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Bio-acoustic: A non-invasive and effective sensing technique in monitoring of dairy buffaloes

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ABSTRACT

The present study was performed to observe the significant effect of individuality of dairy buffaloes on the acoustic features of their vocal signals. The mean call duration, pitch, 1st formant, periodicity and degree of voice breaks of adult lactating Murrah buffaloes were observed to be 2.15±0.05 s, 143.48 ± 2.51 Hz, 900.11 ± 4.21 Hz, 95.31% (183.95 periodic pulses out of 192.99 pulses) and 20.78 ± 0.89 % respectively. Analysis of bioacoustics features extracted from 300 voice samples of 10 adult lactating Murrah buffaloes revealed that differences for amplitudes (minimum, maximum and mean), total energy, mean power, pitch (median, minimum, range and mean), intensities (mean, minimum and maximum), formants (F1, F2, F3, F4 and F5), bandwidths (B1, B3 and B4), number of pulse, number of period, mean period, unvoiced frames, degree of voice breaks, jitter, shimmer, mean noise to harmonic ratio (%) and mean harmonic to noise ratio (dB) were highly significant. Out of these only few acoustic features viz. formants (F1, F2, F3, F4 and F5), number of pulse, number of period, degree of voice breaks, mean noise to harmonic ratio (%) and mean harmonic to noise ratio (dB) were observed to have significant difference for each and every individual dairy buffalo, hence only these features could be selected as the best suited acoustic features for discrimination of individual Murrah buffaloes from their herd.

Key words: Acoustic features, Bio-acoustics sensing, Dairy buffaloes, Vocal signals

In Indian subcontinent, dairy farming is rapidly shifting from unorganized to organized sector due to industrialization and urbanization. The high density rearing of animals at these farms had made their monitoring more cumbersome. Being 'Animal friendly' vocalization of dairy animals is now considered one of the best means of identification. Experienced husbandry men are even able to recognize the individuals and their needs (Weary and Fraser 1995) only by hearing their voice. Vocalizations provide information on the age, sex, dominance status and reproductive status of the caller (Gunderson and Mahan 1980, Hinch *et al*. 1982, Hall *et al*. 1988 and Watts and Stookey 2000). Animals can recognize the calls their offspring and vice versa (Arnold *et al*. 1975, Lenhardt 1977, Shillito *et al*. 1981 1982 and 1983, Murphey *et al*. 1990,Tamaki *et al*. 1993, Barfield *et al*. 1994, Blackshaw *et al*. 1996,Vankova *et al*. 1997, Ikeda *et al*. 2000, Clemins *et al*. 2005 and Lee *et al*. 2006). Some researchers have started using vocal behavior as an indicator of animal welfare (Weary *et al*. 1997, Grandin 1998). In several vocal signals, the receivers can simultaneously gain information about the caller's identity, motivational state and communication context (Gerhardt 1992, Hauser 1996). There exists some individual specific stable difference between vocalizations of animals (Kiley 1972, Koene 1997, Holekamp *et al.* 1999, Frommolt *et al*. 2003, Yin and McCown 2004).

A variety of species-typical calls of cattle like fundamental frequency, or lowest harmonic, of the various calls of spontaneously vocalizing cattle (50 to 1250 Hz) have been studied so far (Kiley 1972). In contrast to the extensive literature for wild vertebrates, particularly birds (Kroodsma and Miller 1996) and primates (Cheney and Seyfarth 1990), the studies on vocalization of dairy buffaloes are scanty. Thus, the main aim of the present investigation was to propound the individuality in acoustic features of vocal signals uttered from dairy buffaloes.

MATERIALS AND METHODS

Selection of animals: Voice signals of 10 adult lactating Murrah buffaloes were recorded for discrimination of their individuality, based on their acoustic features. Recording of voice signals of dairy buffaloes maintained at Cattle Yard,

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National Dairy Research Institute, Karnal, Haryana, India, was performed during morning hours between 8 AM to 10 AM. Each and every recording was made only after separating the animals from their herd. All the buffaloes under present investigation belonged to second and third parity and early stage of lactation. Although the buffaloes were managed in a group of 40 but recording for each and every buffalo was done only after separating them from the herd. All the other management practices (feeding, breeding, housing etc.) were performed as per normal schedule of the farm.

Recording and editing of voice signals: To avoid any overlapping of sound signals, the buffaloes were housed in individual sheds at the time of recording. The dimension of each individual shed was 6m × 3m with open and covered space in equal proportion. The buffaloes were kept loose in these sheds at the time of recording so that their natural behavior was not disturbed. Recording of sound signals was done for a sufficient period of time so that at 30 complete voice signals could be received from each buffalo. Sound recording was performed by using a video camera equipped with a good quality microphone available at Video Lab (Communication Center) of the institute. The microphone was fixed in the front wall of the recording shed at a height of 150 cm from floor. The video camera was kept at a tripod at a suitable height and distance in such a position so that it could capture each and every activity of the buffalo under recording. The buffaloes were not disturbed with these recording devices and environment during the experiment. Since the weather under which the experiments were conducted was clear, the background noise was only the low level sound produced due to rubbing of the body of animals. Other environmental disturbances were not captured due to specification of unidirectional microphone. The recorded vocal signals were transferred to a computer. All the superimposed sound signals were detected and eliminated manually by observing the spectrogram of each and every signal during editing. Numbers of clips of complete voice signals for each buffalo were prepared from all the recordings, by using audio-visual editing software package.

