer from disorders problem [38]. Another study was conducted by [23] in Jordan, which studied the prevalence of speech disorders among the University of Jordan students. According to this study, 7.5 % of the selected population which was 400 undergraduate students suffer from a speech disorder problem, where 3% of the population suffer from articulation disorders problem. Another study was conducted by the voice research and studies center in The University of Jordan (UJ) in the period between 1/1/2007 to 30/5/2008. This study investigated the prevalence of speech disorders (in specific /r/ speech problems) between

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

236 cases. The result showed that 132 of the cases suffer from speech disorder in "R" letter [28].

Furthermore, 6% of people around the world suffer from stuttering speech disorders, where 1% of the population are adults and the rest are children [33]. In [39], they studied the problem of voice disorders; the researchers stated that 7.6% of adult population suffer from voice disorder, which ranges from the complete absence of voice to different degrees of vocal impairments. The voice speech disorders have been studied by [40]. The researcher studied the prevalence of speech disorders between school teachers during lifetime and stated that 57.7% of teachers suffer from speech disorders during their lifetime, while 28.8% of non-teachers suffer from this problem.

Speech disorder is a problem that is not related to a specific language. People who speak English, Arabic, etc… suffer from this problem. This problem is crucial in one language as in any other language. In contrast, the identification of such a problem could be enhanced or hindered by the characteristics of selected language and the determined rules for its use [41]. In this work, Arabic language has been selected as a language of interest due to its importance, complexity, and wide use. Arabic language is one of the six official languages of the United Nations (UN). It is the largest semantic language in the world in terms of number of speakers. 250 million people around the world speak Arabic language, while the number of people who speak Arabic as a second language can reach four times that number. It is the official language for 22 countries in the Arab world and it is the language of The Holy Qur'an [42, 43]. Arabic alphabet are used in many other languages such as Azerbaijani, Baluchi, Eastern Cham, Comorian, Dogri, Hausa, Kashmiri, Kurdish and many more [42]. Finally, Arabic is the official spoken language for Jordan [41].

Arabic language has two major forms including Standard Arabic that encompasses the Classical Arabic (CA) and Modern Standard Arabic (MSA), and Dialectal Arabic (DA) that varies from one country to another [42-44].

As mentioned earlier, articulation disorders is a type of disorders where the speaker has a problem in producing a specific sound/s during the speaking process due to a motoric problem. Substitution is one of the famous cases of articulation disorders were the speaker replaces a standard speech sound with a different standard one. As an example: replacing the /r/ letter in the word "rabbit" with /w/ as "wabbit" [30, 31]. In Arabic language the substitution appears in a situation like replacing the "r" letter in the word "رجل" (Rajul) to "l" letter as "لجل"(Lajul) [44].

Another case of articulation disorders is distortion were the speaker replaces a standard speech sound with a nonstandard one as in distorting the letter "s" in the word "soup" [30, 31]. In Arabic language the problem could appear if the person distorted the "r" letter in the word "مريم" (Mariyam) to be like "y" letter as "مايم" (Mayam) [44].

2.2 RELATED WORKS ON ARABIC PRONUNCIATION DICTIONARIES

There has been a number of attempts to produce and enhance phonetic dictionaries for Arabic ASR systems in the last decade. It is noticed that most pronunciation dictionary generation attempts were based on phonological rules introduced in detail in [6, 7], which are used for speech synthesis and recognition tasks for Arabic language. Phonological rules for Arabic language are clearly stated in [6], which consist of 20 rules that depend on the written texts and diacritical marks. They are also context dependent, where every letter/grapheme and/or diacritic/vowel are directly replaced unless a phonological rule must be applied.

Among the few attempts to generate pronunciation dictionaries for Arabic ASR purposes include the work presented in [8-13]. The approach used in [8, 9] is widely used, convenient, and well established since it is based on valid and complete phonological rules that are presented in [6, 7].

Many researchers [5-13] stated that the development of phonetic dictionaries can either be manually by human experts or automatically by rule-based grapheme-to-phoneme and phonological rules of the target language. However, the human experts based generation is costly and time consuming, whereas the cost and time are reduced using the rule-based approach. Therefore, for the development of our phonetic dictionary generator, the rule-based approach is selected.

Based on our literature investigation, it is important to mention that none of the research attempts for generating Arabic phonetic dictionaries have explicitly addressed pronunciation variations for Arabic disordered speech. In our phonetic dictionary generation, we adopted similar approach with [8, 9] and similar phonological rules as

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

presented in [6, 7]. However, we added additional rules for Arabic disordered speech, and have created an automated tool with proper and user-friendly Graphical User Interfaces (GUIs). The automated tool generates a Phonetic Dictionary (PD) for MSA based ASR systems for normal speakers and a Hybrid Phonetic Dictionary (HPD) that contains pronunciation variations of the MSA as spoken by both speakers suffering from speech disorders and normal speakers for the purpose of developing ASR systems that can be used by both types of speakers.

To the best of our knowledge, the pronunciation variations of speakers suffering from speech and articulation disorders have not been considered in generating phonetic dictionaries for Arabic ASR purposes. This shows one of our major contributions by integrating the pronunciation variations of speakers suffering from speech and articulation disorders with those of normal speakers. Consequently, the HPD is resulted that integrates all variations of the normal and speech disordered speakers. This highly likely will increase the performance of the ASR systems especially if they are developed for speaker-independent purposes.

Therefore, this work has contributed to the state-of-the-art by developing a rule-based PDG for producing PD for MSA pronunciation variations by normal speakers, and HPD for MSA pronunciation variations by normal and speech disordered speakers. Hence, the automated tool is the first tool that clearly tackles the generation of pronunciation variations of Arabic speech disorders using user-friendly GUIs.

3. DEVELOPMENT OF ARABIC DISORDERED SPEECH PHONETIC DICTIONARY GENERATOR

This rule-based PDG is developed using Java programming language, which receives Arabic texts (preferably fully vowelized) and transforms them into their corresponding phoneme sequences, using pre-defined grapheme-to-phoneme and phonological rules.

In this release of the rule-based PDG automated tool, the substitution and distortion articulation speech disorders are considered for their importance and frequent recurrence. Other types of speech disorders will be attended in future versions of our automated tool.

