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FORMING THE SET OF RECOGNITION UNITS FOR THE SPEECH RECOGNITION SYSTEM FOR THE AZERBAIJANI LANGUAGE

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Abstract. Any algorithm for speech recognition always has a procedure for comparison of an input signal with the etalons available in memory, for definition of its belongings to an appropriate class. In this paper the definition of the set of etalons for the 1st version of the Automatic Speech Recognition (ASR) system for the Azerbaijani language is described.
Key words: Automatic speech recognition, speech processing, speech technologies, the Azerbaijani language.

1. Introduction

Despite the automatic recognition of the human speech by machine has been a part of scientific fiction for many years, after the creation] of the computers this "fiction" ceased to be fiction. From the first researches in 1950s [12], reliable solution to the problem of the recognition of human speech by computer became a goal of many researchers in the field of the development of information technologies.

Speech recognition and speech synthesis technologies have particular importance among intellectual linguistic technologies. Ideally the computer should "comprehend" user's natural speech and produce information according to user's expectation accurately. For the solution of this most complicated problem, at first it is necessary to solve more "simple" problem: transform the speech to text by using the computer. "Simplicity" of this problem is that, in this case computer's comprehension of the speech is not required. On the other hand, of course, most people can speak several times faster than they can type from the keyboard, because speech is a much more natural form of communication than a computer keyboard and consequently in modern computer systems more and more attention is given to the construction of the interface of natural input-output of the information. The most perspective systems for today are the systems of speech input and it is not casual that the majority of the "speech interface" programs, produced nowadays, are focused on speech input. In the first stage, the basic goal of the researches which are carried out on the development of speech recognition system for the Azerbaijani language is also to develop the computer system for transforming the Azerbaijani speech to text.

Speech recognition systems follows the standard; three-stage pattern classification paradigm is illustrated in Figure 1 graphically [15].

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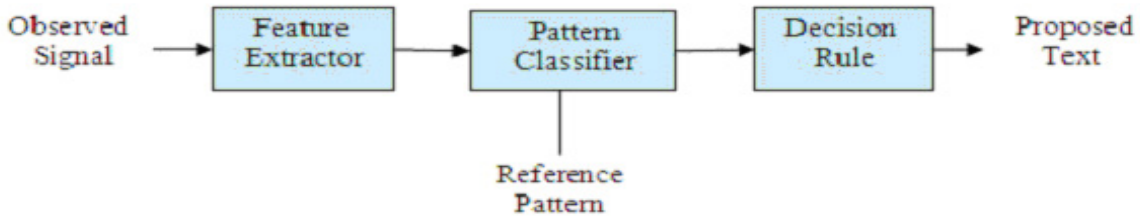

Figure 1.

The goal of any speech recognition system is to define the word which is presented by the speech signal.

In this paper, one of the important parts of the researches carried out on the direction of the development of such system – the forming of the set of recognition units (more exactly allophones of phonemes) as a set of etalons for the speech recognition system for the Azerbaijani language is described.

2. Background

Although many scientific works on different aspects of computer linguistics for the Azerbaijani language have been carried out since 70th years of previous century, the majorities of these scientific works have theoretical character and have not led to the development of practical computer systems for the demand of any problems of Azerbaijani-speaking computer users. It is possible to specify only on two - the spell checker program*[1] (www.tqdk.gov.az) and the machine translation system (Dilmanc MT System*[2]*, www.dilmanc.az) [1].

In Dilmanc MT system for the first time (for the Azerbaijani language) it is possible to voice the text after its translation into English and thereby, technologies of machine translation and text-to-speech (in English) have been attached together within the same program module.

We must note that the development of the machine translation system for the Azerbaijani language is very important from the point of creating of the national linguistic technologies. Because the majority of the scientific results is received in the frame of this project for formal analysis of the Azerbaijani language (formal grammar, grammatical and semantic formalisms, morphological ant syntactical analyzers, etc.) and algorithms developed on the basis of these results can be used while creating other intellectual technologies as Natural Language Processing, Speech Signal Processing, Text-To-Speech Systems, Human-Computer Dialogues, Speech Production and Speech Perception, Speech Recognition and Understanding, Speaker Identification, etc.

As we touch upon the problem of speech technologies for the Azerbaijani language, there are much more modest results in this and related fields including Speech Signal Processing, Text-To-Speech Systems, Human-Computer Dialogues, Speech Production and Speech Perception, Speech Recognition and Understanding, Speaker Identification, etc. On the recognition of separate words of the Azerbaijani language some theoretical researches are known [5], [6], but researches on the development of other speech technologies mentioned above were not carried out at all.

