Acoustic analysis of Bangla vowel inventory

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Abstract

This paper describes the acoustic characteristics of Bangla vowels, obtained by analyzing the recordings of male and female voices. First, the duration of each phoneme was identified by averaging both the male and female voice data; then, formants were analyzed for all the phonemes and finally vowel phoneme inventory was designed and presented in this paper.

1 Introduction

The goal of this paper is to determine the total number of vowel phonemes (includes monophthons and diphthongs) and their acoustic properties in Bangla language. A monophthong (Ladefoged P., 2002) is a vowel in which there is no appreciable change in quality during a syllable. A diphthong (Ladefoged P., 2002) is a vowel in which there is a change in quality during a single syllable. This analysis is an essential component in linguistic of a language and in the diphone concatenation technique where proper duration and prosodic characteristics are needed to synthesize natural sounding speech. With nearly 200 million native speakers, Bangla (exonym: Bengali) is one of the most widely spoken languages of the world (it is ranked between four[1] and seven[2] based on the number of speakers). There have been quite a few articulatory investigations on Bangla phonemes during the last several decades. These analyses have resulted in a set of phoneme inventories. This study is focused on acoustic evidences of Bangla vowel phonemes based on the acoustic cues of Pickett (1998) and durational characteristics. Acoustic evidence is the perfect cue to identify front, back, low, high, duration and other important features in vowel phoneme. The durational and formants characteristics were measured for each classes of vowel phoneme. A list of dictionary word containing all possible vowel phonemes was selected for recording in different syllabic patterns. The carrier sentence was designed using the listed words. These sentences were then recorded by both male and female speakers. The recording data was analyzed with the help of Praat (2007).

A brief literature review is given in section 2, followed by a description of the methodology in section 3. The analytical results are presented and discussed in section 4. A summary and conclusions of the study are given in section 5.

2 Literature Review

There have been several studies in the past, mostly based on articulatory phonetics, of the articulatory and acoustic properties of Bangla vowels. Abdul Hai (1967, pp-12-35) showed the following monophthongs: ই/i/, এ/e/, এ্যা/æ/, আ/a/, অ/ɔ/, ও/o/, ঔ/ou/ উ/u/. He also mentioned these phonemes can be nasal in Bangla but less frequent. Manzur Morshed A. K. (2001, pp-219-237) has shown the following monophthongs ই/i/, এ/e/, এ্যা/æ/, আ/a/, অ/ɔ/, ও/o/, উ/u/, ইঁ/ĩ/, এঁ/ẽ/, এ্যাঁ/æ̃/, আঁ/ã/, অঁ/ɔ̃/, ওঁ/õ/, উঁ/ũ/. Daniul Huq (2002, pp-81-93) showed the same number of monophthongs as Abdul Hai (1967) showed. According to Zeenat Imtiaz Ali (2001, pp-67-91) Bangla have the following monophthongs ই/i/, এ/e/, এ্যা/æ/, আ/a/, অ/ɔ/, ও/o/, উ/u/, ইঁ/ĩ/, এঁ/ẽ/, এ্যাঁ/æ̃/, আঁ/ã/, অঁ/ɔ̃/, ওঁ/õ/, উঁ/ũ/ (14 monophthongs). We have selected all 14 monophthongs from the published studies in this analysis.

Several studies explained Bangla diphthongs based on the articulatory phonetic technique. The number of diphthongs is significantly distinct among them. Abdul Hai (1967, pp-12-35) told about 31 diphthongs whereas Manzur

[1] http://www2.ignatius.edu/faculty/turner/languages.htm, Last accessed December 26, 2007.

[2] http://en.wikipedia.org/wiki/List_of_languages_by_total_speakers, Last accessed December 26, 2007.

Morshed A. K. (2001, pp-219-237) showed 29, Rameswar Shaw (1988, 291-331) and Sunitikumar Cottopadhay (1989) said about 25. On the other hand Pobitro Sarkar (1985-86) said only 17 diphthongs.

The diphthong vowel phoneme list used in this study is basically the union of all diphthongs from the published studies. Table 1 shows the result of union operation.

