SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V10I5P118

Volume 10 Issue 5, 194-204, May 2023

Original Article

An Intelligent Speech Quality Measurement Method for Transmission over Low Bandwidth Wireless Network

Vivekanand K Joshi[1], T. Kavitha[2]

[1, 2]*Electronics and Communication Department,*
Vel Tech Rangarajan Dr. Sangunthala R&D Institute of Science & Technology, Awadi, Chennai, India

[1]*Corresponding Author : vivekanandkrishnajijoshi@gmail.com*

Received: 17 March 2023 Revised: 26 April 2023 Accepted: 18 May 2023 Published: 31 May 2023

Abstract *- Wireless communication has become increasingly popular in recent years due to its mobility, portability and efficient service. Quality Voice Communication is the basic need of all such devices. Due to the significant spectrum demand, the bandwidth allocated to Professional Radio devices is decreasing. This results in lowering voice/ speech quality. Due to limited bandwidth, the design of Radio is changing. The main change is shifting from Analogue signal processing to Digital signal processing of speech and radio signals. The conversion of analogue-natured speech to digital form itself creates loss and faithfulness. Such Radio includes a voice coder for analogue to digital conversion of speech. Human spoken language, speaker (male or female), and pronunciation play an essential role in direct voice and Radio communication. It is the primary object which decides the design of low bandwidth coder. This paper deals with Marathi language characteristics and the interdependence of language constructs that affects voice/speech quality. In this paper, we extracted features of the Marathi language using PRAAT software and analyzed its constructs using statistical tools. The actual testing on Radio is carried out. The speech quality observed during such testing is correlated with statistical results. It is shown that the standard deviation in pitch and formants in male speech is less (average 35%) compared to the standard deviation in pitch and formants in female speech. This results in lowering the quality of male speech compared to female speech. It is also shown that some vowels and combinations of certain vowels and consonants produce poor speech quality compared to others.*

Keywords *- Formant frequency, Formant bandwidth, Marathi vowels, Marathi consonants, Pitch.*

1. Introduction

Speech is the primary mechanism for communication among human beings, and language is the media through which human speech occurs. Every language construct is different from other languages. A language construct decides parameters for speech processing. Here we consider the Marathi language in India, the State Language of Maharashtra State. ISO 639-2 has allocated code 'mar' [1] and the English name of the language as 'Marathi'. Language construct is classified into Vowels and Consonants. These are based on their processing through human vocal organs. Vowels require more energy and are essential for speech understanding. Consonants have less energy but are still crucial in providing meaning to speech. In this work, the parameters of vowels and consonants are extracted using PRAAT software [2] and analyzed using Statistical tools.

The measurement process is carried out as listed below.

- Wireless communication setup is arranged with Radio Transmitter and Radio Receiver to establish good communication between them.
- Trained 25 wireless operators of native Marathi language are chosen. They are asked to talk, one by one, vowels and consonants of the Marathi language from low bandwidth Radio Transmitter. At the same time, each vowel and consonant parameter, such as pitch, formant frequency, formant bandwidth etc. extracted using PTAAT software.
- Their reception is taken at a different place in Radio Receiver. Expert wireless operators noted each vowel and consonant speech quality regarding the M0S value at the Radio receiver end.
- The statistics analysis of vowels and consonant parameters spoken at the Radio Transmitter is carried out. Radio Receiver already records each vowel and consonant's speech quality. The statistical analysis of vowels/ consonants spoken at the transmitter end is correlated to the received MOS value at the Receiver.
- Conclusions are drawn from statistical Results and speech quality obtained through radio communication.
- All other radio parameters are kept consonant during this test. (The effect of Radio and environment parameters on low bandwidth radio speech is separately considered in my other papers. Here only the effect of language constructs is

considered) Male and female expert wireless operators carry out this test in the age range of 30 to 40. This allows us to keep the sample size low.

Results show that speech quality for all vowels and consonants differs even though the radio environment and speaker (wireless operator) are the same. It is also observed that speech quality for the same language differs for different radio bandwidths. The paper is organized as follows, no

1. Section 1 - Introduction: It briefly introduces the subject.
2. Section 2 - Literature Survey: It briefly discusses previous research papers on this subject.
3. Section 3 - Structure of Marathi Language - It explains Marathi constructs and basic units.
4. Section 4 - Analysis of Language Construct: It analyses the constructs of language using ‘PRAAT’ software.
5. Section 5 - Conclusion.

2. Literature Survey

In [3], Sakthi Vel provides speech parameters such as Pitch and Duration of vowels in the Tamil language. After analysis of monosyllabic words in Tamil pronounced from male and female, it is concluded that vowel diphthongs /oo/ and /i/ have a maximum frequency. /0/,/i/ have the highest pitch value for each monosyllabic word and /a/,/e/,/u/ have the least pitch values.

In [4], Askar Hamdulla provides different syllable words (mono Syllable, two Syllable, three syllables and four syllables) words are counted from the Uyghar language database. Their parameters for fixed CV-type syllables (in different word positions) are extracted, and statistical analysis is carried out.

The parameters include the Duration of Vowels and Constants, whole syllable duration and pitch of the Syllable. When CV type syllable contains different vowels, the duration of the Syllable with low vowels is longer than that of high vowels. In [5], Zhou Xuewen analyses data retrieved from the Unified Minority Speech Parameter Database platform; it examines the main acoustic parameters of Uigur vowels. After analysis, it is concluded that the position of a vowel in a Syllable decides its acoustic space, which is closely related to its duration. As the number of syllables increases, vowel duration is decreased.

In [6], Pradeep Singh compares the analysis of the Panjabi language vowel phonemes, Produced by speakers of Panjabi People with ten English vowel phonemes. Acoustic phonetic analysis for both languages' formant frequencies and vowel duration shows a significant difference between formant frequencies and vowel duration.