Figure 4 shows the welcoming GUI of our phonetic dictionary generator, whereas Figure 5 shows the main GUI of our phonetic dictionary generator that also shows the main features provided by our first version of the generator.

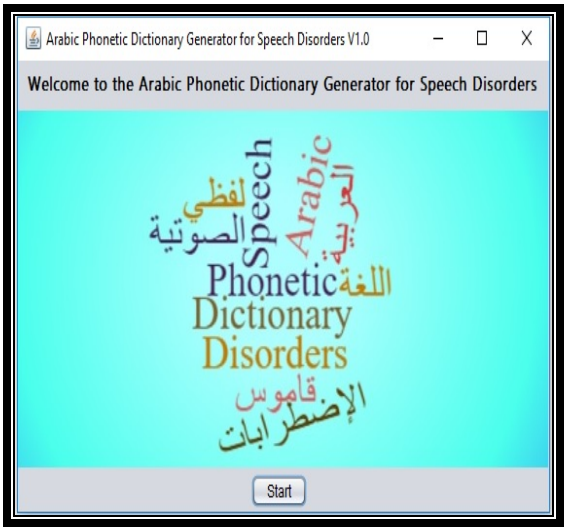

Figure 4: Welcoming GUI of the Arabic Phonetic Dictionary Generator for Speech Disorders V1.0

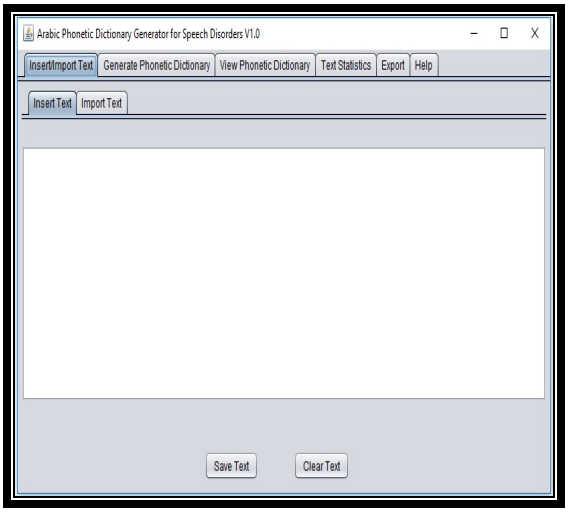

Figure 5: Main GUI of the Arabic Phonetic Dictionary Generator for Speech Disorders V1.0

Based on Figure 5, users choose the first tab namely "Insert/Import Text", where they can either insert text directly to the phonetic dictionary generator through typing the target text and/or copying and pasting text from other source to the generator as shown in Figure 6, and/or import text from already stored text file(s) in a directory as shown in Figure 7.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Once a text is either inserted or imported, a user can open the second tab namely "Generate Phonetic Dictionary". This consists of two main options as shown in Figure 8 depending on the type of the phonetic dictionary the user wish to generate. The first option is the phonetic dictionary for Modern Standard Arabic that can be used for ASR systems for normal speakers. The second option is the phonetic dictionary for Arabic disordered speech that can be used for ASR systems that are expected to be used by not only normal speakers, but also by speakers suffering from speech and articulation disorders. The two options are generated using grapheme-to-phoneme and phonological rules set prior to the generation process.

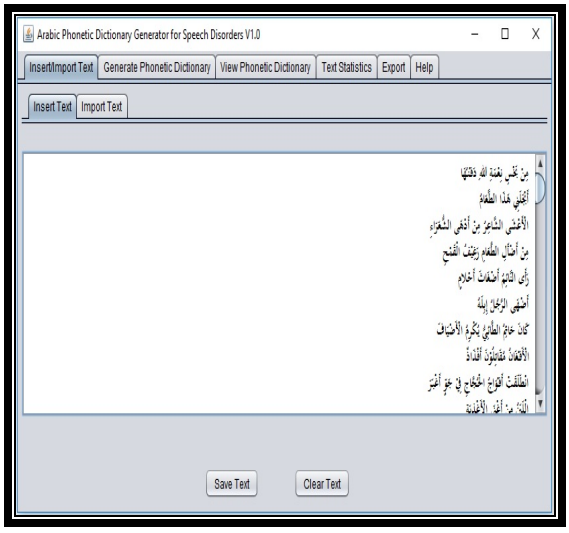

Figure 6: Inserted Fully Vowelized Arabic Text

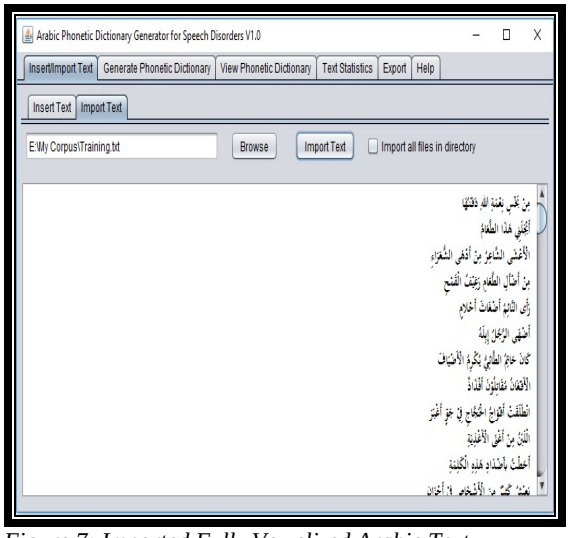

Figure 7: Imported Fully Vowelized Arabic Text

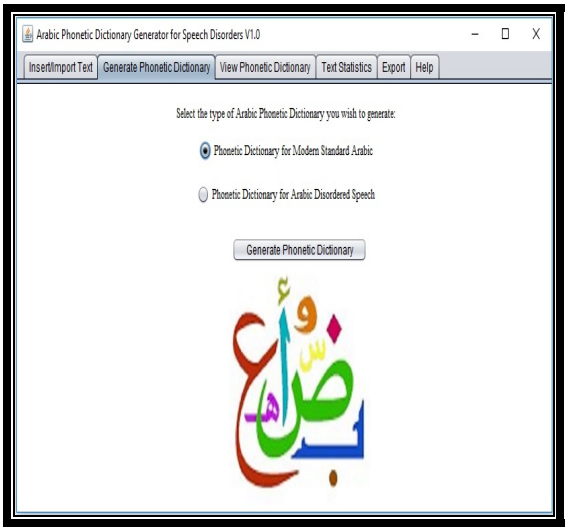

Figure 8: Types of Phonetic Dictionaries to be Generated

Arabic language contains 28 basic letters or consonants and 6 short and long vowels. These letters and vowels have a standard and normal pronunciation style, whereas with disordered speech will have other speaking sounds and pronunciation styles [45]. Table 1 shows Arabic letters and their pronunciation variations for normal and disordered speech with International Phonetic Alphabet (IPA) representations.

