
Journal of Engineering and Technology
DergiPark AKADEMİK

Journal of Engineering and Technology

Examining Vowels' Formant Frequency Shifts Caused by Preceding Consonants for Turkish Language

[1]Yunus Korkmaz, [2]Aytuğ Boyacı

[1,2]Department of Digital Forensics Engineering, Fırat University Elazığ, Turkey,

ARTICLE INFO

Article history:
Received 24 Nov 2018
Received in revised form 12 Dec 2018
Accepted 13 Dec 2018
Available online 28 Dec 2018

Key words:
Speech Processing
Formant Frequency Shifts
Vowels
Plossive Stop Consonants
Turkish Language

* Corresponding author.
E-mail address:
ykorkmaz@firat.edu.tr

ABSTRACT

Formant frequency of vowels in a language is considered as one of the important acoustical parameter of speech signal. This parameter can be seen as acoustic resonance of human vocal tract. Although formant frequencies which is changeable across genders, age, and languages have been studied for various purposes by many researchers in some languages, alteration effects of stop consonants on adjacent vowels hasn't been worked yet for Turkish language. In this study, formant frequency values (F1, F2 and F3) of eight isolated vowels (/a/, /e/, /ı/, /i/, /o/, /ö/, /u/, /ü/) have been compared to formant frequency values of vowels that come after any stop consonant (/p/, /t/, /k/, /b/, /d/, /g/) to detect any changes caused by stop consonants in formant frequencies. Totally 48 meaningful Turkish syllables (combinations of all stop consonants and all vowels) and 8 isolated vowels have been uttered by 10 male speakers three times repeatedly for each unit. At the end of this study, the plosive stop consonants /p/ and /g/ among others have been found as the ones having most alteration effects on F1 value of adjacent vowel /a/ in a CVC-context syllable. F2 of isolated vowel /a/ has been shifted up with /k/ and /g/ visibly. Also, F3 of /a/ has been shifted down by approximately 150 Hz with the same plossive stop consonants /k/ and /g/. These findings can help researchers studying on formant frequencies of vowels in Turkish language in order to specify right syllables to deal with.

1. Introduction

The concept of formant is defined as the concentration of sound wave energy in a certain frequency while formant frequency is frequency value where this concentration occurs. Formant frequency values depend on human vocal tract. Because individuals have different shape of vocal tract, formant frequencies can vary accross people [1]. Therefore formants are known as distinctive frequency components of the acoustic signal produced by human speech. The overall distribution of formant frequencies in speech is related to vocal tract length [2].

The main energy source of human speech is lungs. During speaking, air flow is passed through glottis between vocal cords and larynx to the three main cavities of the vocal tract, which are pharynx, oral and nasal cavities. Airflow leaves vocal tract from oral cavity by the mouth and from nasal cavity by the nose as in Fig. 1 which demonstrates the human speech production system. In this system, the vocal cords mainly modulate air flow by opening and closing in a rapid manner. They are formed in different shapes during speech. For the stop consonants (/p/, /t/, /k/, /b/, /d/, /g/), vocal cords are opened suddenly while they stay in a completely closed position. On the contrary, they are entirely open with unvoiced consonants, such as /s/ or /f/, and they can be found open and vibrating while uttering vowels [3].

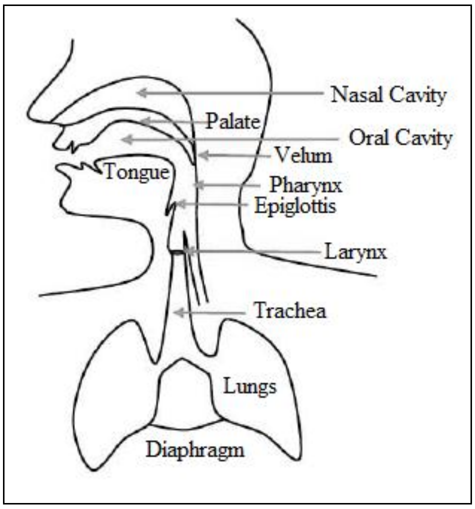

Figure 1. Human speech production system [17].

