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A Novel Algorithm for Dividing Uzbek Language Words into Syllables for Concatenative Text-to-Speech Synthesizer

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ABSTRACT

Demand for multimedia systems, including speech synthesis systems, is growing rapidly to simplify and facilitate the use of rapidly evolving modern technologies. Designing text-to-speech systems capable of producing natural-sounding speech segments in the Uzbek language is a challenging and open problem. In this paper, we propose an algorithm based on concatenative methods for dividing Uzbek language words into syllables for text-to-speech synthesis. First, the electronic dictionary of the Uzbek word and syllables was developed based on the proposed algorithm. Then, the structure and characteristics of these words and syllables were analyzed. This electronic dictionary has more than 31.5 thousand words and 3 thousand syllables.

Key words : Concatenative, Electronic Dictionary, Phonetics, Sounds, Syllables, Text-to-Speech Synthesis, Uzbek language, Words.

1. INTRODUCTION

The invention of new technology makes life more comfortable for people, however, numerous problems appeared related to human-machine interaction, storage, and data transmission. History has confirmed that voice communication is essential for social communication because it is a simple and useful system of communicating. Therefore, from the earliest times of computer technology, efforts have been made to train computers on how to communicate with humans utilizing a natural speech interface. Several powerful methods and algorithms have been developed in this field over the years. However, the creation of the Uzbek language speech synthesizer remains an open problem.

Speech synthesis is the method of artificially generating human speech. A machine operation applied for this goal is described as a speech synthesizer and can be utilized in hardware and software. Speech synthesis, more specifically identified as text-to-speech (TTS), is a complete technology that incorporates various disciplines such as digital signal processing, sentiment text classification [1], statistics, linguistics, and acoustics. It is cutting-edge technology in the area of data processing, especially for the advanced smart speech interaction systems. The principal task is to transform text input into speech output [2]. Nowadays, there are many projects for industrial TTS systems with various characteristics and performance. Therefore, it seems that a comparative study of them would be quite useful for signal processing researchers, among others. With the advancement of digital signal processing technologies, the research purpose of speech synthesis and text analysis has been developing from intelligibility and clarity to naturalness and expressiveness. Intelligibility describes the accuracy of the synthesized speech, whereas naturalness refers to the ease of listening and global stylistic consistency [3], [4].

We propose an algorithm for dividing words into syllables for the Uzbek language text-to-speech synthesizer that uses the concatenative method. The main contributions of the proposed method are summarized as:

- The first Uzbek language electronic dictionary that has more than 31.500 words and 3.000 syllables is created.
- Uzbek language words are divided into syllables using the proposed algorithm for concatenative Uzbek language text-to-speech synthesizer.

The rest of the article is organized as follows. Section 2 gives an overview of speech synthesis including its basic concept, history, and technologies. In Section 3, this paper discussed the methods of speech synthesis. Brief information is given in Section 4 about phonetic units of speech in the Uzbek language. In Section 5, the Uzbek language electronic dictionary is developed. The proposed algorithm for dividing Uzbek words into syllables is explained in Section 6. provides discussions on new research directions. Finally, Section 7 concludes the article.

2. LITERATURE REVIEW

Several TTS systems are currently available for application, but in this section, we are going to describe some of them. There are various articles where the most appropriate TTS systems are listed [5], [6]. The research work of A. Kaliyev et

al. [7], the existing methods from the beginning of the methods of synthesis of intonation speech to the present day was discussed in detail. Such technologies are one of the best solutions not only to simplify the use of technical systems but also to ensure the use of electronic systems by people with disabilities, as well as the organization of the educational process in special boarding schools for children [8], [9].

The main problems in their development are to define the kind of synthesis, to determine how to synthesize speech from a source, such as text, images, sound, and so on [10], [11]. The development of synthesis methods is also a significant challenge. A study by T. Yousef et al. [12] analyzed several speech synthesizer algorithms which have been developed for other languages. Such algorithms vary according to the literary rules of the synthesis language. The development of such a system in the Uzbek language requires the use of algorithms and methods that fully cover the literary grammatical rules of the language.