Serial No	Union	Abdul Hai (1967, pp-12-35)	Rameswar Shaw (1988, 291-331)	Manzur Morshed A. K. (2001, pp-219-237)	Sunitikumar Cottopadhay (1989)	Pobitro Sarkar (1985-86)
1.	অআ /ɔa/	অয়া /ɔa/	অআ /ɔa/	অআ /ɔa/		
2.	অএ /ɔe/		অএ /ɔe/	অএ /ɔe/		অএ /ɔe/
3.	অও /ɔo/	অও /ɔo/	অও /ɔo/	অও /ɔo/	অও /ɔo/	অও /ɔo/
4.	অওয়া /ɔa/				অওয়া /ɔa/	
5.	অয় /ɔj/	অয় /ɔj/			অয় /ɔe/	
6.	অ্যাএ, এ্যাএ /æe/		অ্যাএ /æe/	এ্যাএ /æe/		এ্যাএ /æe/
7.	আআ/ আয়া /aa/			আআ /aa/		
8.	আই /ai/	আই /ai/	আই /ai/	আই /ai/	আই /ai	আই /ai/
9.	আউ /au/	আউ /au/	আউ /au/	আউ /au/	আউ /au/	আউ /au/
10.	আএ /ae/		আএ /ae/	আএ /ae/		আএ /ae/
11.	আও /ao/	আও /ao/	আও /ao/	আও /ao/	আও /ao/	আও /ɔo/
12.	আয় /aj/	আয় /aj/			আয় /ae/	
13.	ইঅ /iɔ/			ইঅ /iɔ/		
14.	ইআ /ia/	ইয়া /ia/	ইআ /ia/	ইআ /ia/	ইয়া /ia/	
15.	ইই/ii/	ইই /ii/		ইই /ii/		ইই /ii/
16.	ইউ	ইউ	ইউ	ইউ	ইউ	ইউ
	/iu/	/iu/	/iu/	/iu/	/iu/	/iu/
17.	ইএ /ie/	ইয়ে /ie/	ইএ /ie/	ইএ /ie/	ইএ /ie/	
18.	ইও /io/	ইও /io/	ইও /io/	ইও /io/	ইও /io/	
19.	উআ /ua/	উয়া /ua/	উআ /ua/	উআ /ua/	উয়া /ua/	
20.	উই /ui/	উই /ui/	উই /ui/	উই /ui/	উই /ui/	উই /ui/
21.	উউ /uu/	উউ /uu/				
22.	উএ /ue/	উয়ে /ue/	উএ /ue/	উএ /ue/	উয়ে /ue/	
23.	উয়ো /uo/	উয়ো /uo/	উও /uo/	উও /uo/	উও /uo/	
24.	এই /ei/	এই /ei/	এই /ei/	এই /ei/	এই /ei/	এই /ei/
25.	এউ /eu/	এউ /eu/	এউ /eu/	এউ /eu/	এউ /eu/	এউ /eu/
26.	এএ /ee/			এএ /ee/		
27.	এও /eo/	এও /eo/	এও /eo/	এও /eo/	এও /eo/	
28.	এয়া /ea/	এয়া /ea/	এআ /ea/	এআ /ea/	এয়া /ea/	
29.	এ্যাও /æo/	এ্যাও/ æo/	অ্যাও /æo/	এ্যাও/æ o/	অ্যাও /æo/	এ্যাও/ æo/
30.	এ্যায় /æj/	এ্যায় /æj/			অ্যায় /æe/	
31.	এ্যায়া /æa/	এ্যায়া /æa/				
32.	এয়ো /eo/	এয়ো /eo/				
33.	ওই /oi/	ওই /oi/	ওই /oi/	ওই /oi/	ওই /oi/	ওই /oi/
34.	ওউ /ou/	ওউ /ou/	ওউ /ou/		ওউ /ou/	ওউ /ou/
35.	ওও /oo/	ওও /oo/				ওও /oo/
36.	ওয় /oj/	ওয় /oj/			ওয় /oe/	
37.	ওয়া /oa/	ওয়া /oa/	ওআ /oa/	ওআ /oa/	ওয়া /oa/	
38.	ওয়ে /oe/	ওয়ে /oe/	ওএ /oe/	ওএ /oe/		ওএ /oe/

Table 1: Diphthong list after applying the union operation on different studies

Out of them, we eliminated 5 diphthongs. These are sl. no. 2, 4, 6, 10, and 13. Followings describe why these diphthongs were eliminated.

Sl. No. 2: Here Manzur Morshed A. K. (2001, pp-219-237), Rameswar Shaw (1988, 291-331)

and Pobitro Sarkar (1985-86) said about the diphthong অএ/ɔe/. As an example, Manzur Morshed A. K. (2001, pp-219-237) showed the example of word শোয়, ধোয় and Rameswar Shaw (1988, 291-331) showed the example of word ছয় and Pobitro Sarkar (1985-86) represented as ভয়. According to them the pronunciation of these words are শোয়/ʃɔe/, ধোয়/d^hɔe/, ছয়/c^hɔe/, ভয়/b^hɔe/ but the correct pronunciation of these words are শোয়/ʃoj/, ধোয়/d^hoj/, ছয়/c^hɔj/, ভয়/b^hɔj/. The diphthongs /ɔj/ is already in sl. no. 5 and /oj/ is already in sl. no. 36.