It is important to highlight that the phonemes for disordered speech as shown in Table 1 are extracted from [45] and checked with a speech and hearing specialist from Hearing and Speech Sciences Department, School of Rehabilitation Sciences, The University of Jordan. We conducted several sessions in order to produce the possible pronunciation variations for disordered speech for every Arabic letter especially for the substitution and distortion articulation speech disorders.

In addition to Table 1 that only showed the phoneme set for the Arabic 28 letters, Table 2 shows the phoneme set for the short and long vowels, and diphthongs together with other important phonemes that are used against the grapheme-to-phoneme rules in generating the phonetic dictionary.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 1: Arabic Letters and Their Phonemes for Normal and Disordered Speech

Arabic Letter	Phoneme for Normal Speech	IPA Representation	Phoneme for Disordered Speech	IPA Representation
ء	/E/	/ʔ/	--	--
ب	/B/	/b/	/M/	/m/
ت	/T/	/ t/	/D/	/d/
ث	/TH/	/θ/	/D/ /N/ /T/	/d/ /n/ / t/
ج	/JH/	/dʒ/	/SH/ /HH/ /D/	/ʃ/ /ħ/ /d/
ح	/HH/	/ħ/	/H/	/h/
خ	/KH/	/x/	/HH/ /GH/	/ħ/ /ɣ/
د	/D/	/d/	/T/	/ t/
ذ	/DH/	/ð/	/TH/	/θ/
ر	/R/	/r/	/Y/ /L/ /GH/	/j/ /l/ /ɣ/
ز	/Z/	/z/	/DH/ /S/	/ð/ /s/
س	/S/	/s/	/TH/ /SH/ /H/	/θ/ /ʃ/ /h/
ش	/SH/	/ʃ/	/S/	/s/
ص	/SS/	/sˤ/	/TH/ /S/	/θ/ /s/
ض	/DD/	/dˤ/	/D/ /DH/ /Z/ /DH2/	/d/ /ð/ /z/ /zˤ/
ط	/TT/	/tˤ/	/T/	/ t/
ظ	/DH2/	/zˤ/	/D/	/d/
ع	/AI/	/ʕ/	/E/	/ʔ/
غ	/GH/	/ɣ/	/GH/	/ʕ/
ف	/F/	/f/	/B/	/b/
ق	/Q/	/q/	/D/ /K/	/d/ /k/
ك	/K/	/k/	/T/ /H/	/ t/ /h/
ل	/L/	/l/	/Y/	/j/
م	/M/	/m/	/B/	/b/
ن	/N/	/n/	/D/	/d/
ه	/H/	/h/	/E/	/ʔ/
و	/W/	/w/	--	--
ي	/Y/	/j/	--	--

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 2: Additional Arabic Phonemes

Vowels and Diphthongs	IPA Representation	Phoneme
بَ ---> ـَ	/æ/	/AE/
بَاب ---> ـَا	/æ:/	/AE:/
خَ ---> ـَ	/a/	/AA/
قَد ---> ـَ	/a/	/AH/
بُ ---> ـُ	/u/	/UH/
دُون ---> ـُو	/u:/	/UW/
عُصن ---> ـُ	/o/	/UX/
بِنت ---> ـِ	/e/	/IH/
فِيل ---> ـِي	/i:/	/IY/
صِنف ---> ـِ	/i/	/IX/
لَوم ---> ـَو	/ʊ/	/AW/
ضَيف ---> ـَي	/aj/	/AY/
نَنجي ---> ـُ	/un/	/UN/
نَم ---> ـَ	/an/	/AN/
مِما ---> ـِ	/in/	/IN/

Based on Figure 8 and Table 1, the first type of phonetic dictionaries that can be generated from our tool is the phonetic dictionary for Modern Standard Arabic that can be used for ASR systems for normal speakers. This phonetic dictionary used grapheme-to-phoneme rules based on the entries in the column for phoneme for normal speech, which is a one-to-one relationship. On the other hand, the second type of phonetic dictionaries that can be generated from our tool is the phonetic dictionary for Arabic disordered speech that can be used for ASR systems for normal speakers as well as speakers with speech disorders specifically speakers suffering from substitution and distortion articulation speech disorders, which makes it a hybrid phonetic dictionary suitable for ASR systems that are speaker-independent. Furthermore, this phonetic dictionary used grapheme-to-phoneme rules based on the entries in the column for phoneme for normal speech and the column for phoneme for disordered speech. This is a one-to-many relationship except for the Arabic letters (ء, و, ي) since they were not reported at all as having pronunciation variations pertaining speech disorders.

Besides the direct grapheme-to-phoneme conversion rules, Arabic phonological and pronunciation rules as described in [6-13] were used in generating both types of the phonetic dictionary in our work.

Every rule matches specific conditions based on the context of the Arabic letter, which consequently gets a replacement from the phoneme list. The replacement can either be one or sometimes more than one phoneme. In cases where the letter does not affect the pronunciation or the context has no effect on the pronunciation, the replacement is set to be empty as denoted by an asterisk (*). Furthermore, context-dependent grammars shape the pronunciation rules using the following format [8, 9]:

(pre_condition) . (post_condition) -> replacement

Where the *pre_condition* and *post_condition* represent rules that are related to the content of the Arabic letter being investigated and also denoted as the dot (.)