The developed speech synthesis designs and methods have been implemented in several systems, either individually or in hybrid form, depending on the application technology and the capabilities of the given language [13]. One of the main disadvantages of synthesized speech is that the author's ability to express emotional experiences is insufficient. However, it can be seen from the research work of J. Bhaskar et al. [14] and Ya Li et al. [15] that a number of achievements have been made. In the research of M. B. Akçay et al. [16], we also see the achievements of modern synthesis systems in this regard.

Neural networks, one of the most superior technologies today, are being adopted to analyze the features of phonetic segments of speech and to improve the similarity of synthesis to actual pronunciation. The performance of neural networks considered a turning point in a study in this field. V.R. Reddy et al. [17] proposed prosody modeling for syllable based text-to-speech synthesis using feedforward neural networks. N.P. Narendra et al. [18] introduced an optimal tuning method for unit selection cost functions in syllable based text-to-speech synthesis based on joint fragments.

The results of research by world scientists and local researchers show that it is possible to develop several methods and algorithms for synthesizing Uzbek texts into speech signals. Speech is made up of a series of meanings on the inside and a chain of sounds on the outside. The shortest, smallest part of the meaning is a morpheme, whereas the smallest indivisible part is a syllable. In the speech, sounds are not pronounced separately. The word cannot be pronounced in sounds, it is pronounced in syllables. In the speech, sounds are arranged in a certain order. Thus, speech is made up of a chain of sounds representing syllables.

3. METHOD OF SPEECH SYNTHESIS

Speech synthesizers can be used in many important areas such as education, manufacture of electronic equipment, public transportation, or service systems to facilitate the use of communication technologies by people with disabilities in their interactions with the environment. Attempts to control and observe electronic devices by voice have led to a sharp increase in demand for technologies that allow text-to-speech or speech-to-text conversion. Such technologies may be available on a computer as part of any system or as standalone software.

Synthesis systems generate artificial speech signals that are close to the established language standard, using appropriate methods and algorithms. All methods of speech synthesis can be divided into the following groups:

- parametric synthesis;
- concatenative synthesis;
- synthesis according to rules;

In parametric synthesis, the speech signal is represented by a small set of constantly changing parameters. The advantage of this method is the ability to record the speech of any speaker in any language. The quality of parametric synthesis can be low or very high depending on the degree of compression of the parametric information. Parametric speech synthesis can only be used when the message set is limited. The main drawback of such systems is the inability to apply them to unknown incoming texts.

Concatenative synthesis is based on the use of a pre-written dictionary of speech elements. Obviously, the size of the messages to be synthesized depends on the dictionary coverage. The main problem with this method is the amount of memory used to store the dictionary. In this regard, various methods of compressing and encoding speech signals are used. In this way, as the number of memory increases, it is possible to synthesize as much text as you want. However, it is not possible to synthesize arbitrary unknown text because pre-recording is required.

Synthesis according to the rules provides control of all parameters of the speech signal and thus can create a speech from previously unknown text. In this case, the parameters obtained during the analysis of the speech signal are stored in memory in the same way as the rules for combining sounds into words and phrases. Synthesis is accomplished by modeling the speech tract using analog or digital technology [19].

It is necessary to clearly define the method of synthesis used in the development of speech synthesizers. The technology used and the literary norms of the language are crucial in choosing a method. Uzbek is a language of the Altaic language family of Turkic languages and is the state language in accordance with the Constitution of the Republic of Uzbekistan.

Turkic languages are also one of the most ancient languages, and the period from BC to the 10th century is known in science as the "ancient Turkic languages". The language used in the 11th and 14th centuries is called "Old Turkic languages". The language used from the 15th to the second half of the 19th century was called "Old Uzbek

Literary Language". The language used from the second half of the 19th century to the present is called "modern Uzbek literary language". The Uzbek language began to emerge as an independent language in the 11th century, and the old Uzbek literary language was formed in the 13th century [20].

The use of parametric synthesis for speech synthesis in the Uzbek language, which has a long history and a large vocabulary, causes technical problems with memory in the formation of a set of parameters.

In order to use the method of synthesis according to the rules, it is necessary to develop a linguistic basis for all the rules related to the rules of spelling and pronunciation in the Uzbek language. Even if this problem is solved, we will face a difficult problem, such as learning the features of words and terms borrowed from other languages and developing appropriate pronunciation rules for them.