Sl. No. 4: Here Sunitikumar Cottopadhay (1989) said about the diphthong অওয়া. As an example, he showed the example of word সওয়া. According to him the pronunciation of the word is সওয়া/ʃɔa/ where the correct pronunciation of the word is সওয়া/ʃɔoa/. The diphthong /ɔo/ is already in sl. no. 3.

Sl. No. 6: Here Rameswar Shaw (1988, 291-331) and Manzur Morshed A. K. (2001, pp-219-237) said about the diphthong অ্যাএ, এ্যাএ/æe/. As an example, Rameswar Shaw (1988, 291-331) presented the word দেয় and Manzur Morshed A. K. (2001, pp-219-237) demonstrated the word ব্যয়, নেয়, দেয়. According to him the pronunciation of the words are দেয়/d̪æe/ ব্যয়/bæe/, নেয়/næe/ but the correct pronunciation of the words are দেয়/d̪æj/ ব্যয়/bæj/, and নেয়/næj/. The diphthong /æj/ is already in sl. no. 30.

Sl. No. 10: Here Rameswar Shaw (1988, 291-331) and Manzur Morshed A. K. (2001, pp-219-237) explained the diphthong আএ/ae/. Manzur Morshed A. K. (2001, pp-219-237) showed the example of word খায়, চায়, নায় and Rameswar Shaw (1988, 291-331) represented the word খায়. According to them the pronunciation of these words are খায়/k^hae/, চায়/cae/, নায়/nae/ but the correct pronunciation of these words are খায়/k^haj/, চায়/caj/, নায়/naj/. The diphthongs /aj/ is already in sl. no. 12.

Sl. No. 13: Here Manzur Morshed A. K. (2001, pp-219-237) said about the diphthong ইঅ/iɔ/. As an example, Manzur Morshed A. K. (2001, pp-219-237) showed the example of word নিয়ন্তা/niɔn̪ta/. The correct pronunciation of this word is নিয়ন্তা/nion̪ta/. The diphthongs /io/ is already in sl. no. 18. The correct pronunciation has taken from Byabaharik Bangla Abhidhan (Bangla Academy. 1992).

Couple of studies by Hossain et. al. (2004, 2005, 2007) shows acoustic properties of Bangla vowel. They showed six vowels (Hossain et. al., 2004, 2007) and seven vowels (Hossain et. al., 2005) in Bangla also represented acoustic space of Bangla vowels. Their studies does not mentioned about nasal and diphthong vowels.

3 Methodology

This study seeks to find the answer of the following two questions to develop Bangla vowel phoneme inventory: (1) to determine the diphthongs; (2) to determine duration and formant characteristics of the vowels in spoken Bangla utterances for the phoneme inventory. A list of dictionary word embedded in carrier utterances was chosen for analysis. Different patterns were selected for identifying the list of word. This data was recorded by number of speakers and analyzed by praat software.

3.1 Recording material

Three different patterns were selected with nearest number of phoneme segment in each pattern. Each pattern carried two to three syllables. The main intuition of selecting these patterns was duration calculation and formant measurement of vowels. These patterns are:

1. cV.Cv.cvc where V is the target vowel and C is either voiced or voiceless plosive.
2. cV.v.cvc where V is the target vowel
3. cV?V.Cvc where V?V indicates diphthong C is either voiced or voiceless plosive.

The tricky part was the data collection comprising these patterns. For each pattern we have selected four words from Byabaharik Bangla Abhidhan (Bangla academy, 2005) to make balance of recording data. For the first pattern the C of second syllable is voiced plosive in two words and voiceless in two words. The reason behind this is that the vowel before voiced is longer than the voiceless plosive (Pickitt, 1998, pp-87). So we will get average duration in both cases. For the second pattern we were unable to find any word from Byabaharik Bangla Abhidhan (Bangla academy, 2005).

Then we changed the pattern to v.v.cv.cvc, as the main intention of this pattern was to calculate the duration of the two consecutive vowels appears in two syllables. But with this new pattern we got only two words. For the third pattern, four words were selected for each target diphthong. But due to word limitation of this pattern, the first consonant of the second syllable was chosen arbitrarily. In some cases we got only two words then we repeated these two to make it four which was our balancing criteria for all phonemes in this analysis. Then another two carrier words were embedded to form sentences. For example

এখন গবেষক বলো

ek^{h}on kɔ̤dahar bɔlo

Now researcher say.pres

[Say researcher now]

The middle word is our target word. The list of words selected for this investigation consist all possible phonemes with the above patterns, embedded in carrier words to form the utterances. So as a total 192 utterances were designed for recording with the following form for the above three patterns:

1. 14x4 (14 possible phonemes x 4 words) = 56
2. 1x4 (1 phoneme x 4 words) = 4
3. 33x4 (33 possible phonemes x 4 words) = 132

   Total = 192 words

So the utterances were selected in such a way such that the prosodic variation (such as stress, tone, emphasis and vocal effort) and feature dependent segment duration do not have any effect on the target phoneme. Also, the manner of articulation was considered when these utterances were collected, as the manner of articulation is the usual first basis for segmentation or duration calculation. All listed word phonetically defined if required, an assertion that was confirmed by linguists.