In [7], Kimako Tsukada relates cross-language speech perception. It compares phonemic vowel length contrasts in three topologically unrelated languages, namely Standard Arabic, Japanese and Thai, to decide whether vowel length contrasts are similar. It shows that short and long categories were differentiated, but the short-to-long ratio did not differ. Thus, listeners attend to more than acoustic vowel duration in perceptual judgment on short vs. long vowels.

In [8], Aymen Trigui carries out our measurement of constant duration characteristics in VCCV and VCV sequences in the Arabic Language. It shows that the duration of a single constant was different from the geminated the same for the duration of the vowel preceding it. In [9], N Shrotriva R Verma and in [10], Md. Zia U R Rahman adopted a similar approach to Indian Language.

Hindi was taken through deals with the parameters that influence phonetic perception. The main factors for vowels are the first two or three formant frequencies, the direction of formant movements, and vowel duration. It is concluded that vowel duration and other parameters are essential in deciding voice quality. Traditional investigations of speech rhythm are manually analysed and investigate the duration of vowels or inter-phoneme timings.

In [11-13], A Suthana suggested an intuitive approach where speech is processed to follow the switching of spectrograms between different length analysis windows. These variable spectrograms are fed to a dynamic time-wrapping algorithm to produce a time map representing speech rhythm. In [14, 15], Loan Pavaloi evaluated the effect of emotional states, joy, fury, sadness, and natural tone, on the duration variation for speech analysis.

3. Structure of Marathi Language

This section describes the Marathi Alphabet and its components, Syllable or Akshar and their types, Compound Syllables and their types and Union of words and their types. These are basic language constructs [18-30]. The analysis carried out in section 4 is based on these constructs.

3.1. Marathi Alphabet (Varnamala)

Marathi is a subbranch of an Indo-Aryan, Indic and Sanskrit language, mainly spoken in the Maharashtra State in India. It comprises 50 alphabets [16], including 16 vowels and 34 consonants. Two compound consonants are often used, they are “xha (क्ष)” and “dnga (ज्ञ)” [16]. As these are compound consonants, they are not included in the Alphabet chart. The Marathi alphabet are written in the Devnagri script. Marathi vowels are listed in Table 1, and Marathi consonants are listed in Table 2 [17]. Matras (M) are symbols of Vowels used along with vowels or constants to form new akshars. They are as per listed in Table 3. [17]

Table 1. Marathi vowel

Sr.	Devnagri	Type	Symbol	IPA symbol
1.	अ	Short Vowel	V	/ a /
2.	इ	Short Vowel	V	/ i /
3.	उ	Short Vowel	V	/ u /
4.	ऋ	Short Vowel	V	/ru /
5.	लृ	Short Vowel	V	/ lru /
6.	आ	Long Vowel	VV	/ a: /
7.	ई	Long Vowel	VV	/ i: /
8.	ऊ	Long Vowel	VV	/ u: /
9.	अे	Compound Vowel	V	/e /
10.	अै	Compound Vowel	V	/ai/
11.	ओ	Compound Vowel	V	/o/
12	औ	Compound Vowel	V	/ou/
13.	अं	Diacritics	V	/am/
14.	अ:	Diacritics	V	/aha/
15.	अॅ	Diacritics	V	/au/
16.	ऑ	Diacritics	V	/oau/

Table 2. Marathi consonant set

Sr.	Devnagri	Type	Sub-Type	Symbol	IPA Symbol
1.	क	Touch	Hard	C	/ka/
2.	ख		Hard	C	/k^{h}a/
3.	च		Hard	C	/ca/
4.	छ		Hard	C	/c^{h}a/
5.	ट		Hard	C	/ta/
6.	ठ		Hard	C	/t^{h}a/
7.	त		Hard	C	/t.a/
8.	थ		Hard	C	/t^{h}a/
9.	प		Hard	C	/pa/
10.	फ		Hard	C	/p^{h}a/
11.	ग		Soft	C	/ga/
12.	घ		Soft	C	/g^{h}a/
13.	ज		Soft	C	/ja/
14.	झ		Soft	C	/j^{h}a/
15.	ड		Soft	C	/da/

16.	ढ		Soft	C	/d^{h}a/
17.	द		Soft	C	/d.a/
18.	ध		Soft	C	/d.^{h}a/
19.	ब		Soft	C	/ba/
20.	भ		Soft	C	/b^{h}a/
21.	ड.		Nasal	C	/ńa/
22.	ञ		Nasal	C	/ňa/
23.	ण		Nasal	C	/ṇa/
24.	न		Nasal	C	/na/
25.	म		Nasal	C	/ma/
26.	य	Semivowel		C	/ya/
27.	र			C	/ra/
28.	ल			C	/la/
29.	व			C	/va/
30.	श	Ushme		C	/śa/
31.	ष			C	/şa/
32.	स			C	/sa/
33.	ह	Mahapran		C	/ha/
34.	ळ	Independent		C	/lʼa/

Table 3. Marathi matra set

Sr.	Name of Matra	Matra Sign	Where it is Used	New Constants Formed
1.	Devnagari sign A	◌ं	अ	क् +अ = क
2.	Devanagari sign AA	◌ा	आ	क् + आ = का
3.	Devanagari sign I	◌ि	इ	क् + इ = कि
4.	Devanagari sign II	◌ी	ई	क् + ई = की
5.	Devanagari sign U	◌ु	उ	क् + उ = कु
6.	Devanagari sign UU	◌ू	ऊ	क् + ऊ = कू
7.	Devanagari sign E	◌े	अे	क् + ए = के
8.	Devanagari sign AI	◌ै	अै	क्+ ऍ = कै
9.	Devanagari sign O	◌ो	ओ	क् + ओ = को
10.	Devanagari sign AU	◌ौ	औ	क् + ऑ = कौ
11.	Devanagari sign	◌ं	अं	क् + अं = कं
12.	Devanagari sign candra O	◌ं:	अ:	क्+ अ: = क:

These main 12 mantras are used along with all 36 consonants to form different akshars (characters). A group of 12 such mantras, along with consonants or vowels, is called ‘Barakhadi’. One such ‘bara khadi’ of the letter ‘क (k)’ is shown in the fifth column of Table 3. Halanta (H) symbol is used in Marathi writing to specify the lack of inherent vowels [14].