Speech synthesis faces a problem with memory in the formation of a database that covers all words and terms in the Uzbek language when using the concatenative method. It also takes a long time to find and synthesize words from a large database. However, given the fact that words in the Uzbek language are pronounced in syllables, it is possible to express a large number of words with a small number of syllables. Due to the nature of the concatenative method, the problem of memory can be solved by forming a base of syllables, not a base of words. The words learned from other languages can also be expressed through syllables found in Uzbek words. If completely unknown syllables are encountered, the system is improved by adding it to the database of syllables.

The analyzed features and solutions suggest that the use of a concatenative approach to speech synthesis in Uzbek is a relatively convenient and effective approach.

4. PHONETIC UNITS OF SPEECH IN UZBEK LANGUAGE

Speech is divided into successive phonetic units according to the period of pronunciation. This division is also called segmentation (Latin segments - meaning "part"). In this case, each part is called a segment. This division of speech makes it possible to identify large and small segments and the order in which they are connected. Each phonetic unit has its pronunciation, which is the material side of language construction.

Speech consists of the following phonetic units:

1. phrase (sentence);
2. tact (syntagma);
3. word;
4. syllables;
5. sound.

A phrase (sentence) is a part of speech that has intonational integrity between two complete pauses and is often equivalent to a complete sentence. During the pause, the speaker takes the necessary breath to pronounce the next sentence.

Tact is the part of speech that is spoken between two short pauses. Phrases with a broad composition are divided into tacts. Accordingly, speech tacts are also analyzed in the syntax section of the language through the subject of syntagma and phrase: the phrase is a means of sentence construction. A syntagma is phonetic integrity that expresses grammatical-semantic integrity and is a speech element between two pauses. These features indicate that the tact of speech is equivalent to a phrase, a syntagma. However, the tact of speech does not always correspond exactly to the phrase and syntagma [21].

In the Uzbek language, the smallest unit of speech, consisting of one vowel, one or more consonants, and one breath, is called a syllable. A word is made up of syllable or syllables. In the Uzbek Latin alphabet, almost every letter represents a sound, and there are a total of 29 letters and 1 character as shown in Table 1. As can be seen from Table 1, 24 of the 29 letters are represented by a single character, 2 by a combination of letters and symbols, and 3 by a combination of letters. Therefore, it can be said that in the Uzbek language 29 sounds can be expressed in writing.

Table 1: The Uzbek Latin alphabet

№ / Type	1	2	3	4	5	6	7	8	9	10	11	12
Letter	Aa	Bb	Dd	Ee	Ff	Gg	Hh	Ii	Jj	Kk	Ll	Mm
	Nn	Oo	Pp	Qq	Rr	Ss	Tt	Uu	Vv	Xx	Yy	Zz
Letter+Symbol	O‘o‘	G‘g‘										
Letter+Letter	Shsh	Chch	ng									
Symbol	‘											

In the Uzbek language, the pronunciation of letters is divided into two groups of vowels and consonants, according to the fact that there is no obstruction in the pronunciation of the mouth and the exit from the throat. Correspondingly, the characters that represent them are also called vowels and consonants. As a result, the Uzbek spelling based on the Latin alphabet has 6 vowels and 26 consonants as shown in Table 2.

Table 2: Grouping of vowels and consonants in the Uzbek Latin alphabet

№ / Type	1	2	3	4	5	6	7	8	9	10	11	12
Consonants	Bb	Dd	Ff	Gg	Hh	Jj	Kk	Ll	Mm	Nn	Pp	Qq
	Rr	Ss	Tt	Vv	Xx	Yy	Zz	G‘g‘	Shsh	Chch	ng	
Vowels	Aa	Oo	Ii	Ee	Uu	O‘o‘						

In the Uzbek, words are pronounced in syllables. The more vowels in a word, the more syllables there are. Consonants cannot form syllables on their own, they can only form syllables together with vowels. It can also be said that a syllable contains only one vowel and several consonants. According to the literary rules of the Uzbek language, there are syllables consisting of only one vowel sound. A syllable that ends in a vowel is called an open syllable, otherwise it is called a closed syllable [22].