There are several formant (F1, F2, F3 etc.) at different frequencies in speech signal. They are available roughly in each 1000 Hz band. In vocal tract, each formant frequency corresponds to any resonance. Differences in these formant frequencies can be used to distinguish vowels. According to Ladefoged (2006), each vowel has 3 formants F1, F2, F3 and first two formants can characterize the vowel. F1 is inversely proportional related to vowel height, and F2 is related to vowel backness. In this work, we have analyzed the changes caused by stop consonants in F1, F2 and F3 of each vowel for Turkish language [4]. Formants can be detected visually in wideband spectrogram. The spectrograms of all isolated Turkish vowels uttered by a 22-years-old male Turkish speaker are shown in Fig. 2. In spectrograms, dark horizontal lines represent formant frequencies. Because oral constrictions which occur during consonants have antiresonances that eleminate formants in the vocal tract at one or more frequencies, measurement process is easier for the oral vowel sounds than consonantal or nasal sounds [5].

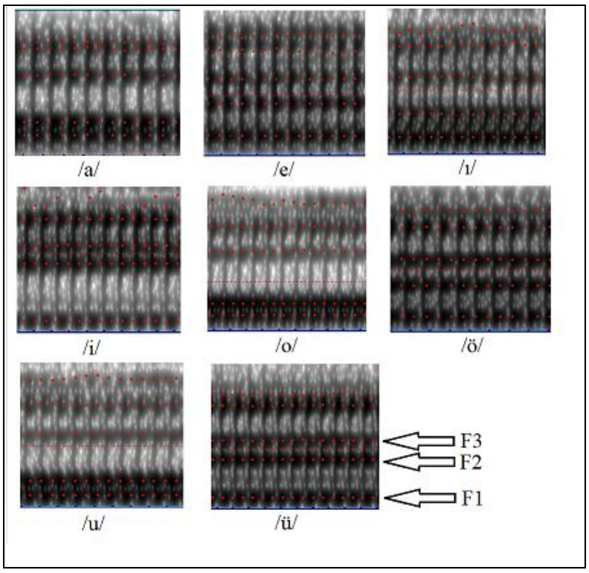

Figure 2. Spectrogram of all Turkish isolated vowels obtained by Praat software.

The purpose of this study is to discover changes in vowel's formant frequencies when they are used with stop consonants in a CVC context. In the second section, studies related to the formant frequencies of vowels and literature gap for Turkish language are mentioned in detail. In third section, information about subjects participated in this study, speech recordings, uttered speech samples and analysis methods are explained respectively. Then in the next section, results are discussed considering present studies. In the last section, future studies and some advices are mentioned to conclude our work.

2. Related Works

The formant frequency values of vowels have been studied by many researchers for different languages in the literature. The topics that these works vary from finding formant frequencies of vowels to detect formant frequency differences of foreign accented languages. The main fields of interests related to formant frequencies are identifying formant frequencies of vowels in a spesific language, comparing languages in terms of formant values, determining the vowel quadrilateral (vowel diagram) and finding age and gender cues in formant frequencies, that is speaker characterization.