3.2. Marathi Syllable or Akshar

A valid syllable or Akshar can be a Vowel syllable or Consonant Syllable. The vowel syllable can be a pure vowel or vowel followed by a modifier, as shown in Table 3, column 3. Constant Syllable can be a complete constant with an inherent vowel, consonant followed by matras, consonant followed by modifier, consonant followed by matra and modifier, half consonant / full consonant followed optionally by matra or modifier or both. If C is a consonant and V is a Vowel, then the Syllable can be C, V, CV, VC, CCV and CVC. These are most often used in voice transmission over wireless networks; hence only those are considered for further analysis [17].

3.3. Marathi Compound Syllable (Akshar) [16]

If the vowel is added to a mixture of two or more consonants, it is called Compound Letter. They are classified as Consonants with a vertical bar (and) at the end/centre and Consonants with no vertical bar. All types of compound letters are examined in the Analysis of words.

3.4. Marathi Union of Words [16]

In two adjacent words, if the last Syllable (Akshar) of the first word and the first Syllable (Akshar) of the second word come together to form a new character, it is called a Union or Combination of Words. It is classified as Vowel Union, Constant Union and Visarg Union.

- Vowel Union: If two adjacent words are connected using two vowels, it is called a Vowel Union.
- Constant Union: If two adjacent words are connected using two consonants or one consonant and one vowel, it is called a Consonant Union.
- Visarg Union: If two adjacent words are connected using one visarg and one constant/vowel, it is called Visarg Union.

4. Analysis of Language Constructs

Language and its pronunciation mainly depend on the geographical location and gender, age, and mouth biological structure of the speaker. It is said that language pronunciation and words change in about 15 kilometres in geographical locations with the same type of language. So, it is not easy to analyze a language from a radio communication point of view. We have taken the core geographical area where most people speak the language to face this difficulty. In our case, the Marathi language is mainly spoken in the Maharashtra state of India. It is an approximately 370 thousand square kilometre area with approximately 12 crore population. Pune district is a centralized location. The language spoken in Pune is taken as a standard to decide its parameters. While considering the age of male and female speakers, we have selected those people who usually can work in telecommunication or wireless office. This limits our search to people with good language knowledge and who are in the age group of 30 to 50. We allowed both male and female speakers. While conducting our testing, we tried to use the exact atmosphere we found in the field work, where radio operators work. The microphone with moderate sensitivity of 17mV/pa and gain of 60 dB is tested. The microphone is omnidirectional and about 2 to 3 inches from the speaker. No noise cancellation algorithm is used. We want to test language constructs in an open-field environment. This is done to check the effect of low-powered portable devices used in wireless communication.

In this section, the Marathi language construct is analysed with the help of PRAAT, a computer program used to analyze speech. Paul Boersma and David Weenink of the University of Amsterdam designed and developed this program. We have used this program with Windows 7 operating system. The PRAAT program supports speech synthesis, including articulatory synthesis. The units of analysis are vowels/consonants duration, mean pitch value, minimum and maximum intensity, the frequency at maximum intensity, first four formants and their bandwidths. After recording the speaker’s speech through the predefined quality of the microphone and in a field environment, we analyzed constructs of the Marathi language.

First, analysis is conducted to decide the best sampling frequency for this application. Then pitch value for all 16 vowels (a1 to a16) is studied for male and female vowels. Variation in formant frequency and formants bandwidth of the first four formants for all 16 vowels is studied for male and female vowels. Similarly, the pitch value for all 34 consonants (c1to c33) is studied for male and female consonants. Variation in frequency and formant bandwidth of the first four formants for all 34 consonants is recorded. Variation in pitch and frequency/ bandwidth of formants for vowels and consonants is statistically verified to find deviation and Correlation. The testing using radio sets is carried out, and speech quality is noted for each vowel and consonant. This speech quality is coupled with statistical results already obtained.

4.1. Analysis of Vowels

Marathi has total 16 vowels. The mean pitch value of all vowels for different sampling frequencies of a male voice is shown in Figure 1. It is seen that the mean pitch value for all vowels (for Male) is around 150 Hz, and its range is from 130 Hz to 160 Hz.