3.2 Speaker selection

Both male and female speakers were selected by considering different ages, heights and the speakers' locality in Bangladesh. Unfortunately, we were unable to include any speaker from the Indian State of West Bengal in this analysis. We have selected three male and three female speakers. The speaker's ages between 25 to 29 years. Each speaker was given flash cards containing the utterances. Speakers were asked to record each utterance in a straight tone/pitch level and without assigning any stress in a word.

3.3 Recording

The recording of the utterances was done using the Nundo speech processing software. A professional recording studio was chosen to record the utterances. The equipment consisted of an integrated Tascam TM-D4000 Digital-Mixer, a high fidelity noise free Audiotechnica microphone and two high quality speakers. The recorded waveform files were used for acoustic analysis with Praat version 4.6.27. The speakers were asked to keep a distance of 10-12 inches from the microphone. The speech data was digitized at 44100 Hz at 24-bit resolution and stored as wave format. After each recording, the moderator checked for any wrong pronunciation during the recording, and if so, the affected utterances were re-recorded.

3.4 Analysis

Total 192x6 = 1152 (192 sentences x 6 speakers) segment were analyzed in this study. Scarborough R. (2005) showed a set of segmentation criteria (i.e beginning and ending position of each classes of phoneme), in her lecture which was considered when the duration was calculated using Praat. The duration for each phoneme was computed from the recorded voice. The start position of the vowel is the preceding stop release, if there is one; else onset of complex voicing (with higher frequency components). The end position of the vowel is the offset of higher-frequency components (low-frequency voicing during a following consonant does not count in vowel).

3.4.1 Monophthongs

The duration and formants F1, F2 and F3 were calculated for each monophthong vowel from the spectrogram. Formant chart was computed for monophthongs according to average value of F1 and F2 value. The front, back, rounded and unrounded vowel features were determined according to formants value. Final output is explained in the result section.

3.4.2 Diphthongs

The duration and formants also computed for each diphthong. The acoustic pattern of diphthongs changes gradually due to change in vocal tract configuration of the vowels forming the diphthongs. The diphthong has five critical points (Pickett, J.M. 1998, pp-70) where their formants present some meaningful information such as onglide, target 1, glide, target 2 and offglide. For example, in diphthong ওই (ঐ)/oi/, the target 1 is the first vowel of ও/o/, then target 2 is the second vowel of ই/i/ and the glide (transition) is from ও/o/ to ই/i/ of the vocal tract configuration. In our analysis, we have considered three critical points such as target 1, transition and target 2. To identify number of diphthong in Bangla we have followed three steps. First, we have looked the formants, whether three critical points exist on diphthongs or not. Second, we have made comparison on duration of the diphthong (third pattern) and the duration of two vowels (second pattern). In the third step, target 2 formants were checked for each diphthong to check whether the target 2 belongs to the approximant or not.

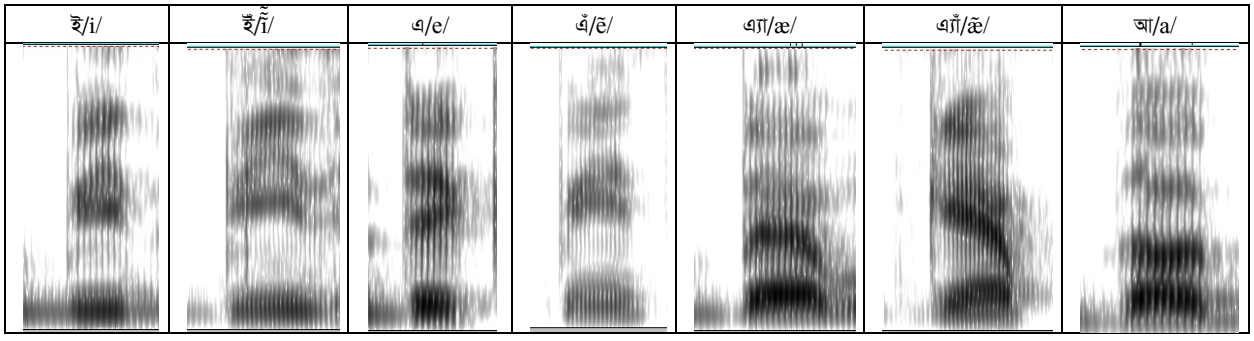
In our first step of analysis of the diphthong, we have eliminated the phonemes ইই/ii/, উউ/uu/, এএ/ee/ and ওও/oo/ (Table 1, sl. no. 15, 21, 26 and 35) from the diphthong list as there is no transition state within these phonemes. Another observation of the phoneme ওও/oo/ is that speakers were unable to pronounce this phoneme in the words শোওয়ার/ʃoojar/ and ধোওয়ার /d̪^{h}oojar/. But no transition presents within this phoneme segment ওও/oo/ in the words শোও/ʃoo/ and ধোও /d̪^{h}oo/.