5. UZBEK LANGUAGE ELECTRONIC DICTIONARY

Before talking about all the words and terms related to a language, it is necessary to refer to the explanatory dictionary of that language. The dictionary includes words and phrases widely used in the literary language of the period, terms related to science, technology, art and culture, some dialects, as well as historical and ancient words. An annotated dictionary is a type of linguistic dictionary. It defines and interprets the meaning of each word in the dictionary.

A relatively comprehensive dictionary of the Uzbek language was developed in 1981 at the Pushkin Institute of Language and Literature of the Academy of Sciences of the Uzbek SSR [23]. By the Resolution of the Cabinet of Ministers of the Republic of Uzbekistan No. 311 of September 10, 1996, a multi-volume dictionary was included in the state program, taking into account the changes that took place in the Uzbek language after the publication of the two-volume annotated dictionary in 1981. Taking into account the cultural and national values of Uzbekistan after independence, the Institute of Language and Literature of the Academy of Sciences of Uzbekistan and the State Scientific Publishing House "National Encyclopedia of Uzbekistan" published a multi-volume annotated dictionary of the Uzbek language in 2006-2008 [24]. An electronic database of more than 31.5 thousand words was created based on the analysis of all words in the Uzbek dictionary. The alphabetical statistics of words in this dictionary can be seen in Table 3.

Table 3: An electronic database of the Uzbek dictionary

The number of words beginning with the specified letter			
Alphabet letters	**Number of words**	**Alphabet letters**	**Number of words**
A	1538	Q	1968
B	2694	R	768
D	1419	S	2239
E	647	T	2634
F	607	U	482
G	824	V	468
H	862	X	813
I	1056	Y	1098
J	663	Z	466
K	1846	O'	502
L	461	G'	452
M	1900	SH	900
N	776	CH	943
O	1164	ng	0
P	1318		
Total:	**31 508**		

The difference between the number of words and terms in the Uzbek dictionary and the number of words in the electronic dictionary can be explained by the interpretation of phrases, expressions, metaphorical words in addition to the root words in the glossary [25]. The electronic dictionary does not include phrases and expressions due to the fact that the metaphorical meanings of words are not important in the concatenative method of text-to-speech synthesis.

Research shows that with the development of modern technology and globalization, words and terms from many other languages are entering in the Uzbek language. Such foreign words are widely used in our oral and written speech, as they help us to fully express our thoughts in terms of meaning. Based on this, the following additional electronic dictionary was created:

- geographical names (mountain, river, sea, continent, place names, etc.);
- geopolitical names (states, capitals, cities, languages, nations, etc.);
- terms in the technical and natural sciences (physical quantities, units of measurement, chemical, formatting, historical terms, etc.);
- names and prominent nouns;
- terms in the field of information and communication, medicine;
- terms used in social life.

The electronic dictionary will include Uzbek words and popular foreign words in Uzbek, and it is advisable to take measures to optimize the generated additional words as much as possible and to reduce their share in comparison with pure Uzbek words. The result is a database of additional words containing more than 7,000 words.

As a result of combining all the words in the created electronic dictionary, an electronic dictionary was improved, which is used in the Uzbek language, has a generalized structure and covers a total of more than 38,000 words and terms.

6. ALGORITHM FOR DIVIDING UZBEK WORDS INTO SYLLABLES

Human speech is made up of sentences and words. The words also consist of syllables. Thus, the organization of syllabic reading to convert words and sentences into sound signals is also a solution to the problem of synthesis. First of all, it is necessary to create a database of syllables. Finding the optimal way to create a database of syllables is required. This depends on the number and size of the syllables, the size of the space they occupy in memory, and the degree to which they affect the operation of the system.

In pure Uzbek language words, up to four sounds can be present in one syllable. Given the fact that a syllable contains a single vowel sound, there are the following 9 types of syllable structure models as shown in Table 4. Conditionally, V is a vowel, C is a consonant.

Some foreign words may have up to five sounds. Research-based on the developed dictionary shows that words

and terms from other languages do not correspond to the above platforms. Therefore, it is advisable to add additional types of syllables as illustrated in Table 5.