There are only a few studies in literature for the Turkish language and none of them is related to formant frequency alteration effects of stop consonants on adjacent vowels. Türk O., Şayli Ö., Özsoy A.S. and Arslan L.M. have examined formant frequencies of Turkish vowels. In their study, they have worked with 15 adult males, 14 adult females, 15 boy children and 8 girl children. As a result of their study, they have found that formant frequencies of F1 and F2 are discriminative features for adults and distinguishing children gender by formant frequencies is a harder issue than distinguishing adults' gender by formant frequencies [6]. Malkoç E. has determined formant frequency range of Turkish vowels uttered by males and females. He has also tried to compare the vowel diagram acquired by bark values to the vowel diagram that he has obtained using formant frequencies in order to detect any difference related with of vowels' oral exit locations [7]. In [8], Manwa L.N., Chen Y. and Sadaka J. have anayzed vowel features in Turkish accented English. Two formant frequencies (F1 and F2) have been extracted from 11 English monophthong vowels acquired from 20 Turkish accented English bilinguals and 20 native American speaker in their work. They have used Euclidean distance to measure distinction between these two types of speakers. In another work, Hunter G. and Yarkiner J. have studied formant frequency values of British English vowels produced by Cypriot Turkish. They have used vowels in words within a carrier phrase. Similar to previous studies, F1 and F2 formants of vowels has been measued to deal with. They have compared results to measurements of British English and Turkish vowels produced by L1 (first language) speakers from previous studies [9]. Formant frequencies have also been examined to indicate the amount of misarticulation in bilinguals' speech. In a work titled "Pronunciation of English vowels of native Turkish speakers", Sadaka J. and Manwa L.N. have studied on effects of the first language (L1) over the target language (L2) considering F1 and F2 formant frequencies of 20 males Turkish speakers [10]. They have used all english vowels in /hVd/ context, and deteremined F1 and F2 values have been compared to native English speakers. At the result of their study, F1 and F2 values of the Turkish accented English vowels have been found to be slightly different from those produced by native English speakers. At the earliest of studies related to vowels' formant frequencies, Kılıç M.A. has investigated acustical and perceptional characteristics of 8 vowels in Turkish language [11]. He has also given a prediction about which IPA (International Phonetic Association) symbols are appropriate for Turkish vowels in phonemic transcription. In conclusions of Kılıç M.A.'s study, it has been emphasised that using [ɑ], [ɛ], [ɯ], [i], [ɔ], [œ], [u] and [y] IPA symbols for *a, e, ı, i, o, ö, u* and *ü* vowels respectively would be more suitable for Turkish language.

In addition to studies in Turkish language, there are many studies related formant frequency of vowels for other languages in the literature. Contribution of voice fundamental frequency and formants to gender [12], formant analysis of vowels in Kurdish language [13], the comparisons between the formants values in French and Romanian [14], the effect of age on formant frequencies of Malay children between 7-12 [15] and vowel detection by formant frequencies [16] are just some of them. However, the effects of stop consonants on adjacent vowels for Turkish language haven't been analyzed yet. Therefore in this study, it is aimed to examine formant frequency alteration effects of plossive stop consonants on adjacent vowels in Turkish language.

3. Materıals and Methods

The materials and methods section consists of four sub-sections. Information about syllables is given in first sub-section. Then, speakers who have participated in this study are mentioned in the second sub-section. The third sub-section mentions about how recordings have been acquired. and analysis method of formant frequency extration from syllables is referenced at the last part.

3.1.Syllables

To see formant frequency alteration effects of all consonants on all vowels, we have selected syllables which formed as combination of six plosive consonants (/p/, /b/, /t/, /d/, /k/, /g/) and eight vowels (/a/, /e/, /ı/, /i/, /o/, /ö/, /u/) in CVC context which means that all syllables start with a consonant followed by a vowel and end with another consonant. Each of the syllables has been uttered 3 times repeatedly by a speaker. This is because of the fact that any speech disorder can occur while recording. Same acquisition methods has been applied on isolated vowels too. In our dataset, there are totally 48 meaningful syllables including all possible combinations of stop consonants and vowels. Also we used 8 isolated vowels to detect the formant shift results. The selected syllables are shown below in Table 1, and the vowels available in Turkish Language are shown in Table 2.

Table 1. Selected Syllables.