In the second step, we have eliminated the diphthongs অয়া/ɔja/, আও/ao/ ,এ্যাও/æo/ (Table 1, sl. no. 1, 11, 29). As an average duration of these diphthongs অয়া/ɔja/ (228.28 ms), আও/ao/ (207.03 ms), and এ্যাও/æo/ (235.47 ms) is greater than the duration of the two vowels অউ/ɔu/ (204.58 ms). The duration of two vowels অউ/ɔu/ appears in the two syllable in our selected words অউপকার/ɔ.u.po.kar/ and অউপজাত/ɔ.u.po.ɟaṭ/ whereas the diphthong appears in a single syllable.

In the third step, we have eliminated the phonemes অয়/ɔj/, আয়/aj/, এ্যায়/æj/, ওয়/oj/ (Table 1, sl. no. 5, 12, 30, 36) as analysis shows that these diphthong formed by vowel following the approximant য়/j/ sound. The spectrogram and formant value shows that the phoneme segment এয়ো/eo/ and এও/eo/ (Table 1, sl. no. 27, 32) are the same, so we considered those as a single phoneme এয়ো/এও/eo/.

Acoustic cues (Ladgefoged, 2002) of all phonemes were classified by place and manner of articulation in the formant chart. Table2 and Table 3 shows the spectrogram of all possible phoneme segment with pattern cVc where V is the vowel corresponding to the phonemes. Each figure of the spectrogram is represented in the scale of 0 to 5000 Hz in the vertical axis as shown in Table 2 and Table 3.

Praat settings: The Praat spectrogram and formant settings were maintained for both male and female speakers. In spectrogram settings the window length is 0.005 second, the window shape Gaussian and the view range up to 5000 hz. Fourier analysis method is used in spectrogram analysis settings. In formant settings, we used maximum formant 5500 Hz for five formants with window length 0.025 second. Pitch range was used 75 Hz to 500 Hz which covers both male and female speakers.