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[1]* Researches has been carried out in the frame of the project NICTS-1

[2]** Development of the Azerbaijani-English MT system has been carried out within the joint project of The Azerbaijani Ministry of ICT and UNDP-Azerbaijan

3. Recognition units and the Azerbaijani language

As mentioned above , over the recognition of the Azerbaijani speech some researches are carried out on the basis of artificial neural networks [5], [6]. In these researches, possibility of the recognition of separate words and word-forms (word-form consists of the root of word and the suffix chain) is investigated.

As the Azerbaijani one is agglutinative language, this approach can be useful at a very small volume of the dictionary of recognized words. The matter is that, there are a lot of suffixes and suffix chains and it is possible to generate tens, sometimes hundreds and thousands of word-forms from one root of a word in the Azerbaijani language [19, p. 84]. Therefore, while developing the practical systems on the bases of speech processing, for example, the development of the speech recognition system it is required to recognize the smaller units (a syllable, a phoneme, etc.) of speech rather than the word forms [22]. But the recognition of such smaller units is fraught with large difficulties.

Modern systems of speech recognition are mainly developed on the basis of artificial Neural Networks and/or on the HMM (Hidden Markov Model). In any case, speech recognition algorithm always has a procedure for the comparison of an input signal with patterns available in memory, for the definition of its belongings to an appropriate class. Therefore, in order to carry out the recognition process, it is necessary, at first; to form the set consisted of the patterns of recognition – recognition units.

A speech recognizer has to separate parameterized speech into series of symbols, rarely words or word components. Traditionally, recognition has been carried out on whole words [8],[16],[18] [22], syllables [13],[17],[20],[23] and phoneme-like units [4],[10],[11].

But as mentioned above, the Azerbaijani language is an agglutinative one and it is very difficult to develop word-by-word speech recognition system for this language. Using only active word-forms (all word-forms used in the modern Azerbaijani language, we call active word-forms) in recognition system is not an avail approach too, because not only all word-forms, but also active word-forms of the Azerbaijani language compose a very large set. The large text corpus (consisting of more than 12 million word-forms) comprised of different electronic texts taken from Internet and other electronic sources has been used for this purpose. For guaranteeing the "repsezentativeness" of the received results, texts on different themes (from mass-media, religious, philosophical, economical, political, etc.) were included in this text corpus [3].

On the result of the researchers carried out on the definition of active word-forms of the modern Azerbaijani language, it is possible to say that, there are more than 100 thousand active word and word-forms in the Azerbaijani language (It should be noted that, this text corpus have been used while developing the Azerbaijani-English machine translation system and can be used for the detection of the different linguistic rules of the Azerbaijani language [2], [3]).

Frequency of all word-forms in this corpus was defined with the aim of especial computer program developed for the processing of this corpus. After forming the database consisting of these word-forms, the database is processed visually and numbers, human names, non-Azerbaijani word-forms are excluded from this database. Thus, after carrying out the cleaning process we get that the number of remaining word-forms is about 100 thousand.

Because of the large volume of this corpus we can surely note that the words in this corpus form the set of active words of the Azerbaijani language. While developing the speech recognition system, it does not seem "attractive" to form the set of recognition units from such volume of the word-forms.

From the first side, taking the syllables as recognition units may seem much better. Because, the number of the syllables is many times fewer than the number of word-forms. On our computing, the number of the different syllables which the active word-forms are consisted of is about 5000. On the other hand, it is important to note that, it is not possible to separate input speech signal into the traditional syllables in all cases. Consequently, besides traditional syllables we will get non-empty set of the "machine syllables" as the result of technological

imperfection. That is if we cut the input speech signal **into** such parts (**into** the machine syllables) we will get more than 5000 recognition patterns. So, the great number of the syllables decreases the attractiveness of the approach for the development of the speaker independent speech recognition systems on the syllables.

While developing the speech recognition system it is possible to choose the phoneme-oriented approach based on the eliminating of the phonemes from the speech. In the next paragraph, a phoneme-oriented approach for the development of the speech recognition system for the Azerbaijani language is described.

4. Phoneme as a recognition unit

Taking into account all above mentioned complicating factors, we can consider that as the recognition units for the recognition system, it is the better to choose the phonemes set of the natural language. Though the difficulties are the same the number of patterns in this case is minimal.

In this work, phonemes are proposed as recognition units for use in the recognition process.

A phoneme is the smallest unit of the sound system of a language. If two sounds have the same phoneme, they are treated equally. In human language, a phoneme is the smallest unit of speech that distinguishes meaning.