Vowels	Stop Consonants					
	/ p /	/ b /	/ t /	/ d /	/ k /	/g/
/ a /	pas	bal	tas	dal	kar	gar
/ e /	pek	bez	tek	def	kem	gen
/ ı /	pır	bık	tın	dış	kır	gık
/ i /	pil	bir	tik	dik	kim	git
/ o /	poz	boş	tor	doz	kol	gol
/ ö /	pöç	böl	tör	dök	köz	göl
/ u /	put	buz	tuz	dur	kul	gut
/ ü /	pür	bük	tül	düz	küs	güz

Table 2. Isolated Vowels ın Turkısh Language.

Isolated vowels							
/ a /	/ e /	/ ı /	/ i /	/ o /	/ ö /	/ u /	/ ü /

3.2.Speakers

In this study, we have worked with 10 volunteer male speakers. They are all monolingual Turkish-speaking (as native language) university students. The reason behind this is that in bilingual people speech, there may occur misarticulation originated from L1 or L2, and this misarticulation can cause incorrect formant shifts, so the results can be partially inaccurate [10]. All of the speakers are from East region of Turkey and non-smokers. Because gender and age may affect formant frequency values, we have included only males in this work, and we have kept age range in small interval (it ranges between 19 and 25). The average age is 21.8 for ten speakers.

3.3.Acquisition of Utterances

Speech samples have been acquired in a room with a quiet environment (with the normal room level of noise) by using Digital Recorder mobile application existing in IPhone App Store for IPhone 5s. All samples have been recorded first with .m4a extension, then converted to .wav for compatible analyzing via Praat software which is an open source advanced tool for speech processing. Sampling rates of recordings have been set to 44.1 kHz. The recorder has been kept at approximately 20 cm away from speakers' mouth. These conditions are same for all the speakers.

3.4.Analysis

Formant frequency estimation has been performed by Praat software automatically on spectrogram of speech signals. This is a visual extraction process. In literature, there are some other formant frequency extraction methods available. The LPC (Linear Predictive Coding), MFCC (Mel-Frequency Cepstrum Coefficient) and PSD (Power Spectrum Density) are just a few of them. However, using visual way (by Praat) to get formant frequencies is more preferable for the consistent results. Extracting vowel region in a whole syllable have been done by manually with the same software. The reason of manual extraction is to obtain stable region, where formant trajectories draw a nearly straight horizontal line (red dots) as shown in Fig. 3, for formant analysis. A spectrogram window for syllable "bal", means "honey" in English, is given in Fig. 3. The straight horizontal lines consisting of red dots show the formant frequencies F1, F2, F3, F4 and F5 belongs to vowel /a/ comes after stop /b/. As indicated in majority of the studies related to formant frequency, using only first three formants (F1, F2 and F3) is enough for vowel distinction. Also, spectrogram of an isolated vowel /a/ is shown in Fig. 4. Both of two speech samples have been uttered by a 20-years-old male speaker.

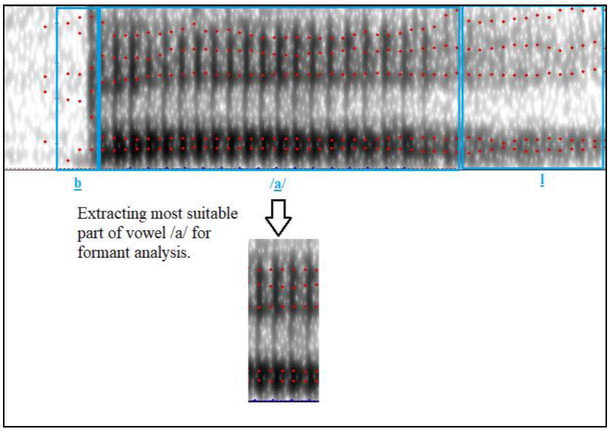

Figure 3. Manual extraction of most stable region in spectrogram of "bal" syllable uttered by a male speaker.