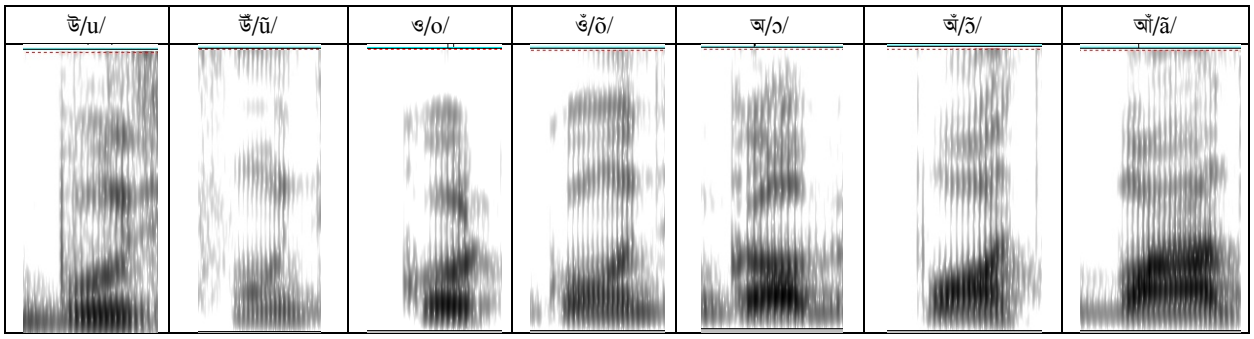
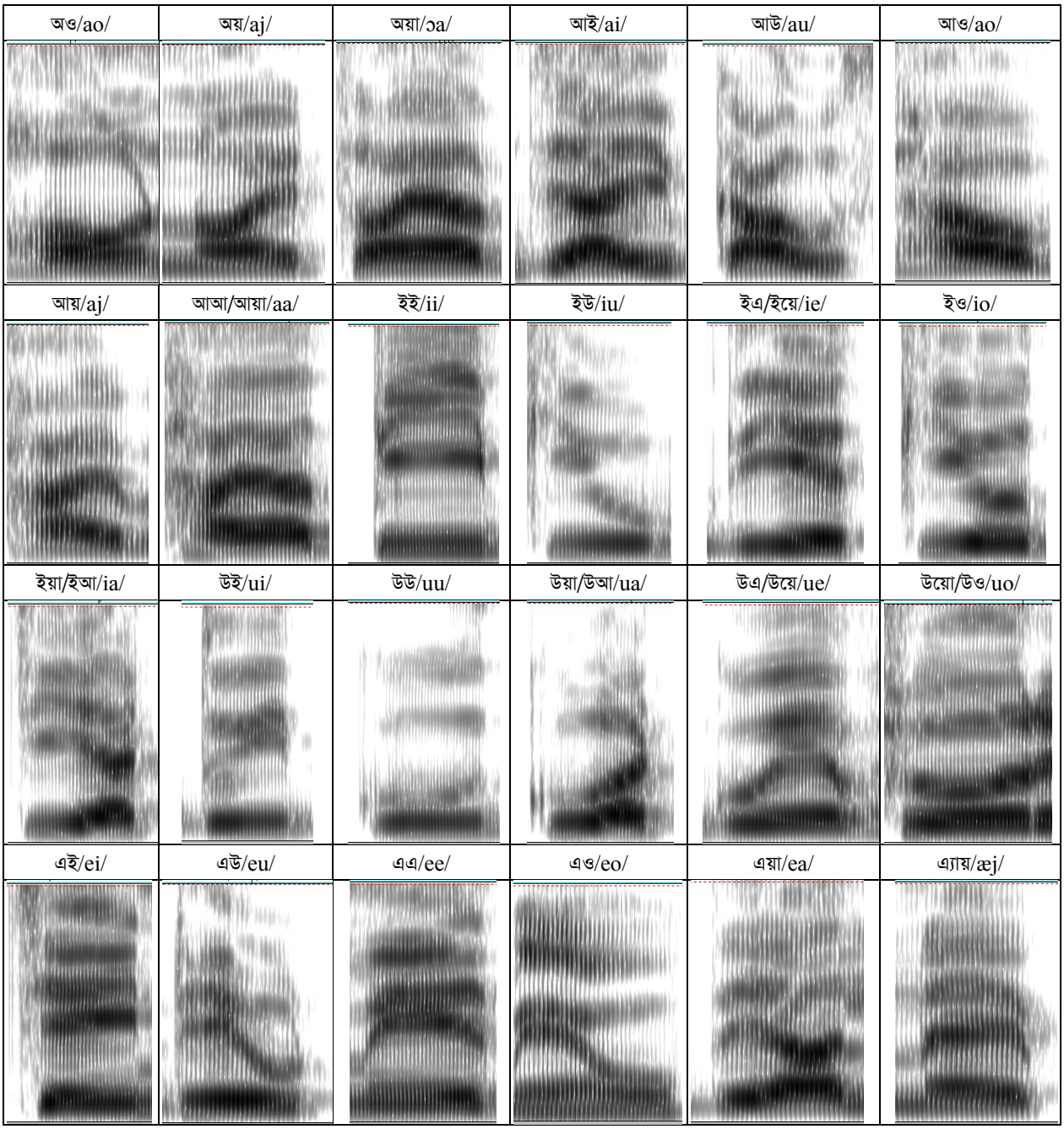


Table 2: Spectrogram Bangla vowel (monophtong)