According to [8, 9], various classes were defined to simplify the rules syntax, where every class is referenced by its symbol (L, D, S, etc.), which is also surrounded by angle brackets (< >). The classes as extracted from [8, 9] are:

- <L>: All Arabic consonants.
- <D>: Diacritic marks (FATHATAN (ً), DAMMATAN (ٌ), KASRATAN (ٍ), FATHA (َ), DAMMA (ُ), KASRA (ِ), SHADDA (ّ), and SUKUN ْ).
- <S>: Word Start.
- <T>: Word End.
- <SH>: Shamsi Letters (TEH (ت), THEH (ث), DAL (د), THAL (ذ), REH (ر), ZAIN (ز), SEEN (س), SHEEN (ش), SAD (ص), DAD (ض), TAH (ط), ZAH (ظ), LAM (ل), and NOON (ن)).
- <V>: Vowels (FATHA (َ), DAMMA (ُ), KASRA (ِ), and SHADDA (ّ)).
- <VA>: Vowels without SHADDA (ّ) (FATHA (َ), DAMMA (ُ), AND KASRA (ِ)).
- <P>: Prefix letters (WAW (و), BEH (ب), FEH (ف), KAF (ك), and LAM (ل)).
- <E>: Emphatic letters (TAH (ط), SAD (ص), DAD (ض), and ZAH (ظ)).
- <PH>: Pharyngeal letters (QAF (ق), GHAIN (غ), KHAH (خ), and REH (ر)).

In addition, the pre-condition has one of the following formats [8, 9]:

- (?<=pattern): context before the current position matches the pattern.
- (?<!pattern): context before the current position does not match the pattern.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Similarly, the post-condition has one of the following formats [8, 9]:

- (?=pattern): context after the current position matches the pattern.
- (?!pattern): context after the current position does not match the pattern.

Patterns also use certain operators to define expressions such as vertical bar (|) to show alternatives, parentheses () to define groups, and question mark (?) to mark parts that may or may not exist in the expression [8, 9].

The pronunciation rules as presented in [8, 9], were completely used to develop the first type of the phonetic dictionary for MSA in our newly developed tool. However, we have added our pronunciation variations and rules based on pronunciation variations extracted from [45] and consulting the speech and hearing specialist to accommodate to the needs for the second type of the phonetic dictionary for Arabic disordered speech. Based on Table 1, among the most important differences between pronunciation rules for both types are shown for letters (ث, ج, ر, س, ض), which have at least three different pronunciation variations to accommodate the Arabic disordered speech for such cases. An example for letter (ر), the rule says in [8, 9] that this letter is normally replaced by the phoneme /R/, which we also used for the first type of generating the phonetic dictionary as shown in Table 3. However, we added other pronunciation variations and rules for the letter (ر) to generate the second type of the phonetic dictionary that can also tackle the needs of speakers suffering speech disorders, whereby this letter in the second type of the phonetic dictionary can now be replaced by the phonemes /R/, /Y/, /L/, and /GH/ as also shown in Table 3. The same scenario is applied to other letters that have clear pronunciation variations as shown in Table 1.

Once all pronunciation rules are applied and the phonetic dictionary is generated, the tool prompts the users with a message indicating the successful generation of the phonetic dictionary.

Users can also view the generated phonetic dictionary by visiting the third tab namely "View Phonetic Dictionary" as shown in Figure 9.

Table 3: Impact of Arabic Letter (ر) for the Two Types of the Phonetic Dictionary

Type	Rule	Description
First Type: MSA Phonetic Dictionary	REH: .-> R	This letter is always matched to its corresponding phoneme.
Second Type: Arabic Disordered Speech Phonetic Dictionary	REH: .-> R .-> Y .-> L .-> GH	This letter is always matched to its corresponding phonemes.

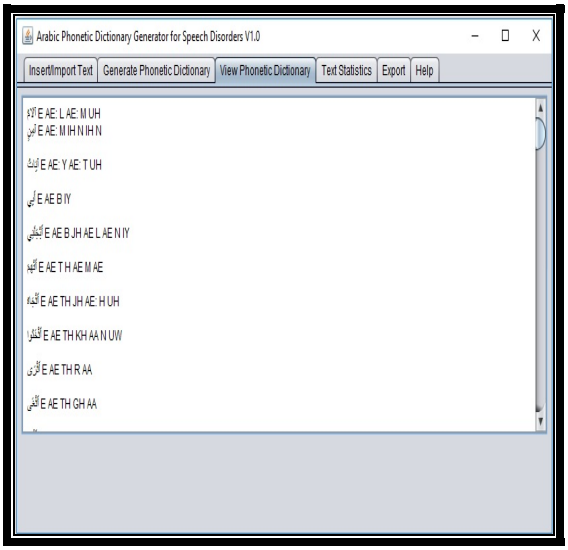

Figure 9: The Generated Phonetic Dictionary in the Tool's View

The fourth tab namely "Text Statistics" in our phonetic dictionary generator provides some text analysis in terms of the number of unique words and number of occurrences for every unique word as extracted from the inserted or imported text. Figure 10 shows the number of unique words associated with a list that contains the unique words, whereas Figure 11 shows a list of unique words associated with the number of occurrences for each unique word in the list. This text statistics can be needed at times to know basic measures and analysis of the inserted and/or imported text.

Journal of Theoretical and Applied Information Technology
29th February 2020. Vol.98. No 04

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

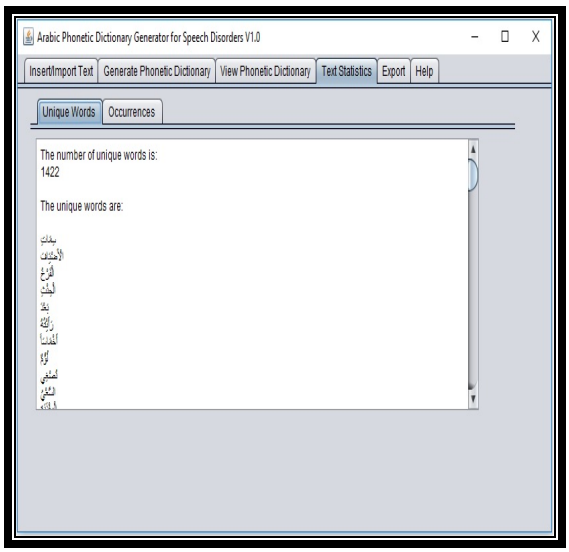

Figure 10: View of the Number of Unique Words and List of Unique Words as Extracted from the Inserted and/or Imported Text