Because a phoneme is defined as the smallest unit of speech that distinguishes one word or word element from another, any language can be completely defined by a set of phonemes (http://en.wikipedia.org/wiki/Phoneme). Identical phoneme pronounced in different contexts has slightly different sounds, so a phoneme may have variants, called allophones. A phoneme is a sound that has a definite shape as a sound wave, while a phoneme is a basic group of sounds that can distinguish words (i.e. changing one phoneme in a word can produce another word); speakers of a particular language perceive a phoneme as a single distinctive sound in that language.

For the development of the speech recognition system, at first, it is necessary to define the set of phonemes which will be used as the recognition patterns. Therefore, the set of floor amount words which envelops all phonemes of the Azerbaijani language must be defined. Of course, when we talk about the set of phonemes we consider that we must include enough number of allophones to this set for the correct recognition of the speech.

The goal of this article is to define the set of allophones for the development of the acoustic model for the Azerbaijani speech recognition system.

The Azerbaijani alphabet *Table 1*

a	b	c	ç	d	e	ə	f	g	ğ	h	x	ı	i	j	k	q	l	m	n	o	ö	p	r	s	ş	t	u	ü	v	y	z

Table 1 For the definition of the set of allophones, all pairwise combinations of the letters of the Azerbaijani alphabet are constructed (Table 2).

Pairwise combinations of the letters *Table 2*

aa	ab	ac	aç	ad	ae	aə	af	ag	ağ	ah	ax	aı	ai	aj	ak	aq	al	am	an	ao	aö	ap	ar	as	aş	at	au	aü	av	ay	az
ba	bb	bc	bç	bd	be	bə	bf	bg	bğ	bh	bx	bı	bi	bj	bk	bq	bl	bm	bn	bo	bö	bp	br	bs	bş	bt	bu	bü	bv	by	bz
ca	cb	cc	cç	cd	ce	cə	cf	cg	cğ	ch	cx	cı	ci	cj	ck	cq	cl	cm	cn	co	cö	cp	cr	cs	cş	ct	cu	cü	cv	cy	cz
...	...	...																													
za	zb	zc	zç	zd	ze	zə	zf	zg	zğ	zh	zx	zı	zi	zj	zk	zq	zl	zm	zn	zo	zö	zp	zr	zs	zş	zt	zu	zü	zv	zy	zz

It should be noted that, in order to identify the allophones more exactly the letter combinations must be used in threes (triphones) but not pairwise, then the allophone of the middle letter of each triphone must be taken as a pattern. But in that case the number of available combinations will be $32 \times 32 \times 32 = 32768$. The number of word-forms which cover this kind of available combinations in the Azerbaijani language is more than 11000. Sounding such a big number of word-forms by different announcers and using them as patterns deals with many difficulties.

While creating the majority of patterns we have used another approach. The essence of this approach is that recognition percentage of some phonemes in the Azerbaijani language is high enough; in other words, only a few allophones are necessary to identify such phonemes. Therefore, at first, allophones are defined by using letters pairwise, then recognition of the speech is tested by using these allophones. The allophones in threes for phonemes recognized by low percentage are added to patterns database. In this way recognition percentage of poorly recognized phonemes could be improved. This process has been described below.

The Azerbaijani language has 32 letters so the number of such combinations is 1024. Further more, for checking the possibility of every combination, the frequency of every combination is defined by using the above mentioned text corpus and the received results are included in database. Combinations *zj*, *k*, *pj*, *fj*, *z*, *jx*, *js*, *j*, *gf*, *g* are not specified at all. Further combinations whose frequencies are less then 0.00001 have been excluded from the database too. All such combinations are indicated in the Table 3 (in the second column of this table are indicated the number of occurrences of the corresponding combination in the first column, frequency =occurrence/12000000).