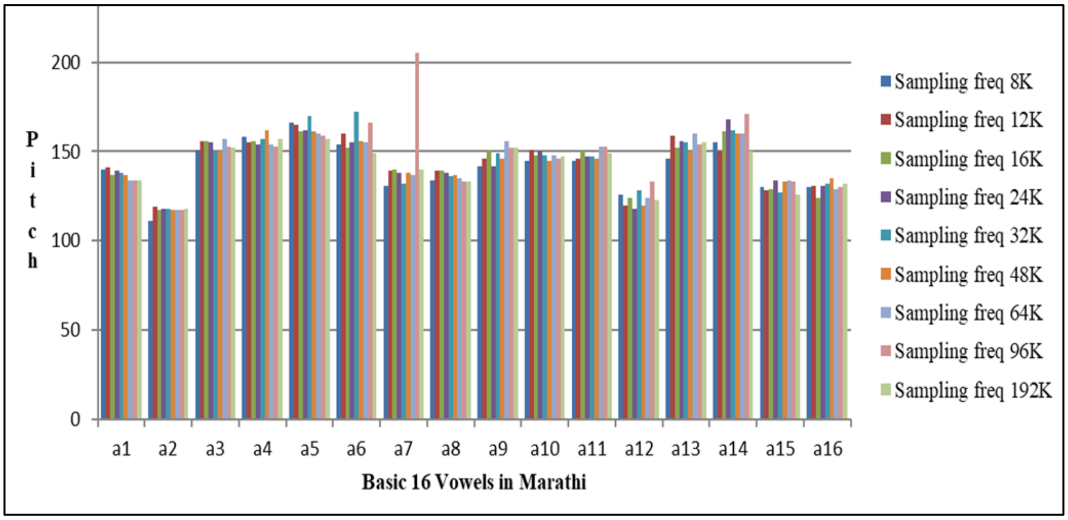

Fig. 1 Variation of pitch of vowels as per sampling frequency

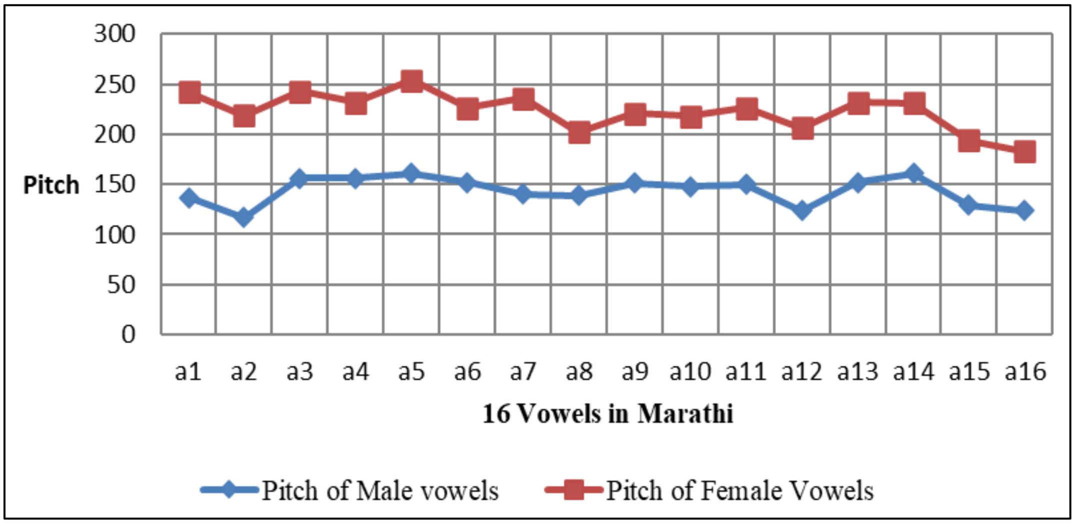

Fig. 2 Variation of pitch according to vowel for male and female

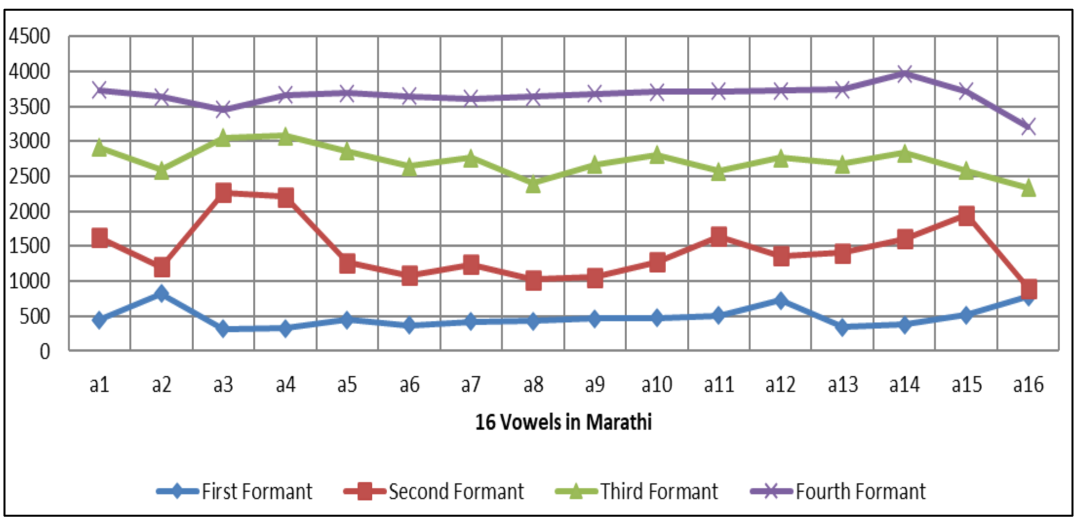

Fig. 3 Variation of formant frequency according to vowel for male

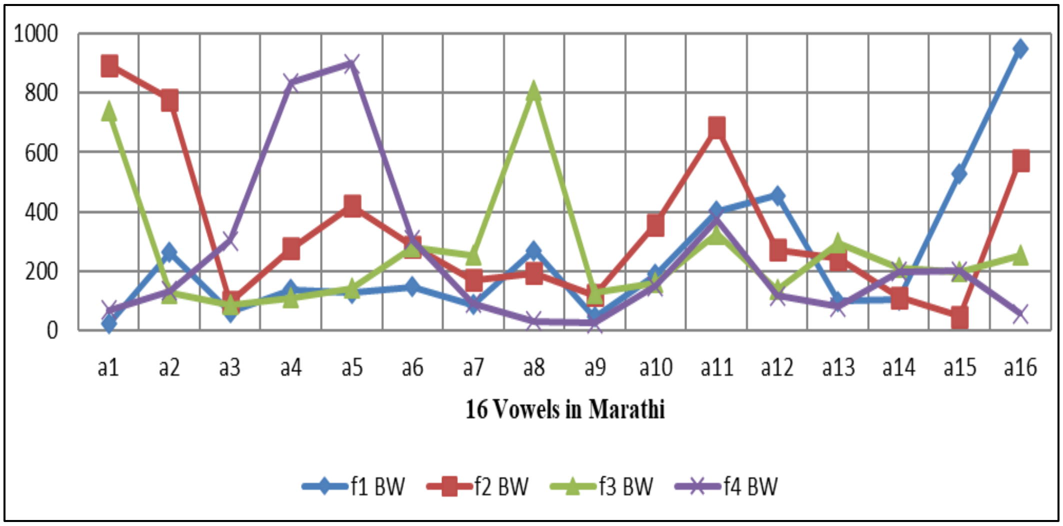

Fig. 4 Variation of formant bandwidth according to vowel for male

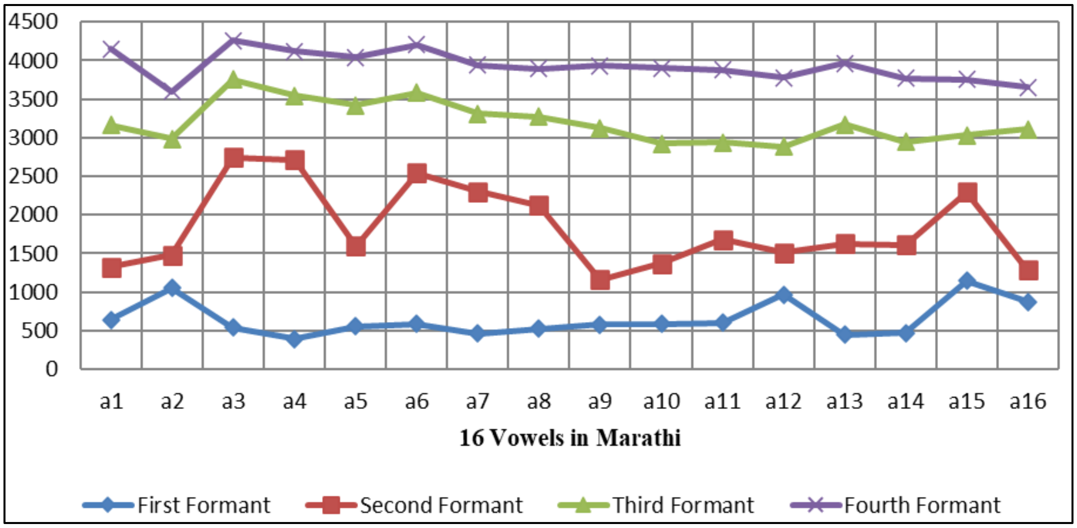

Fig. 5 Variation of formant frequency according to vowel for female

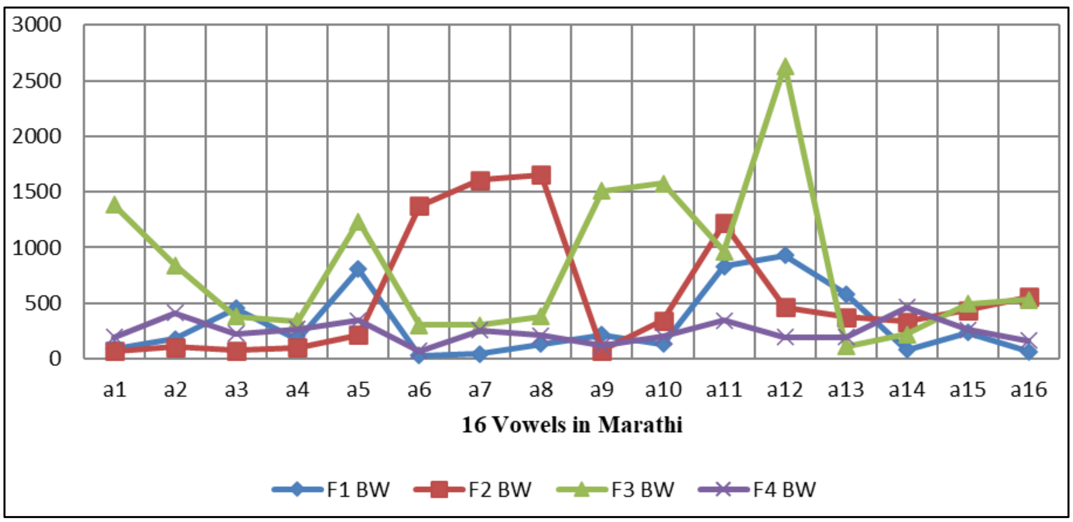

Fig. 6 Variation of formant bandwidth according to vowel for females

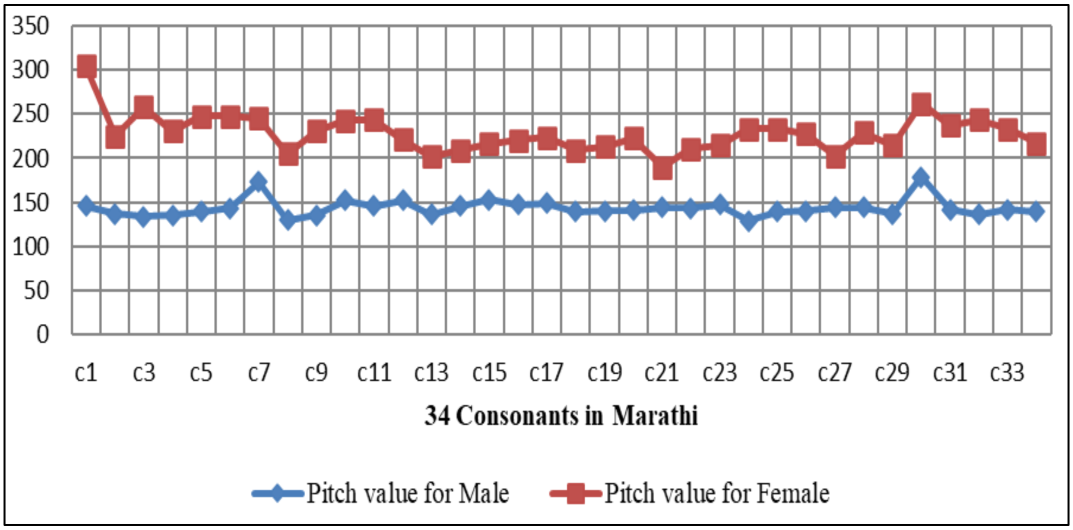

Fig. 7 Pitch value of consonants for male and female

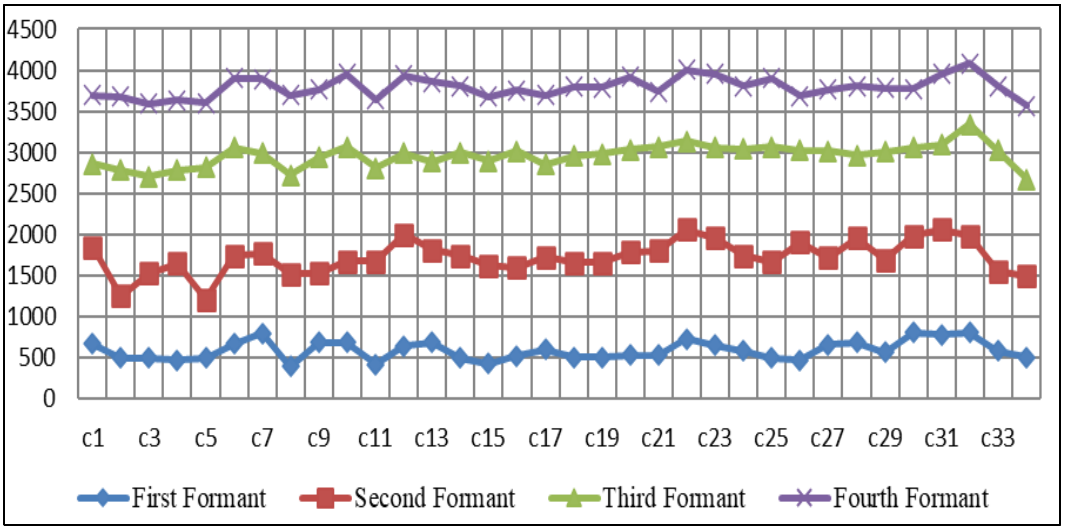

Fig. 8 Variation of formant frequency according to consonants for male