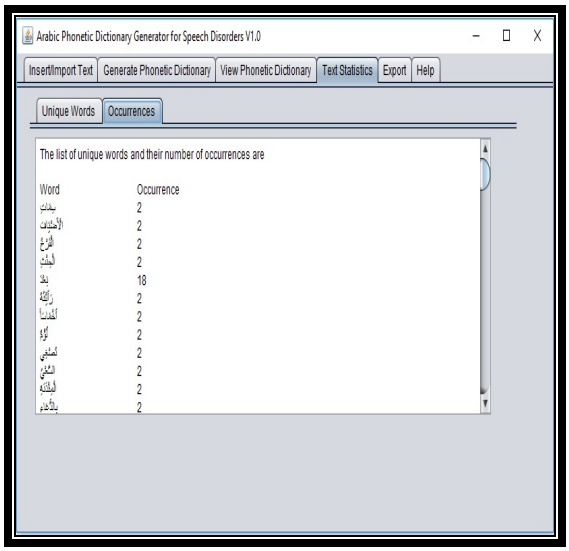

Figure 11: View of the Number of Occurrences for Every Word in the Words List as Extracted from the Inserted and/or Imported Text

The fifth tab namely "Export" in our phonetic dictionary generator provides export features of the phonetic dictionary and text statistics into well-known file extensions. Figure 12 shows that the generated phonetic dictionary can be exported into "*.dic" and/or "*.txt" file extensions, which are normally used for ASR support. In addition, Figure 13 shows that the text statistics can be exported into "*.txt" and/or "*.xlsx" file extensions, which are used for text analytics purposes.

Finally, the sixth tab provides important information and contact details. It also provides some help support to users. Furthermore, if users wish to exit the tool, they simply can close the tool by clicking the (X) icon in any window of the tool. However, users will be prompted to confirm that they wish to exit the tool, and once they confirm the tool is stopped from working.

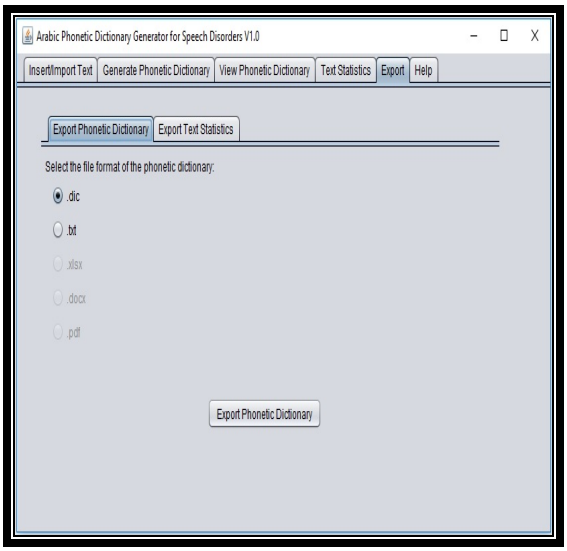

Figure 12: Exporting the Phonetic Dictionary into Well-Known File Extensions for ASR Support

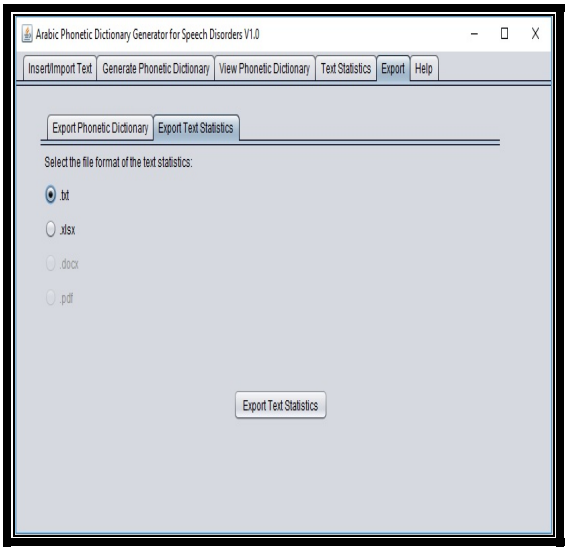

Figure 13: Exporting the Text Statistics into Well-Known File Extensions for Text Analytics Purposes

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

4. EVALUATION OF ARABIC DISORDERED SPEECH PDG

In order to evaluate the first version (V1.0) of our newly developed Arabic Phonetic Dictionary Generator for Speech Disorders (APDGSD), we imported an Arabic text file that contains 415 fully vowelized Arabic sentences written in MSA [4]. Table 4 shows a sample of the sentences.

Table 4: Sample Sentences of the Imported Arabic Text

Sentence	IPA Representation
أَصَابَنَا مَطَرٌ سَالَ مِنْهُ الغُبَّانُ	ʔasˤa:bana: matˤaru: sa:la minhu lɣubba:nu
زُرْ غِبّاً تَزْدَدْ حُبّاً	zur ɣibba: tazdad ħubba:
كَثْرَةُ الْعِتَابِ تُقَلِّلُ الْأَصْدِقَاءَ	kaθratu lʕita:bi tuqallilu lʔasˤdiqa:ʔa

The 415 sentences were uploaded to our PDG and showed that there are 1,623 unique words out of 2,088 words.