Based on the above, it is possible to develop an algorithm for segmentation as follows. That is, the division of any word into syllables is based on the following sequence:

1. Determine the number of letters in a word. At this stage, it is mainly a matter of word separation. A word is a continuous sequence of letters between a paragraph, punctuation, and spaces.
2. Determine the number of vowels in a word. This step allows you to move on to the next step based on the fact that only one vowel can be present in a syllable.
3. From the last letter of the word, the sequence is divided into syllables corresponding to any of the above syllable platforms.

Table 4: Types of syllables in Uzbek language

№	Syllables	Types	Example
1.	V	vowel	o-na, o-pa, a-ka;
2.	CV	consonant+vowel	bo-bo, to-za, ki-tob;
3.	CCV	two consonant+vowel	bri-ga-da, tri-mó, stu-dent;
4.	VC	vowel+consonant	or-zu, os-mon, ep-chil;
5.	VCC	vowel+two consonant	umr, ost, ishq, aql-li;
6.	CVC	consonant+vowel+ consonant	mak-tab, bog‘-bon, ki-tob;
7.	CVCC	consonant+vowel+ two consonant	qarz, dars, sharq;
8.	CCVC	two consonant+vowel+ consonant	stul, kran, trak-tor;
9.	CCVCC	two consonant+vowel+ two consonant	sport, start, shtamp;

Table 5: Forms of Syllables

№ of sounds / Conditions	1	2	3	4	5
1- condition	V	VC	VCC	VCCC	
2- condition		CV	CVC	CVCC	CVCCC
3- condition			CCV	CCVC	CCVCC
4- condition				CCCV	CCCVC

In this way, a word can be divided into syllables in several different ways. For example, the word “MATEMATIKA” can be divided into syllables in MA-TE-MA-TI-KA (CV-CV-CV-CV-CV) or MAT-E-MAT-I-KA (CVC-V-CVC- V-CV) and others. In this case, it is necessary to take into account the rules of syllable translation in Uzbek. It is also important to note that some foreign words retain their meaning. The following algorithm can be developed to determine whether a syllable is an open or closed syllable, beginning with a vowel or a consonant, and taking into account the position and characteristics of the syllable. The block diagram of the proposed Uzbek language word division into syllables algorithm is shown in Figure 1.

In the block diagram of the proposed algorithm for Uzbek language word division into syllables “C” is a consonant, “V” is a vowel, “&” is a hyphen in the Latin alphabet (’), a (ъ) delimiter in the Cyrillic alphabet, or a softening sign (ь). The division algorithm is based on distinguishing the appropriate syllable form by comparing the sequence of letters in a word to the step-by-step reference case forms. That is, given the length of a word, its conformity to a standard case means that the form of the syllable defined for that case must be distinguished. The relationship between the reference cases and the joint forms can be seen in the Table 6.

The beginning of a syllable with a vowel or a consonant determines the properties of the consonant sounds in the syllables before and after it. This can be explained by the conclusions drawn from the analysis of the developed electronic dictionary and the rules of syllable translation in the Uzbek language.

The principle of operation of the proposed algorithm can be explained by dividing a word into syllables. For example, if we divide the word “O‘ZBEKISTON” into syllables, it goes through the following stages:

1. The total number of sounds in a word is determined:
   $O‘_1\ Z_2\ B_3\ E_4\ K_5\ I_6\ S_7\ T_8\ O_9\ N_{10}$ Word length S = 10
2. Determine the total number of vowels in a word:
   $O‘_1\ Z_2\ B_3\ E_4\ K_5\ I_6\ S_7\ T_8\ O_9\ N_{10}$
   $V_1\ C_2\ C_3\ V_4\ C_5\ V_6\ C_7\ C_8\ V_9\ C_{10}$
   $V_1\ C\ C\ V_2\ C\ V_3\ C\ C\ V_4\ C$ Vowels = 4
3. Comparison of the reference syllable formats begins with a vowel (AllVowel =! 1):

Condition	Syllables
$V_1\ C_2\ C_3\ V_4\ C_5\ V_6\ C_7\ C_8\ V_9\ C_{10}$	
V C C+V	V C
$O‘_1\ Z_2\ B_3\ E_4\ K_5\ I_6\ S_7\ T_8\ O_9\ N_{10}$	O‘ Z