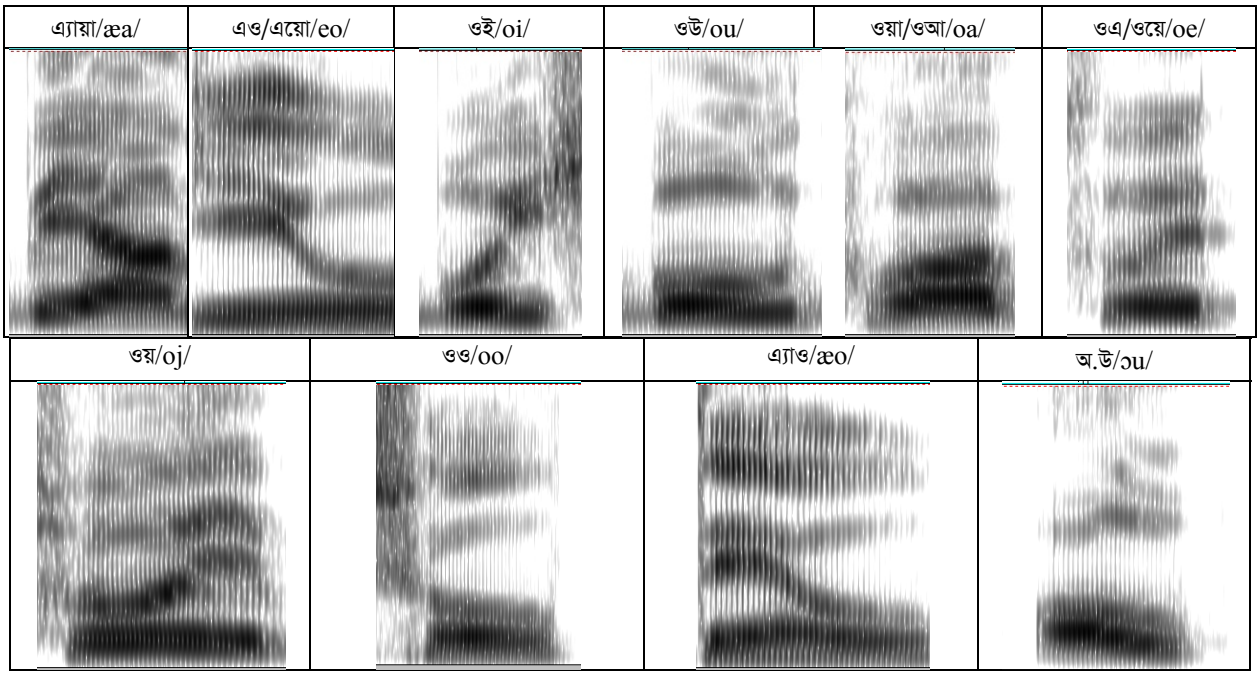


Table 3: Spectrogram of Bangla vowel (diphtong)

4 Results

The durations, diphthong identification and vowel phoneme inventory were computed and identified in this analysis. The output of the analysis is presented and discussed in this section. The durational characteristics of Bangla vowel phonemes are shown in Table 4 (monophthong) and Table 5 (diphthong). Table 6 shows the formants of monophthong and Figure 1 shows the Bangla vowel phonemes (monophthong) in the formant chart represented in bark scale.

4.1 Durational characteristics

In Table 4 and Table 5, column 2 shows the vowel phonemes and the rest of the column shows the average duration of male and female, total average of both male and female. The IPA (International Phonetic Alphabet) symbol we used in table 4, 5 and 6 according to our formant analysis.

4.2 Vowel phoneme inventory

Finally we come up with 14 monophthong including 7 oral vowels and 7 nasal vowels and 21 diphthongs in Bangla vowel phoneme inventory with their acoustic features. In the table 4, the first 7 phoneme is the oral vowel and the rest of them are the nasal vowels. When we collected recording data we observed that the nasal vowel is less frequent than oral vowel in Bangla. The front, back, low, and highness of monophthong vowel are represented in formant chart. The diphthongs does not represented in formant chart in this paper. More data and more analysis are required for diphthongs analysis. As front and back is defined by high F2 and low F2, so the front vowels of Bangla are ই/i/, এ/e/, এ্যা/æ/, ইঁ/ĩ/, এঁ/ẽ/, এ্যাঁ/æ̃/ and the back vowels are উ/u/, ও/o/, অ/ɔ/, উঁ/ũ/, ওঁ/õ/, অ/ɔ̃/. The আ/a/, আঁ/ã/ is the central vowel according to our formant data. Roundness is defined by low F2, so all the back vowels are rounded.

	Phoneme	Male (avg)	Female (avg)	Total (avg)
1.	অ/ɔ/	69.11	80.19	74.65
2.	আ/a/	93.75	102.29	98.02
3.	ই/i/	70.40	67.59	68.99
4.	উ/u/	67.80	68.80	68.30
5.	এ/e/	67.39	83.51	75.45
6.	ও/o/	66.94	84.54	75.74
7.	এ্যা/æ/	82.28	99.51	90.89

8.	অ/ɔ̃/	81.06	93.72	87.39
9.	আঁ/ã/	89.46	112.24	100.85
10.	ইঁ/ĩ/	80.47	86.11	83.29
11.	উঁ/ũ/	64.57	87.14	75.85
12.	এঁ/ẽ/	83.65	97.94	90.80
13.	ওঁ/õ/	73.49	91.12	82.30
14.	এ্যাঁ/æ̃/	118.20	121.76	119.98