Based on our experimental work, there are 2,473 phoneme sequences using standard pronunciation rules for MSA that can be purely used for ASR systems that intend to serve normal speakers. Each phoneme sequence represents one pronunciation variation as shown in Figure 14.

```
أَلَمْ E AE L AE M
أَمَّا E AE M AE:
أَمْرٌ E AE M R UX N
أَمْشَاجٌ E AE M SH AE: JH UH N
أَمْصَالٌ E AE M SS AH: L UH N
أَنِيْنُ E AE N N UH
أَنَّ E AE N AE
أَنْ E AE N
أَنْتَ E AE N T AE
أَنْذَرَ E AE N DH AE R AA
أَنْفَعُ E AE N F AE AI UH
أَنْفُكَ E AE N F UH K AE
أَنْفُهُ E AE N F UH H UH
```

Figure 14: Sample of the Arabic Phonetic Dictionary Using Standard Pronunciation Rules

On the other hand, the HPD for normal speakers with those speakers suffering from speech disorders contains 62,997 phoneme sequences. Here, each phoneme sequence represents one pronunciation variation. If the ASR system intends to be speaker-independent, we highly recommend using this phonetic dictionary. Figure 15 shows a sample of the HPD that not only can be used by normal speakers, but also by speakers suffering from speech and articulation disorders.

```
أَلَمْ E AE L AE M
أَلَمْ(2) E AE L AE B
أَلَمْ(3) E AE Y AE M
أَلَمْ(4) E AE Y AE B
أَمَّا E AE M AE:
أَمَّا(2) E AE B AE:
أَمْرٌ E AE M R UX N
أَمْرٌ(2) E AE M Y UX N
أَمْرٌ(3) E AE M L UX N
أَمْرٌ(4) E AE M GH UX N
أَمْرٌ(5) E AE B R UX N
أَمْرٌ(6) E AE B Y UX N
أَمْرٌ(7) E AE B L UX N
أَمْرٌ(8) E AE B GH UX N
أَمْشَاجٌ E AE M SH AE: JH UH N
أَمْشَاجٌ(2) E AE M SH AE: SH UH N
أَمْشَاجٌ(3) E AE M SH AE: HH UH N
أَمْشَاجٌ(4) E AE M SH AE: D UH N
أَمْشَاجٌ(5) E AE M S AE: JH UH N
أَمْشَاجٌ(6) E AE M S AE: SH UH N
أَمْشَاجٌ(7) E AE M S AE: HH UH N
أَمْشَاجٌ(8) E AE M S AE: D UH N
أَمْشَاجٌ(9) E AE B SH AE: JH UH N
أَمْشَاجٌ(10) E AE B SH AE: SH UH N
أَمْشَاجٌ(11) E AE B SH AE: HH UH N
أَمْشَاجٌ(12) E AE B SH AE: D UH N
أَمْشَاجٌ(13) E AE B S AE: JH UH N
أَمْشَاجٌ(14) E AE B S AE: SH UH N
أَمْشَاجٌ(15) E AE B S AE: HH UH N
```

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

أَمْشَاجٌ(16) E AE B S AE: D UH N
أَمْصَالٌ E AE M SS AH: L UH N
أَمْصَالٌ(2) E AE M SS AH: Y UH N
أَمْصَالٌ(3) E AE M TH AH: L UH N
أَمْصَالٌ(4) E AE M TH AH: Y UH N
أَمْصَالٌ(5) E AE M S AH: L UH N
أَمْصَالٌ(6) E AE M S AH: Y UH N
أَمْصَالٌ(7) E AE B SS AH: L UH N
أَمْصَالٌ(8) E AE B SS AH: Y UH N
أَمْصَالٌ(9) E AE B TH AH: L UH N
أَمْصَالٌ(10) E AE B TH AH: Y UH N
أَمْصَالٌ(11) E AE B S AH: L UH N
أَمْصَالٌ(12) E AE B S AH: Y UH N
أَنِيْنُ E AE N N UH
أَنَّ E AE N AE
أَنْ E AE N
أَنْتَ E AE N T AE
أَنْتَ(2) E AE N D AE
أَنْذَرَ E AE N DH AE R AA
أَنْذَرَ(2) E AE N DH AE Y AA
أَنْذَرَ(3) E AE N DH AE L AA
أَنْذَرَ(4) E AE N DH AE GH AA
أَنْذَرَ(5) E AE N TH AE R AA
أَنْذَرَ(6) E AE N TH AE Y AA
أَنْذَرَ(7) E AE N TH AE L AA
أَنْذَرَ(8) E AE N TH AE GH AA
أَنْفَعُ E AE N F AE AI UH
أَنْفَعُ(2) E AE N F AE E UH
أَنْفَعُ(3) E AE N B AE AI UH
أَنْفَعُ(4) E AE N B AE E UH
أَنْفُكَ E AE N F UH K AE
أَنْفُكَ(2) E AE N F UH T AE
أَنْفُكَ(3) E AE N F UH H AE
أَنْفُكَ(4) E AE N B UH K AE
أَنْفُكَ(5) E AE N B UH T AE
أَنْفُكَ(6) E AE N B UH H AE

أَنْفُهُ E AE N F UH H UH
أَنْفُهُ(2) E AE N F UH E UH
أَنْفُهُ(3) E AE N B UH H UH
أَنْفُهُ(4) E AE N B UH E UH

Figure 15: Sample of the HPD for Normal Speakers and Speakers with Speech and Articulation Disorders

A simple comparison is shown in Figure 14 and Figure 15, whereby Figure 14 contains 13 entries produced by the PDG that are contained in the standard PD and Figure 15 contains 69 entries produced by the HPD for the same unique words. This indicates that the second type of the phonetic dictionary contains more pronunciation variations, which makes it more realistic and convenient to be used in real time and speaker-independent ASR systems.

5. CONCLUSION

This research paper presented our methodology for developing an Arabic PDG for normal speakers as well as speakers suffering from speech and articulation disorders. PD is a very crucial component for any ASR system, which is also considered as the mediator and the link between other components of the ASR system including the acoustic and language models during the decoding process. The newly developed automated tool not only generate a standard PD for MSA based ASR systems, but also HPD that attempted to indulge Arabic disordered speech into the generation of the PD. Our HPD is very closer to reality if the intended ASR system is real time and speaker-independent. In the development of our PDG, we utilized a rule-based approach using pronunciation rules and grapheme-to-phoneme conversion rules for Arabic language as many were reported in previous research attempts. The PDG was also evaluated using an Arabic text that contains 1,623 unique words out of 2,088 words.

The output PD for normal speakers contains 2,473 phoneme sequences, whereas the output of the HPD for both normal speakers and disordered speech speakers contains 62,997 phoneme sequences. This indicates that the generated HPD for disordered speech speakers with normal speakers is more comprehensive and contains more possibilities and variations of the same unique

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

word, which would ease the recognition task in ASR systems.