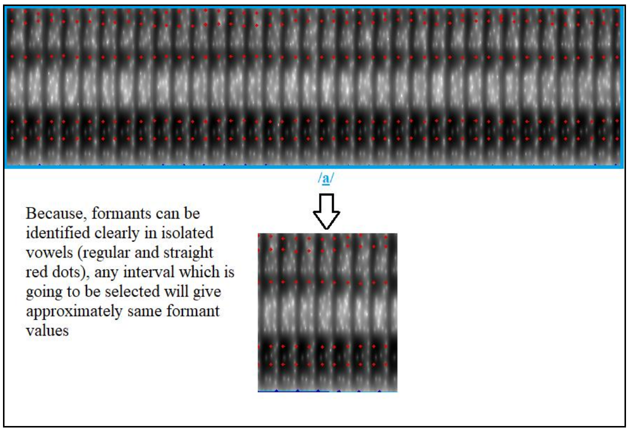

Figure 4. Spectrogram of isolated vowel /a/ uttered by a male speaker and formant trajectories.

4. Results and Discussions

The average formant frequencies (all in Hertz) of vowels within every syllables have been given in Table 3. The value in each cell of Table 3 is average of related formant frequencies 10 male speakers.

Table 3. Average Formant Frequency Values Of Vowels in Each Syllable.

Vowel	**Syllables**	**Formants Frequencies (Hz)**		
		f1	***f2***	***f3***
/ a /	***pas***	679	1125	2678
	bal	646	1036	2783
	tas	654	1177	2752
	dal	645	1060	2771
	kar	646	1210	2560
	gar	624	1201	2528
/ e /	***pek***	498	1845	2604
	bez	497	1750	2602
	tek	474	1861	2614
	def	498	1780	2614
	kem	581	1704	2531
	gen	561	1768	2577
/ ı /	***pır***	438	1427	2456
	bık	417	1434	2479
	tın	432	1460	2465
	dış	394	1675	2547
	kır	428	1501	2366
	gık	399	1544	2360
/ i /	***pil***	314	2070	2914
	bir	297	2084	2869
	tik	318	2049	2833
	dik	294	2091	2899
	kim	352	2077	2886
	git	303	2080	2907
/ o /	***poz***	499	841	2748
	boş	485	826	2719
	tor	520	889	2657
	doz	500	897	2793
	kol	508	844	2667
	gol	492	884	2577
/ ö /	***pöç***	462	1434	2343
	böl	477	1387	2388
	tör	496	1333	2397
	dök	451	1539	2373
	köz	469	1465	2307
	göl	481	1428	2321
/ u /	***put***	413	895	2685
	buz	391	832	2695
	tuz	392	982	2617
	dur	378	985	2597
	kul	385	875	2656
	gut	374	968	2457
/ ü /	***pür***	370	1622	2323
	bük	315	1772	2293
	tül	340	1714	2300
	düz	313	1701	2386
	küs	335	1752	2290
	güz	301	1829	2311

In Table 4, formant frequency values (*f1*, *f2* and *f3*) of isolated vowels averaged from 10 male Turkish speakers have been given to make a clear comparision with results indicated in Table 3.

Table 4. Isolated Vowels' Formant Frequencıes.

Vowel	Formant Frequencies (Hz)		
	f1	*f2*	*f3*
/ a /	643	1089	2708
/ e /	526	1768	2571
/ ı /	425	1381	2472
/ i /	303	2123	2861
/ o /	499	852	2762
/ ö /	473	1440	2404
/ u /	339	838	2537
/ ü /	313	1698	2371

As we can infer from the results, plossive stop consonants of *p* and *g* affect *f1* value on adjacent vowel /*a*/. When we consider *f2* of */a/*, we can easily see that *f2* of isolated vowel */a/*, which is 1089 Hz, has been shifted up more than 100 Hz with *k* and *g* stop consonants. Also, *f3* of */a/* has been shifted down by approximately 150 Hz with the same plossive stop consonants *k* and *g*. These findings are just related to the alteration effects of plossive stop consonants on vowel /a/ in Turkish language.