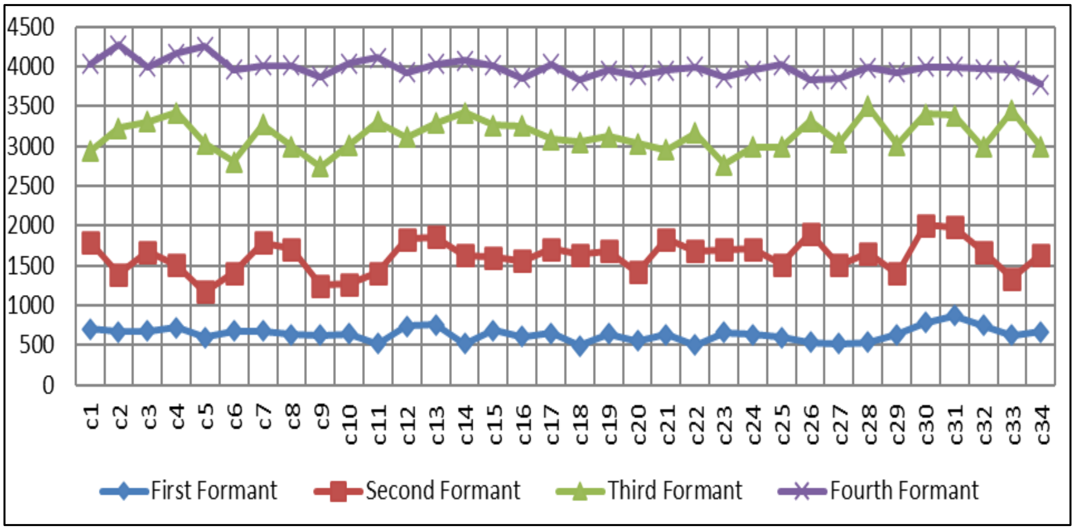

Fig. 9 Variation of formant frequency according to consonants for female

For Low Bandwidth Radio, sampling is done at 16KHZ, so here, all analysis is carried out for a sampling frequency of 16 KHZ for males and females. To analyse vowels and consonants, samples for each vowel and consonant are taken from 25 trained wireless operators. These wireless operators are well familiar with wireless working environments. After recording each sample for every vowel and consonant, its mean value is taken and plotted in the figures (Figure 2 to Figure 9).

The confidence level for the measurement is 95%. For example, in Figure 2, the mean pitch value for a vowel named a1 is 243-a confidence level of 95% and a standard deviation of 4.87. With an alpha level of 0.025 and a degree of freedom of 24, the Z score is calculated as 2.0639, which gives a confidence interval of 2.010. The confidence interval for the pitch of the a1 vowel is (245.44, 241.42). Similarly, for other vowels a2 to a16 and consonants (c1 to c34) confidence interval for pitch is calculated.

A similar calculation is carried out for all remaining vowels and consonants for the parameters mentioned in this paper. Figure 2 shows mean pitch value for vowels varies from 117 HZ to 161 HZ for Males and 183 HZ to 254 HZ for female speech. Vowel आ (a2), अ: (a12), ॲ (a15), ऑ (a16) has the lowest pitch value. At the same time, उ (a5) has the highest pitch value. This is valid for both male and female vowels. The standard deviation for the female pitch value (18.88) is more significant than the standard deviation for the male pitch (13.99).