Based on our literature investigation and to the best of our knowledge, none of the research attempts for generating Arabic phonetic dictionaries have explicitly addressed pronunciation variations for Arabic disordered speech. In other words, the pronunciation variations of speakers suffering from speech and articulation disorders have not been considered in generating phonetic dictionaries for Arabic ASR purposes, which shows one of our major contributions by integrating the pronunciation variations of speakers suffering from speech and articulation disorders with those of normal speakers. Consequently, the HPD integrates all variations of the normal and speech disordered speakers. This highly likely will increase the performance of the ASR systems especially if they are developed for speaker-independent purposes that accommodate different needs and pronunciation characteristics of speakers and users.

Therefore, this work has shown a real state-of-the-art contribution through developing a rule-based PDG for producing PD for MSA pronunciation variations by normal speakers, and HPD for MSA pronunciation variations by normal and speech disordered speakers. Hence, the automated tool is the first tool that clearly tackles the generation of pronunciation variations of Arabic speech disorders using user-friendly GUIs.

Although this release of the rule-based PDG automated tool integrated the substitution and distortion articulation speech disorders for their importance and frequent recurrence, future versions of our automated tool will take into consideration other types of speech disorders. This target will be one of our future works and a room for other researchers to consider for their research.

6. ACKNOWLEDGEMENT

Authors would like to thank the late Mrs. Jehad Alaraifi, a teacher and speech and hearing specialist from Hearing and Speech Sciences Department, School of Rehabilitation Sciences, The University of Jordan, Jordan, for her great efforts. We would also like to extend our gratitude to Prof. Dr. Moustafa Elshafei and Mr. Mohamed Ali from King Fahd University of Petroleum and Minerals, Saudi Arabia, for their great efforts in the field and sharing resources.

REFRENCES:

[1] D. Yu and L. Deng, "*Automatic Speech Recognition*", London: Springer, 2015.

[2] M. Solatu, G. Saon, L. Mangu, H.-K. Kuo, B. Kingsloung, S. Chu and F. Biadsy, "Automatic Speech Recognition", in *Natural Language Processing of Semitic Languages*, Berlin, Springer, 2014, pp. 409-459.

[3] R. E. Gruhn, W. Minker and S. Nakamura, "Automatic Speech Recognition", in *Statistical Pronunciation Modeling for Non-Native Speech Processing*, Berlin, Heidelberg, Springer, 2011, pp. 5-17.

[4] M. A. M. Abushariah, "TAMEEM V1.0: speakers and text independent Arabic automatic continuous speech recognizer", *International Journal of Speech Technology,* 2017, pp. 261–280.

[5] M. Adda-Decker and L. Lamel, "Multilingual Dictionaries", in T. Schultz and K. Kirchhoff (Eds.), *Multilingual Speech Processing*, USA, Academic Press, Elsevier, 2006, pp. 123-168.

[6] M. Alghamdi, H. Almuhtasib and M. Elshafei, "Phonetic Rules in Arabic Script", *King Saud University Journal: Computer Sciences and Information*, Vol. 16, 2004, pp. 1–25.

[7] M. Elshafei Ahmed, "Toward an Arabic Text-to-Speech System", *The Arabian Journal for Science and Engineering*, Vol. 16, No. 4B, 1991, pp.565 – 583.

[8] M. Ali, M. Elshafei, M. Alghamdi, H. Almuhtaseb and A. Al-Najjar, "Generation of Arabic Phonetic Dictionaries for Speech Recognition", *IEEE Proceedings of the International Conference on Innovations in Information Technology*, UAE, 2008, pp. 59-63.

[9] M. M. Ali, "Framework and Implementation for Dialog Based Arabic Speech Recognition", Master Thesis, King Fahd University of Petroleum and Minerals, Kingdom of Saudi Arabia, 2012.

[10] H. Hyassat and R. Abu Zitar, "Arabic speech recognition using SPHINX engine", *International Journal of Speech Technology*, Vol. 9, No.3-4, Springer, 2008, pp. 133-150.

[11] D. M. A. AbuZeina, "Utilizing Data-Driven and Knowledge-Based Techniques to Enhance Arabic Speech Recognition", PhD Thesis, King Fahd University of Petroleum and Minerals, Kingdom of Saudi Arabia, 2011.

[12] F. S. Al-Anzil and D. AbuZeina, "The impact of phonological rules on Arabic speech recognition", *International Journal of Speech*

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Technology, Vol. 20, No.3, Springer, 2017, pp. 715-723.

[13] M. Labidi, M. Maraoui and M. Zrigui, "New Birth of the Arabic Phonetic Dictionary", *IEEE Proceedings of the International Conference on Engineering and MIS (ICEMIS'2016)*, Agadir, Morocco, 2016, pp. 1-9.

[14] B. Al-Diri, Ahamd Sharieh and M. Qutiashat, "A Speech Recognition Model Based on Tri-Phones for the Arabic Language", *Advanced in Modeling Series B: Signal Processing and Pattern Recognition*, 2007.

[15] S. Al-Majali, A. Sharieh and M. Qutaishat, "Arabic Speech Recognition using SOM-LVQ Neural Networks," *Advances in Modeling and Analysis-B: Signal, Information, Patterns, Data Acquisition Transmission, Processing, and Classification*, Vol. 44, No., 2001, pp1-16.

[16] S. D'Arcy and M. Russell, "Experiments with the ABI (Accents of the British Isles) Speech Corpus. *INTERSPEECH'08*, Australia, 2008, pp. 293 – 296.

[17] T. Kawahara, H. Nanjo, T. Shinozaki and S. Furui, "Benchmark Test For Speech Recognition Using The Corpus of Spontaneous Japanese", *In Proc. ISCA & IEEE Workshop on Spontaneous Speech Processing and Recognition (SSPR)*, Japan, 2003.

[18] L. Chin-Hui and J. Biing-Hwang, "A Survey on Automatic Speech Recognition with an Illustrative Example on Continuous Speech Recognition of Mandarin", *Computational Linguistics and Chinese Language Processing*, Vol. 1, No. 1, 1996, pp. 1-34.

[19] M. Ursin, "Triphone Clustering in Finnish Continuous Speech Recognition", Master Thesis, Department of Computer Science, Helsinki University of Technology, Finland, 2002.