For the vowel /*e*/, plossive stop consonant of *t* shifted *f1* down to 52 Hz that is 10%, and nearly 100 Hz increase in *f2*. Also, the *k* caused an over 10% rise in *f1* of /*e*/. All the plossive stop consonants except *k* made *f3* to be measured as higher than its isolated value. Additionally, it is seen that plossive stop consonant of *g* has almost no change effects on formants of /*e*/.

When we examine the vowel /*ı*/, it is clearly seen that all the stop consonants have shifted *f2* of /*ı*/ up, and the most considerable increment was done by *d* caused over 20% jump. Also *f3* of /*ı*/ have been shifted down approximately 110 Hz, that is 5%, by *k* and *g* stop consonants.

If the vowel /*i*/ is considered, consonant *k* has increased *f1* of /*i*/ over 15%. Another change in formants of /i/ is that all the stop consonants have shifted *f2* of /*i*/ down. Furthermore, there is no remarkable shift in *f3* of /*i*/ even it follows any plossive stop consonant.

Compared to other vowels, the vowel /*o*/ have been identified as the least affected vowel by any preceding plossive stop consonants. There is no noteworthy shifts measured on formants of vowel /*o*/. Only the plossive consonant of *g* let *f3* of /*o*/ to shift down by 7%. This indication implies that one working on formant frequencies of Turkish vowels can ignore shift effect of any plossive stop consonant.

For the vowel /*ö*/, none of the plossive consonant have significiant effect on formant of *f1*. The plossive *d* has shifted *f2* of /*ö*/ up by 7%, on the contrary the plossive *k* shifted it down by the same percentage. All the stop consonants have shifted *f3* of /*ö*/ down, but with a negligible rate, that is under 5%.

The *f1* of vowel /*u*/ has been shifted up by all the plossive consonants. The most noticeable increase has been originated by the consonant of *p*, and the rate in this increase is roundly 22%. The *f2* of /*u*/ has been ascended by preceding consonants of *t*, *d* and *g* with a rate between 15% and 20%. Plossive stop consonants have no perceptible impact on *f3* of /*u*/.

Lastly when looking at the analysis results related to the vowel of /*ü*/, it can be clearly seen that consonant of *p* has rised the *f1* value of /*ü*/ by about 18%. The *f2* value has been increased by all plossive stop consonants except *p*, and none of the consonants has considerably affected *f3* of subsequent /*u*/.

Here, it should be remarked that formant frequencies which can be clearly identified during vowels occur by the airflow originated from lungs, and this airflow never encounters an obstacle through vocal tract up to exit (in this situation, it is an isolated vowel). So, it is obviously clear that the reason behind these results is that plossive stop consonants arising in oral cavity have shift effects on formant frequencies of vowels in mentioned airflow.

5.Conclusions

In this work, the effects of stop consonants on adjacent vowel have been analyzed to discover formant frequency alterations for Turkish language. Because formant frequency of a vowel can vary according to the speaker's vocal path characteristic features, factors such gender, age, state of health, monolinguality etc. have been delimited to be same for all speakers involved in this study. In the further studies, speaker's gender effects on vowel's formant frequencies may also been analyzed in addition to stop consonants effects on vowel's formant frequencies, so that choosing right syllabes and speakers profile will increase the accurateness of any study related to formant frequencies of vowels in Turkish language. This study has been achieved in normal room environment, one may consider same study in completely noise-free environment and see whether the results are same or not. Besides using Praat for feature extraction process, it is also possible to done any further study using LPC, MFCC and PSD as alternative ways to obtain formant frequencies. Only effects of plossive stop consonants have been analyzed in this work, but the effects of other consonants still stay mysterious. This is also a study which should be done in future by a formant frequency researcher. Additionally, using more speakers or speech samples, which means "data" in computer science, will end with more accurate results. Last of all, this work showed that a researcher studying on vowel's formant frequencies for any purpose should choose right syllabes to deal with.