Table 4: Average duration of vowel (monophthong) in millisecond

	Phoneme	Male (avg)	Female (avg)	Total (avg)
1.	অও/ɔo/	170.16	189.61	179.88
2.	আই/ai/	162.26	174.00	168.13
3.	আউ/au/	167.08	174.10	170.59
4.	আয়া/aja/	185.42	204.06	194.74
5.	ইউ/iu/	149.90	146.98	148.44
6.	ইএ-ইয়ে/ie/	173.71	180.03	176.87
7.	ইও/io/	168.40	171.43	141.34
8.	ইয়া-ইআ/ia/	178.82	189.64	184.23
9.	উই/ui/	157.08	157.67	157.37
10.	উয়া-উআ/ua/	166.23	187.07	176.65
11.	উয়ে/ue/	161.98	179.60	170.79
12.	উয়ো-উও/uo/	181.07	196.77	188.92
13.	এই/ei/	172.51	181.22	176.87
14.	এউ/eu/	158.59	154.54	156.57
15.	এও/eo/	182.23	169.03	175.63
16.	এয়া-এআ/ea/	170.73	186.35	178.54
17.	এ্যায়া/æa/	178.57	198.20	188.39
18.	ওই/oi/	153.46	154.96	154.21
19.	ওউ/ou/	190.14	157.50	173.82
20.	ওয়া-ওআ/oa/	173.83	187.99	180.91
21.	ওয়ে/oe/	166.93	187.64	177.29

Table 5: Average duration of vowel (diphthong) in millisecond

Pho-neme	Male (avg)			Female (avg)			Total(avg)		
	F1	F2	F3	F1	F2	F3	F1	F2	F3
অ/ɔ/	585.83	1109.00	2344.25	742.67	1276.83	2632.67	664.25	1192.92	2488.46
আ/a/	693.50	1371.08	2288.25	839.33	1532.50	2394.50	766.42	1451.79	2341.38
ই/i/	356.67	2059.17	2689.58	361.33	2577.42	3030.00	359.00	2318.29	2859.79
উ/u/	346.58	1001.08	2551.08	382.83	1046.00	2958.42	364.71	1023.54	2754.75
এ/e/	480.75	1807.42	2451.50	521.83	1692.92	2482.83	501.29	1750.17	2467.17
ও/o/	423.17	1034.50	2404.08	468.33	1050.08	2971.25	445.75	1042.29	2687.67
এ্যা/æ/	598.58	1619.17	2364.50	789.17	1514.42	2206.08	693.88	1566.79	2285.29
অ/ɔ̃/	589.33	944.75	2227.83	716.50	1184.33	2666.75	652.92	1064.54	2447.29
আঁ/ã/	683.25	1199.08	2417.50	818.67	1265.50	2107.75	750.96	1232.29	2262.63
ইঁ/ĩ/	332.25	2178.33	3003.50	389.58	2533.50	3260.42	360.92	2355.92	3131.96
উঁ/ũ/	398.42	1081.33	2468.42	384.08	1120.67	2770.67	391.25	1101.00	2619.54
এঁ/ẽ/	488.75	1912.08	2547.92	625.08	1660.00	2486.17	556.92	1786.04	2517.04
ওঁ/õ/	468.75	1047.83	2466.17	491.25	1045.92	2972.58	480.00	1046.88	2719.38
এ্যাঁ/æ̃/	600.67	1698.08	2349.83	789.33	1434.58	2247.58	695.00	1566.33	2298.71

Table 6: Average formants F1, F2 and F3 of vowel (monophthong) in Hz

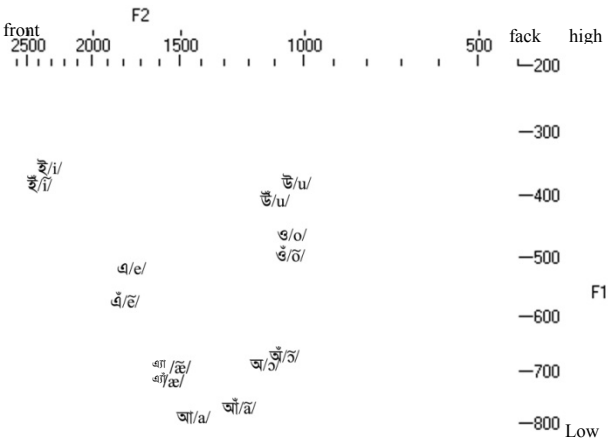


Figure 1: Formant chart of vowel (monophthong)

5 Conclusion and Future Work

Here we described duration of each vowel phoneme as well as we identified acoustic features of Bangla vowel phoneme inventory. We also conclude that Bangla vowel consist 14 monophthong and 21 diphthong phonemes. This phoneme inventory can be used in all Bangla linguistic components and to develop speech application in Bangla. It may also help in diphone database for speech synthesis, speech recognition as well as speech processing such as speech-to-speech translation. The output is based on our acoustic analysis. More recording data and analysis may be required for diphthong analysis as well as their frequency in speech to develop such inventory and to develop such application.

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