[20] M. A. M. Abushariah, R. N. Ainon, R. Zainuddin, M. Elshafei, and O. O. Khalifa, "Phonetically Rich and Balanced Text and Speech Corpora for Arabic Language", *Language Resources and Evaluation Journal*, Springer. Vol. 46, No. 4, 2012, pp. 601 – 634.

[21] M. A. M. Abushariah, R. N. Ainon, R. Zainuddin, A. A. M. Alqudah, M. E. Ahmed, and O. O. Khalifa, "Modern Standard Arabic Speech Corpus for Implementing and Evaluating Automatic Continuous Speech Recognition Systems", *Journal of the Franklin Institute*, Elsevier, Vol. 349, No. 7, 2012, pp. 2215 –2242.

[22] M. A. M. Abushariah, R. N. Ainon, R. Zainuddin, M. Elshafei, and O. Khalifa, "Arabic Speaker-Independent Continuous Automatic Speech Recognition Based on a Phonetically Rich and Balanced Speech Corpus", *The International Arab Journal of Information Technology*, Vol. 9, No. 1, 2012, pp. 84 – 93.

[23] J. Alaraifi, M. Amayreh, and M. Saleh, "The prevalence of speech disorders among university students in Jordan". *College Student Journal*, Vol. 48 No.3, 201 4, pp.425-436.

[24] Y. P. P. Chen, C. Johnson, P. Lalbakhsh, T. Caelli, G. Deng, D. Tay, and M. E. Morris, "Systematic review of virtual speech therapists for speech disorders". *Computer Speech & Language*, Vol. 37, 2016, pp.98-128.

[25] C. Van Riper. "*Speech Correction: Its Principles and Methods*". Prentice-Hall, 1949.

[26] American Speech- Language- Hearing Association (ASHA), (2018a). Speech and Language Disorders and Diseases. Retrieved on February 3 2018 from: http://www.asha.org/public/speech/disorders/

[27] M. Amyreh, and A. Dyson, "The Acquisition of Arabic Consonants", *Journal of Speech, Language*, and Hearing, Vol. 41, No.3 1998, pp. 642-653.

[28] J. Alaraifi, I. Jamil, "Remediation for /r/ in Arabic: A phonetic Remedial Study". *Dirasat,* Vol.40, No.1, 2003, pp. 33-35. (In Arabic)

[29] I. Jamil, "Speech disorders in Sapphire sounds in Arabic Language". *Arab Journal for Humanities*. Vol.115, No.29, 2011. (In Arabic)

[30] J. Patterson, "Articulation". In: J.S. Kreutzer, J. DeLuca, and B. Caplan. (eds) *Encyclopedia of Clinical Neuropsychology*. Springer, New York, NY, 2011.

[31] M. Cuffaro, "Articulation Disorder". In: S. Goldstein, J.A. Naglieri. (eds) *Encyclopedia of Child Behavior and Development*. Springer, Boston, MA, 2011.

[32] E. S. Simmons, "Stuttering". In: Volkmar F. (eds) *Encyclopedia of Autism Spectrum Disorders*. Springer, New York, NY, 2017.

[33] D. Iimura, Y. Yada, K. Imaizumi, T. Takeuchi, M. Miyawaki, and J. Van Borsel. "Public awareness and knowledge of stuttering in Japan". *Journal of communication disorders.* 2018.

[34] American Speech- Language- Hearing Association (ASHA), (2018b). Voice Disorders. Retrieved on February 5 2018 from:

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

https://www.asha.org/Practice-Portal/Clinical-Topics/Voice-Disorders/.

[35] M. Verly, R. Gerrits, L. Lagae, S. Sunaert, N. Rommel, and I. Zink "Evaluation of the language profile in children with rolandic epilepsy and developmental dysphasia: Evidence for distinct strengths and weaknesses". *Brain and language*, Vol.170, 2017, pp.18-28.

[36] The National Institute on Deafness and Other Communication Disorders (NIDCD), 2016. Quick Statistics about Voice, Speech, Language. Retrieved on February 5 2018 from: https://www.nidcd.nih.gov/health/statistics/quick-statistics-voice-speech-language

[37] Canadian Association of Speech- Language Pathologists and Audiologists (CASLPA), 2005. Fact sheet on Speech, Language and Hearing. Retrieved on February 6 2018 from: www. Caslpa.ca.

[38] J. Van Borsel, S. Van Rentergem, and L. Verhaeghe. "The prevalence of lisping in young adults". *Journal of Communication Disorders*, Vol.40, No.6, 2007, pp.493-502.

[39] M. Andrea, Ó. Dias, M. Andrea, and M. L. Figueira, "Functional Voice Disorders: The Importance of the Psychologist in Clinical Voice Assessment". *Journal of Voice*, Vol.31, No.4, 2017, pp.507-e13.

[40] B. Trinite, "Epidemiology of voice disorders in Latvian school teachers". *Journal of Voice*, Vol.31, No.4, 2017, pp.508-e1.

[41] M. M. Amayreh, "Completion of the consonant inventory of Arabic". *Journal of Speech, Language, and Hearing Research*, Vol.46, No.3, 2003, pp.517-529.

[42] M. Elmahdy, R. Gruhn, and W. Minker, "Novel techniques for dialectal Arabic speech recognition". *Springer Science & Business Media*, 2012.

[43] M. A. Abushariah, R. N. Ainon, R. Zainuddin, B. A. Al-Qatab, and A. A. Alqudah, "Impact of a newly developed modern standard Arabic speech corpus on implementing and evaluating automatic continuous speech recognition systems". *In Spoken Dialogue Systems for Ambient Environments*. Springer, Berlin, Heidelberg, 2010, pp. 1-12.

[44] N. Hammami, M. Bedda, N. Farah, and S. Mansouri, "/r/-Letter disorder diagnosis (/r/-LDD): Arabic speech database development for automatic diagnosis of childhood speech disorders (Case study)". *In Intelligent Systems and Computer Vision* (ISCV), IEEE, 2015, pp. 1-7.

[45] I. Albalbalawi, "Speech Disorders: A guide for speech specialists, teachers and parents". Egypt, *Egyptian renaissance library*, 2003.