Acknowledgement

Data in this paper was previously published as a conference paper in "International Engineering and Technology Symposium (IEST'18), May 2018".

6. References

[1] Korkmaz, Y. and Boyacı, A., "Adli Bilişim Açısından Ses İncelemeleri", Science and Engineering Journal of Fırat University, 30(1), pp.329-343, 2018.

[2] Fitch, W.T.S., "Vocal Tract Length Perception and the Evolution of Language", *PhD.Thesis*, Department of Cognitive and Linguistic Sciences at Brown University, 1994.

[3] Phonetics and Theory of Speech Production, Retrieved April 02, 2018, http://research.spa.aalto.fi/publications/theses/lemmetty_mst/chap3.html

[4] Acoustic Analysis of Vowels, Retrieved April 02, 2018, from http://ec-concord.ied.edu.hk/phonetics_and_phonology/wordpress/learning_website/chapter_2_vowels_new.htm

[5] What are formants?, "Praat for beginners", Retrieved April 02, 2018, from http://person2.sol.lu.se/SidneyWood/praate/whatform.html

[6] Türk, O., Şayli, Ö., Özsoy A.S. and Arslan L.M., "Türkçe'de Ünlülerin Formant Analizi", *18.Ulusal Dilbilim Kurultayı*, Ankara Üniversitesi, 2004.

[7] Malkoç, E., "Türkçe Ünlü Formant Frekans Değerleri ve Bu Değerlere Dayalı Ünlü Dörtgeni", Ankara Üniversitesi Dil Dergisi, 146, pp.71-85, 2010.

[8] Manwa, L.N., Chen, Y. and Sadaka, J., "Vowel features in Turkish accented English", International Journal of Speech-Language Pathology, 10(6), pp.404-413, 2008.

[9] Hunter, G. and Yarkiner, Z., "Formant frequencies of british english vowels produced by native speakers of Cypriot Turkish", Proceedings of the Institute of Acoustics, 36, pp.452-459, 2014.

[10] Sadaka, J. and Manwa L.N., "Pronunciation of English vowels of native Turkish speakers", The Journal of the Acoustical Society of America, 119(5), 3423, 2006.

[11] Kılıç, M.A., "Türkiye Türkçesi'ndeki Ünlülerin Sesbilgisel Özellikleri", Studies in Turkish Linguistics, Proceedings of the Tenth International Conference in Turkish Linguistics, pp.3-18, 2003.

[12] Siu-Fung, P. and Manwa, L.N., "Contribution of Voice Fundamental Frequency and Formants to Gender", *The 17th International Congress of Phonetic Sciences*, Hong Kong, China, 2011.

[13] Dinler, Ö.B. and Karabiber, F., "Formant Analysis of Vowels in Kurdish Language", *25th Signal Processing and Communications Applications Conference*, Antalya, Turkey, 2017.

[14] Feraru, S.M., "The Comparisons Between the Formants Values in French and Romanian", *6th International Conference on Languages, E-Learning and Romanian Studies*, Isle of Marstrand, Sweden, 2012.

[15] Zourmand, A., Mahmoudi, A., Marimuthu, J. and Ting, H.N., "The Effect of Age on Formant Frequencies of Malay Children Between 7-12", *The 3rd International Conference on Intelligent Systems Modelling and Simulation*, Kota Kinabalu, 2012.

[16] Gokulan, M., Gandhi, M., Joshi, S. and Karamchandani, S., "Objective Speech Analysis and Vowel Detection", *The 15th International Conference on Communication Technology*, Guilin, China, 2013.

[17] Goswami, S., Deka, P., Bardoloi, B. and Sarma D., "ZCR Based Identification of Voiced, Unvoiced and Silent Parts of Speech Signal in Presence of Background Noise", *International Conference on Computation and Communication Advancement*, JIS College of Engineering, India, 2013.