Allophones which have the frequency less than 0.00001 *Table 3*

gı	58	öğ	22	vp	14	oü	10	öə	7	jc	4	ğğ	2	zj	0
vf	48	bq	21	çç	14	hg	10	uı	6	gp	4	gv	2	kğ	0
eö	44	dğ	21	jt	14	jj	10	üü	6	öö	4	gx	2	pj	0
yj	44	oə	21	ğş	14	öj	10	hx	6	bj	3	gş	2	fj	0
jü	40	çx	21	gö	14	pğ	9	öu	6	pf	3	oı	1	çz	0
oö	35	ıi	21	hğ	13	uö	9	cf	5	çş	3	sj	1	jx	0
çj	35	gm	21	jy	13	şj	9	çv	5	ğh	3	tj	1	js	0
ğü	34	xk	20	ıu	13	pz	8	jö	5	cş	2	xj	1	ğj	0
iö	33	üı	18	öx	13	uü	8	ğp	5	pv	2	çf	1	gf	0
kf	33	jp	18	vj	12	öa	8	qj	4	fğ	2	hj	1	gğ	0
ğe	33	gg	18	ii	12	əı	8	qğ	4	xğ	2	jq	1		
sğ	28	aö	17	çy	12	eı	7	eğ	4	xg	2	jğ	1		
ğf	28	üe	17	əö	12	cğ	7	cç	4	jv	2	gq	1		
df	23	jr	17	nü	11	kj	7	mj	4	jz	2	gç	1		
eü	23	bğ	16	gz	11	jh	7	çg	4	jf	2	gj	1		
şş	22	çğ	16	cj	10	öü	7	jb	4	jg	2	öı	1		

Thus, number of remaining combinations is: 1024-122=902.

The remaining combinations of letters are used to form the allophone set of the recognition system for the Azerbaijani language. For this purpose, at first, by analyzing of the text corpus of the Azerbaijani active word-forms, the set of word-forms which cover all the letter combinations (from the Table 2) is defined. Cardinality (number of elements of a set: in this case number of word-forms) of this set is 692.

In the Table 4 are indicated some of these word-forms (the 1st column) and the combinations which are cut from these word-forms (the 2nd column).

Just these word-forms are used to define the allophone set. These word-forms were voiced by the speakers and the received wave files are used for the definition of the allophones (Sampling rate is 11025 hz). Using the Table 4 the allophones are cut from the appropriate wave files of the word-forms and the allophone (right-allophone - for example, from the pair of *ab* is cut allophone *b*) set is formed on the basis of this cut sounds. For this reason the special computer program is developed. With the aim of the program we cut all wave files of the chosen word-forms into the allophones.

Word-forms for forming the set of allophones *Table 4*

azərbaycan	az,zə,ər,rb, ba,ay,yc,ca
beynəlxalq	yn,əl,lx,xa, al,lq
Lazımdır	zı,ım,md,dı, ır
müəyyən	mü,üə,əy,yy, yə
respublikasının	re,sp,pu,bl, ka
xüsusi	xü,üs,su,us, si
avropa	vr,ro,op,pa
amma	am,mm,ma
böyük	bö,öy,yü,ük
dövlət	dö,öv,vl,ət
iqtisadi	iq,qt,ti,ad
inkişaf	nk,iş,şa,af
mövcud	mö,vc,cu,ud
hüquqi	hü,qu,uq,qi
artıq	rt,tı,ıq
bağlı	ağ,ğl,lı
boyu	bo,oy,yu
bütün	bü,üt,tü
deyil	de,ey,yi
etmək	et,tm,ək
informasiya	nf,fo,rm
istehsal	te,eh,hs
istifadə	st,if,fa
yalnız	ln,nı,ız
yaxşı	ax,xş,şı
yeni	ye,en,ni

müğənni	üğ,ğə,nn
obyektiv	ob,by,ek
olan	ol,la,an
olduğu	du,uğ,ğu
onların	nl,rı,n
onun	on,nu,un
Prezident	pr,ez,nt
Psixoloji	ps,lo,oj
Sonra	so,nr,ra
tərəfindən	tə,əf,fi
ümumi	üm,mu,um
üçün	üç,çü,ün
çıxış	çı,ıx,ış
haqqında	qq,qı,nd
hökumət	hö,ök,ku
güclü	üc,cl,lü
görə	gö,ör,rə
arasında	as,sı
aşağıdakı	ğı,ıd
başqa	şq,qa
belə	be,el
bir	bi,ir
var	va,ar
vergi	rg,gi
vöin	vö,öi
qeyd	qe,yd
qrup	qr,up
qulluqçularının	qç,çu
qıpçaq	ıp,pç
qəbul	əb,ul
qədər	qə,əd

daha	ah,ha
digər	ig,gə
doğru	do,ğr
dünya	dü,ny
edir	ed,di
enerji	rj,ji
ictimai	ct,ai
ilə	il,lə
ismayıl	sm,ıl
isə	is,sə
yazdığı	zd,ığ
keçmiş	ke,çm
kimi	im,mi
konkret	ko,kr
kömək	kö,öm
ləğv	əğ,ğv
milli	ll,li
mümkün	mk,kü
müxtəlif	ük,xt
mühüm	üh,hü
məqsədyönlü	dy,yö
mən	mə,ən
məşhur	şh,hu
məhz	əh,hz
naxçıvan	xç,ıv
neft	ef,ft
neçə	ne,çə
növbədə	nö,vb
nəzərdə	əz,rd
...	