Figure 3 and Figure 4 show formant frequencies and their corresponding bandwidth for male vowels. It is observed that the first and fourth formant have less pitch variation than the second and third formants. For all 16 vowels, the standard deviation is approximately 156 for the first and fourth formant, 409 for the second formant and 205 for the third formant. The correlation index between formant frequencies of adjacent vowels is more than 0.9

Figure 5 and Figure 6 show formant frequencies and their corresponding bandwidth for female vowels. It shows that the first, third and fourth formants have less pitch variation than the second formant. For all 16 vowels, the standard deviation is 228 for the first, 263 for the second and 192 for the third formant. The second formant standard deviation is 532. It indicates a significant variation in second formant frequency, indicating small chances of interference. The correlation index between formant frequencies of adjacent vowels is more than 0.9

4.2. MOS Value of Vowels Observed at Receiver

For Male vowels MOS value observed at Receiver for vowels a1 to a5 is within 4 to 4.2; for vowels a6 to a8, it is between 3 to 3.2; for vowels a9 to a12, it is between 4 to 4.2 while for vowels a13 to a16 it is between 2.5 to 3.0. For Female vowels, the MOS value was observed to be almost constant for all vowels, and it is in the range of 4 to 4.2

4.3. Analysis of Consonants

Figure 7 shows mean pitch value for consonants varies from 129 HZ to 179 HZ for Male and 190 HZ to 305 HZ for female speech. The standard deviation for the female pitch value (21.49) is more significant than the standard deviation for the male pitch (10.12) value. The default vowel अ (a1) is added to every consonant in the Marathi language.

Figure 8 shows formant frequencies for male consonants. It is observed that the first formant has less pitch variation than the second, third and fourth formant. For all 34 consonants, the standard deviation is between 116 to 126 for all four formats. The correlation index between formant frequencies of adjacent consonants is more than 0.9

Figure 9 shows formant frequencies for female consonants. It shows that the first formant has less pitch variation than the second, third and fourth formant. For all 32 consonants, the standard deviation is between 86 to 207 for all four formants. The first formant has a standard deviation of 86 HZ, so there is a possibility of mixing with another formant for low-bandwidth applications. The correlation index between formant frequencies of adjacent consonants is more than 0.9.

4.4. MOS Value of Consonants Observed at Receiver

At the Receiver end, the MOS value for Male consonants, namely C1 to C25, is almost constant at 4.0. For consonants C26 to C29, C30 to C31, and C33 to C34, it is degraded in the range of 3 to 3.2. The same effect of degradation in MOS value is observed for Female consonants also. It means that the MOS value is not uniform for all consonants and vowels of either Male or Female speech keeping all radio and related environment parameters consonants.

5. Conclusion

With experiments in section 4, the following conclusions related to Marathi language constructs and their interdependence are drawn.

1. Male speech will be more vulnerable to transmission errors than female speech over wireless.
2. Male vowels' first, second and third formants have less standard deviation than female vowels' first, second and third formants. This observation of vowel analysis states that male speech quality will be poor compared to female speech.
3. From consonants analysis, the Correlation between the second and third formants of female consonants is poor (0.26 and 0.37) compared to the Correlation between the

second and third formants of male consonants. This improves the speech quality of female speech as compared to male speech.

4. While relating statistical results obtained through PRAAT analysis with speech quality (MOS value) monitored during radio communication, it is found that male speech short vowels (a1 to a5) are less affected as compared to long vowels (a6 to a8), typically MOS value degrades by 20%. Compound vowels a9 to a12 are unaffected, while diacritics (a13 to a16) deeply impact speech quality. For female vowels, an almost uniform response is observed for all vowels. The consonants named semivowels (c26 to c29), Ushme (c30 and c31), Mahapran (c33) and independents (c34) are affected by almost 20% reduction in MOS value for both male and female speech. This results in the degradation of speech quality. Whenever speech-degrading vowels or consonants or different combinations of such vowels and consonants appear, speech quality further degrades.

This analysis stands true for the Marathi Language. However, this framework will help carry out testing for other languages. Such analysis makes it possible to predict language response in wireless networks.

Future work will be compensation of vocoder parameters for the Transmission of speech of such language in wireless Transmission with noisy and low bandwidth conditions.

References

[1] [Online]. Available: https://www.loc.gov/standards/iso639-2/php/code_list.php

[2] Paul Boersma and David Weekink, *PRAAT Software*, 1991.

[3] S. Sakthi Vel, D. Muhammad Noorul Mubarak, and S. Aji, "A Study on Vowel Duration in Tamil: Instrument Approach," *IEEE Conference in Computational Intelligence and Computing Research*, pp. 1-4, 2015. [CrossRef] [Google Scholar] [Publisher Link]

[4] Askar Hamdulla et al., "Statistical Analysis of Syllable Duration of Uyghur Language," *International Conference on Asian Language Processing*, pp. 468-473, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[5] Zhou Xuewen et al., "Acoustic Feature and Variance of Uigur Vowels," *International Conference on Speech Database and Assessment (Oriental COCOSDA)*, pp. 180-184, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[6] Pradeep Singh, and Kamlesh Datta, "Formant Analysis of Panjabi Non-nasalised Vowel Phonenes," *International Conference on Computational Intelligence and Communication Network*, pp. 375-380, 2011. [CrossRef] [Publisher Link]

[7] Kimako Tsukada, "An Acoustic Comparison of Vowel Length Contrasts in Standard Arabic, Japanese and Thai," *International Conference on Asian Language Processing*, pp. 76-79, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[8] Aymen Trigui, Mohsen Maraoui, and Mounir Zrigui, "The Gemination Effect on Consonant and Vowel Duration in Standard Arabic Speech," *11th ACIS International Conference on Software Engineering*, Artificial Intelligence Networking and Parallel/ Distributed Computing, pp. 102-105, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[9] N Shrotriya et al., "Durational Characteristics of Hindi Consonant Clusters,"*In Proceeding of Fourth International Conference in Spoken Language Processing ICSLP* 96, pp. 2427-2430, 1996. [CrossRef] [Google Scholar] [Publisher Link]