4. The rest of the word is compared to compared to the reference syllable formats that start with a consonant (AllVowel =! 1):

Condition	Syllables
$C_3\ V_4\ C_5\ V_6\ C_7\ C_8\ V_9\ C_{10}$	
C V C+V	CV
$B_3\ E_4\ K_5\ I_6\ S_7\ T_8\ O_9\ N_{10}$	B E

5. The rest of the word is compared to compared to the reference syllable formats that start with a consonant (AllVowel =! 1):

Condition	Syllables
$C_5\ V_6\ C_7\ C_8\ V_9\ C_{10}$	
C V C+C	CVC
$K_5\ I_6\ S_7\ T_8\ O_9\ N_{10}$	K I S

6. The rest of the word is considered a single syllable since AllVowel == 1. The word is then divided into syllables as follows:

Word	The syllabic form of a word	Total number of sounds	The number of vowel sounds	Number of syllables
O‘ZBEKISTON	O‘Z - BE - KIS - TON	10	4	4

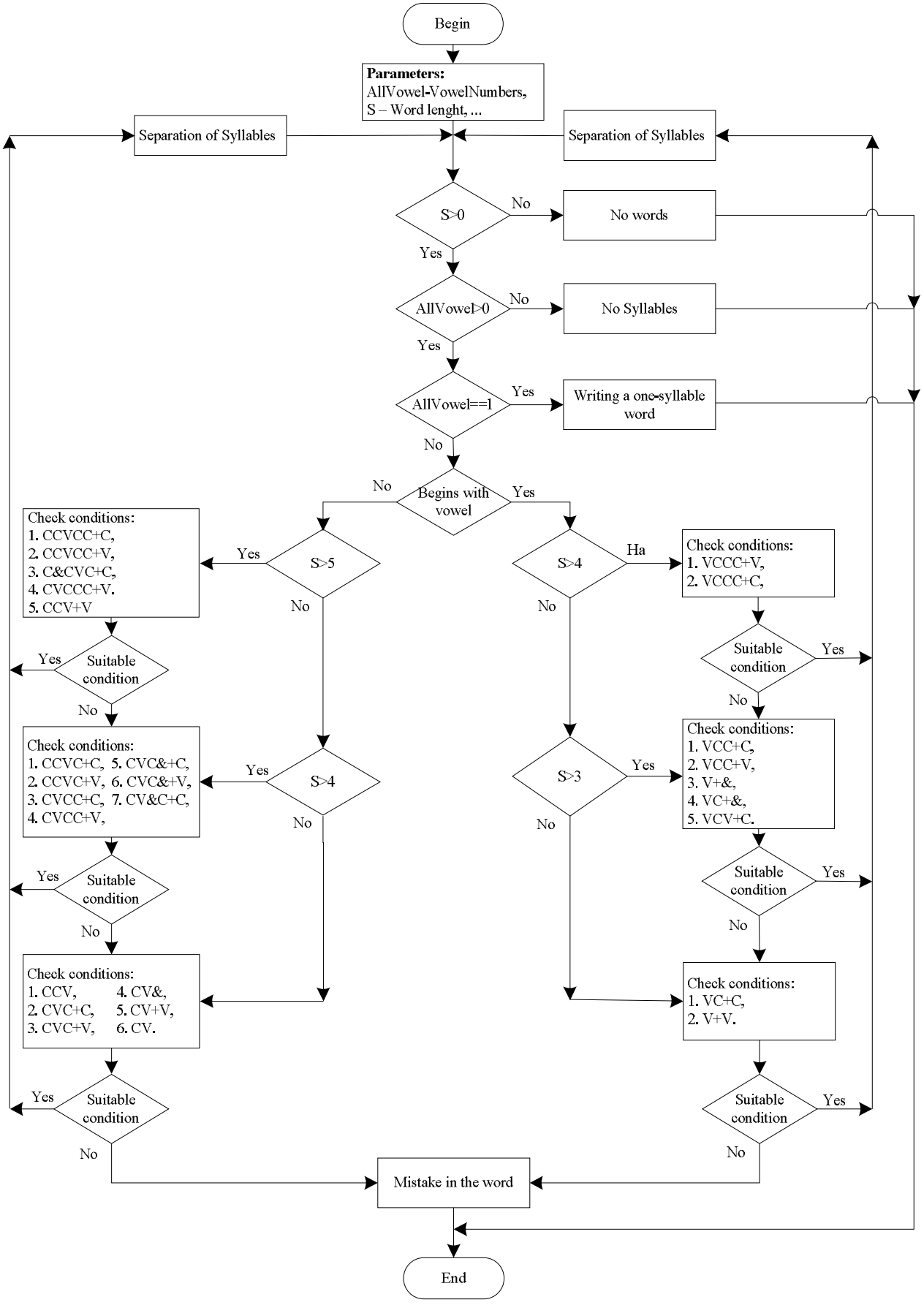

Figure 1: The block diagram of algorithm for Uzbek language words division into syllables

A software called eYespeakAnalyser was developed based on the proposed algorithm and all the words in the electronic dictionary were divided into syllables. Analysis of separated syllables shows that a single syllable can consist of several hundred words, or some syllables can occur in a single word. For example, the number of syllables in a single word is 348. Most of these syllables come from words borrowed from other languages. It should be noted that all analyzes are carried out within the developed electronic dictionary. Changes can be made to the results of the analysis if additional words are added to this dictionary. The statistics of the repetition of syllables in one or more words can be seen in Table 7.

Table 6: Types of syllables forms

The number of words beginning with the specified letter			
Alphabet letters	**Number of words**	**Alphabet letters**	**Number of words**
A	1538	Q	1968
B	2694	R	768
D	1419	S	2239
E	647	T	2634
F	607	U	482
G	824	V	468
H	862	X	813
I	1056	Y	1098
J	663	Z	466
K	1846	O'	502
L	461	G'	452
M	1900	SH	900
N	776	CH	943
O	1164	ng	0
P	1318		
Total:	**31 508**		

Table 7: Repetition of syllables in the dictionary

Number of Syllables	348	356	255	167	144	100	77	75	…	1	1	1
Number of repetition	1	2	3	4	5	6	7	8	…	2424	2453	3678