Further, for every allophone the feature vector is calculated. The overall output of this process is a cepstral feature vector containing a subset of the cepstral coefficients [14],[21].

For checking the quality of the set of patterns, all the word from which these patterns are cut have been recognized by using this patterns. The results of this recognition process have indicated in the Table 5.

Recognition accuracy of the word-forms *Table 5*

Groups	Accuracy (%)	Number of recognized word
1.	100	292
2.	90-99	24
3.	80-89	226
4.	70-79	84
5.	60-69	52
6.	50-59	14
		692

The recognition accuracy of the every phoneme is indicated in the Table 6.

Recognition accuracy of phonemes *Table 6*

NN	Phoneme	The number of the phonemes	The number of the correctly recognized phonemes	The percentage of correct recognition
1.	J	65	63	96,92
2.	X	391	371	94,88
3.	P	419	397	94,75
4.	Ç	90	84	93,33
5.	K	69	64	92,75
6.	Ə	87	80	91,95
7.	A	74	68	91,89
8.	S	112	102	91,07
9.	Ğ	88	80	90,91
10.	Y	240	218	90,83
11.	D	74	67	90,54
12.	L	100	90	90,00
13.	E	130	117	90,00
14.	T	169	150	88,76
15.	Ş	137	121	88,32
16.	I	69	60	86,96
17.	Q	159	136	85,53
18.	M	135	115	85,19
19.	N	126	107	84,92
20.	F	208	176	84,62
21.	C	196	165	84,18
22.	H	64	53	82,81
23.	İ	357	293	82,07
24.	Ö	121	99	81,82
25.	V	54	44	81,48
26.	Z	161	131	81,37
27.	O	250	202	80,80
28.	G	19	15	78,95
29.	R	41	31	75,61
30.	U	121	90	74,38
31.	B	141	103	73,05
32.	Ü	124	88	70,97
		4591	3980	

For the phonemes which have the recognition accuracy less than 90%, are defined the left-allophones and all such allophones of these phonemes are added to the recognition units set. In this case we get the following results indicated in the Table 7 and Table 8.

Recognition accuracy of the word-forms *Table 7*

Groups	Accuracy (%)	Number of recognized word
1.	100	374
2.	90-99	33
3.	80-89	192
4.	70-79	59
5.	60-69	28
6.	50-59	6
		692

Recognition accuracy of phonemes *Table 8*

NN	Phoneme	The number of the phonemes	The number of the correctly recognized phonemes	The percentage of correct recognition
1.	J	19	19	100,00
2.	X	65	64	98,46
3.	P	69	67	97,10
4.	Ç	64	62	96,88
5.	K	137	131	95,62
6.	Ə	391	370	94,63
7.	A	419	396	94,51
8.	S	169	158	93,49
9.	Ğ	41	38	92,68
10.	Y	121	112	92,56
11.	D	161	149	92,55
12.	L	208	192	92,31
13.	E	126	116	92,06
14.	T	196	180	91,84
15.	Ş	90	82	91,11
16.	I	141	128	90,78
17.	Q	135	121	89,63
18.	M	159	142	89,31
19.	N	240	213	88,75
20.	F	69	61	88,41
21.	C	74	65	87,84
22.	H	87	76	87,36
23.	İ	357	311	87,11
24.	Ö	74	64	86,49
25.	V	88	76	86,36
26.	Z	100	86	86,00
27.	O	130	111	85,38
28.	G	54	46	85,19
29.	R	250	212	84,80
30.	U	112	93	83,04
31.	B	121	97	80,17
32.	Ü	124	97	78,23
		4591	4135	

Thus quality of recognition has been considerably improved. On the results of this research it is possible to say that the set of recognition units for the recognition of the Azerbaijani speech consists of about 1500 allophones (about 47 allophones per letter). The number of allophones for every phoneme could be reduced by replacing the feature vectors of group of phonemes with the feature vector of their centre by clustering allophone using decision tree.

5. Conclusion

As the Azerbaijani language is one of low density languages, such researches are not carried out for this language at all. Our research yields possibility to define the phoneme structure of the Azerbaijani more exactly than the theoretical researches carried out in 70s years of the previous centre. At present moment, the researches are carried out on the development of Azerbaijani speech recognition system and the set of allophones is used for the building of the acoustic model of the Azerbaijani language.

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Abulfat Fatullayev,for a photograph and biography, see Apl.Compt.Math. **4**(2005),no.1.,p.9.