[10] Muhammad Zia Ur Rahman, Rafi Ahamed Shaik, and D. V. Rama Koti Reddy, "Efficient and Simplified Adaptive Noise Cancelers for ECG Sensor based Remote Health Monitoring," *IEEE Sensors Journal*, vol. 12, no. 3, pp. 566-573, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[11] Asiya Sulthana, Md. Zia Ur Rahman, and Shafi Shahsavar Mirza, "An Efficient Kalman Noise Canceler for Cardiac Signal Analysis in Modern Tele-Cardiology Systems," *IEEE Access*, vol. 6, pp. 34616-34630, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[12] Natalia Derkach, Olena Pavelko, and Svitlana Luniova, "A Priori Assessment of the Intelligibility of Stereophonic Sound of Speech," *International Journal of Engineering Trends and Technology*, vol. 69, no. 6, pp. 50-55, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[13] N Derkach, M Vdovenko, and S. Lunyova, "Objective Method of Speech Intelligibility with the Artificial Head," *SSRG International Journal of Electronics and Communication Engineering*, vol. 7, no. 1, pp. 15-19, 2020. [CrossRef] [Publisher Link]

[14] Sala Surekha, and Md Zia Ur Rahman, "Cognitive Energy-Aware Spectrum Sensing with Improved throughput for Medical Sensor Networks," *IEEE Sensors Letters*, vol. 6, no. 6, pp. 1-4, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[15] Karush Suri, "Sub - Band Coding and Speech Quality Testing," *SSRG International Journal of Electronics and Communication Engineering*, vol. 3, no. 1, pp. 10-13, 2016. [CrossRef] [Publisher Link]

[16] Chintalpudi S. L. Prasanna, and Md Zia Ur Rahman, "Noise Cancellation in Brain waves using a new Diffusion Normalized Least Power-based Algorithm for Brain-Computer Interface Applications," *Elsevier Measurement: Sensors*, vol. 14, p. 100038, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[17] Federica Vurchio et al., "Comparative Evaluation of Three Image Analysis Methods for Angular Displacement Measurement in a MEMS Microgripper Prototype: A Preliminary Study," *ACTA IMEKO*, vol. 10, no. 2, pp. 119-125, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[18] Technology Department for Indian Language (TDIL) Programme of DIT, GoI, in Association with the Center for Development of Advanced Computing (C-DAC), Script Grammar for the Marathi Language. [Online]. Available: http://mafiadoc.com

[19] Henrik Ingerslev, Soren Andresen, and Jacob Holm Winther, "Digital Signal Processing Functions for Ultra-Low Frequency Calibrations," *ACTA IMEKO*, vol. 9, no. 5, pp. 374-378, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[20] N'Goran Franck Raoul Olivier Konan, Elijah Mwangi, and Ciira Maina, "Enhancement of Signal to Interference plus Noise Ratio Prediction (SINR) in 5G Networks using a Machine Learning Approach," *International Journal of Engineering Trends and Technology*, vol. 70, no. 10, pp. 319-328, 2022. [CrossRef] [Publisher Link]

[21] Surekha Sala, Md Zia Ur Rahman, and Navarun Gupta, "A Low Complex Spectrum Sensing Technique for Medical Telemetry System," *Journal of Scientific & Industrial Research*, vol. 80, no. 5, pp. 449-456, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[22] Lorenzo Ciani et al., "A Hybrid Tree Sensor Network for a Condition Monitoring System to Optimise Maintenance Policy," *ACTA IMEKO*, vol. 9, no. 1, pp. 3-9, 2022. [Google Scholar]

[23] S. Surekha, and M. Z. U. Rahman, "Spectrum Sensing for Wireless Medical Telemetry Systems Using a Bias Compensated Normalized Adaptive Algorithm," *International Journal of Microwave and Optical Technology*, vol. 16, no. 2, pp. 124-133, 2021. [Google Scholar] [Publisher Link]

[24] Md. Zia Ur Rahman et al., "A Collateral Sensor Data Sharing Framework for Decentralized Healthcare Systems," *IEEE Sensors Journal*, vol. 21, no. 24, pp. 27848-27857, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[25] Girika Jyoshna, and Md Zia Ur Rahman, "An Intelligent Reference-Free Adaptive Learning Algorithm for Speech Enhancement," *Journal of Intelligent & Fuzzy Systems*, vol. 42, no. 3, pp. 1895-1906, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[26] Nagesh Mantravadi et al., "Spectrum Sensing using Energy Measurement in Wireless Telemetry Networks using Logarithmic Adaptive Learning," *Acta IMEKO*, vol. 11, no. 1, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[27] Sala Surekha, and Md. Zia Ur Rahman, "Blockchain Framework for Cognitive Sensor Network Using Non-Cooperative Game Theory," *IEEE Access*, vol. 10, pp. 60114-60127, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[28] Sala Surekha, and Md Zia Ur Rahman, "Spectrum Sensing and Allocation Strategy for IoT Devices Using Continuous-Time Markov Chain-Based Game Theory Model," *IEEE Sensors Letters*, vol. 6, no. 4, pp. 1-4, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[29] D. Nancy Kirupanithi et al., "Cybersecurity in Blockchain by Secure Identity Management using Long Short Term Memory (LSTM)," *SSRG International Journal of Electrical and Electronics Engineering*, vol. 10, no. 4, pp. 152-163, 2023. [CrossRef] [Publisher Link]

[30] P. Rajeswari, and Theodore S Chandra, "Partitioning of VLSI Circuits on the basis of Standard Genetic Algorithm and Comparative Analysis of Partitioning Algorithms," *SSRG International Journal of Electrical and Electronics Engineering*, vol. 9, no. 12, pp. 126-133, 2022. [CrossRef] [Publisher Link]