It is pronounced the same regardless of whether one syllable is in one or more words. Therefore, no matter how many times it is repeated in the electronic dictionary, it can be considered as a single syllable. As mentioned above, syllables can contain from 1 to 5 sounds. The existing syllables can be grouped as follows by taking into account this feature. This grouping is presented in Table 8. The results of the study show that more than 38,000 words and terms in the electronic dictionary can be represented by a total of 2,817 syllable fragments. In addition, 67% of these syllables belong to the group of three sound syllables. The number of syllables consisting of only one sound is 6 can be explained by the fact that the Uzbek spelling based on the Latin alphabet has 6 vowels.

Table 8: Grouping of syllables according to the number of sounds

Number of Sounds	1	2	3	4	5
Number of Syllables	6	248	1877	646	40

7. CONCLUSIONS AND FUTURE WORKS

About this article, it is possible to divide all Uzbek words into syllables using the proposed algorithm. Because dialects are distinguished by the different pronunciation of words. However, the rules of syllable translation in literary language can be applied to all dialects. It is also possible to divide words learned from other languages into syllables using the proposed algorithm. In that case, it is important to remember that such words can lead to a loss of pronunciation in the language in which they are learned.Currently, created electronic dictionary is not to generalize and standardize all the words and terms used in the speech of ethnic Uzbeks living or working in Uzbekistan and other countries. Because, Uzbek language is a complex historical language with many dialects. In addition, changes have been made to the language standards of Uzbek peoples living outside the territory of Uzbekistan, depending on the ethnic composition of the population. This means that the electronic dictionary of Uzbek words created in this work includes only words and terms that comply with the standards of literary language, which are legally maintained in the Republic of Uzbekistan.

Finally, it can be concluded that many words can be expressed in Uzbek language using a small number of syllables, using the feature of articulation of words. This solution allows us to avoid the problem of memory, which is the main drawback of the concatenative method in the development of the Uzbek language text-to-speech synthesizer. Future work includes expanding the dictionary created above on demand and supply and forming a database of syllables accordingly, as well as the gradual improvement of the developed algorithm.

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