Sound signals were re-sampled at a sampling frequency of 48 kHz and 16 bit. Various acoustic features, viz. call duration, amplitudes, total energy, mean power, pitch, pitch spreadings, intensity, formants, bandwidths, number of pulse and periods, mean period, unvoiced frame, degree of voice breaks, jitter, shimmer, mean noise/harmonic and mean harmonic/noise ratios were extracted with the help of PRAAT 5.1.36 software package developed by Boersma and Weenink (2010).

The data thus obtained were arranged in appropriate way on MS EXCEL sheet as per the requirement of statistical analysis.

Statistical analysis of acoustic data: The statistical analysis was carried out at the computer center of the institute. The data were analyzed by using least squares technique (Harvey 1987) and significance of difference among various subclasses was examined by using Duncan's multiple range test (Kramer 1957).

Following least squares model was used to examine the significant differences between the different acoustic features of voice signals uttered by individual buffalo:

$$Y_{ij} = \mu + B_i + e_{ij}$$

where, Y_{ij} is the j^{th} acoustic feature of voice signals of i^{th} buffalo; μ is the overall mean; B_i is the effect of i^{th} buffalo; and e_{ij} is the residual error ~ (ì, σ^2).

RESULTS AND DISCUSSION

Acoustic features of Murrah individuals: The data extracted for various bioacoustics features from 300 voice samples of 10 lactating Murrah buffaloes were subjected to least squares analysis to examine the significant differences between them. The spectrogram and waveform for one Murrah buffalo reflecting the values of various acoustic features, viz. call duration (3.48 sec); amplitude (maximum 0.9999 and minimum -0.8829), intensity, pitch, formants, pulse and periods are depicted in Fig. 1. The amplitudes both minimum and maximum of each call were higher during the initial and middle course of call but it was comparatively lower at the end. Thus, the voice produced from buffalo was loud in the beginning which reduced along with the progression of the voice signal. The intensity of each call of Murrah buffalo remained almost constant (83.02 dB) during the course of the call and did not reduced sharply even at the end. The pitch of the call was observed to be almost constant throughout the call duration with slight irregular variations. Surprisingly, a huge random variation was observed for the pitch at the end of the call. The value of each formant changed randomly during the due course of each call.

The mean call duration of lactating Murrah buffaloes was 2.15±0.05 sec. The least squares variance (Table 1) revealed that vocal signals of 10 Murrah buffaloes differed significantly (P<0.001) for minimum, maximum and mean amplitudes; total energy; mean power; minimum, maximum and mean (P<0.01) intensities. Minimum amplitude were

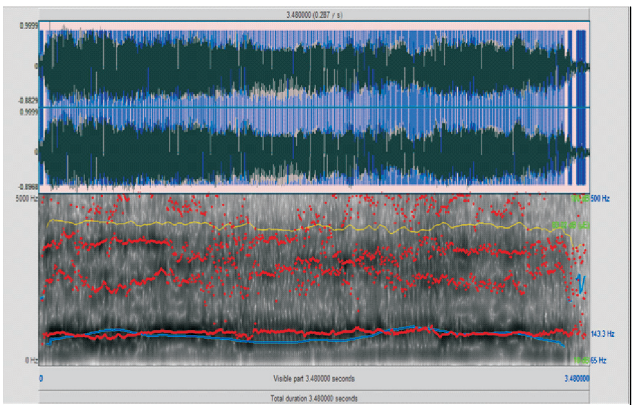

Fig. 1. Waveform and spectrogram of a voice signal of a Murrah buffalo showing its various acoustic features viz. amplitude, intensity, pitch, formants, call duration, periodic pulses etc.

Table 1. Least squares analysis of variance (mean squares only) for various acoustic features of voice signals from Murrah buffaloes showing the effect of individuality on their voice

Source d.f.		Animal 9	Error 290
Amplitude	Maximum	0.059***	0.015
(P)	Minimum	0.035***	0.003
	Mean	0.000003***	0.000000
Total energy (P^2s)	0.099***	0.003	
Mean power (W/m^2)	0.000000***	0.000000	
Pitch	Meadian (Q50%)	37535.83***	3737.84
(Hz)	Minimum	4963.26***	1086.43
	Maximum	21950.87	29931.17
	Range	37406.24***	7618.99
	Mean	25215.12***	1900.18
Estimated	(84-50%)	26549.74***	5280.82
spreading	(50-16%)	25395.18***	2850.61
(Hz)	(90-10%)	91997.61***	7115.42
Intensity	Mean	20.84*	10.62
(dB)	Minimum	297.43***	32.55
	Maximum	11.22***	0.63
Formants	F1	311826.68***	5332.00
(Hz)	F2	908288.59***	30056.95
	F3	660433.76***	37731.46
	F4	1356687.74***	94628.04
	F5	327862.27***	24278.15
Bandwidth	B1	1036418.68*	499825.21
	B2	920360.48	714090.20
	B3	2505361.83***	337314.94
	B4	2669303.42***	607188.79
(289)			
No. of pulse	218354.88***	10706.44	
No. of periods	209180.06***	10234.86	
Mean period (s)	0.000050***	0.000004	
Unvoiced frames (%)	4054.96***	70.69	
Degree of voice breaks (%)	4517.71***	238.94	
Jitter (%)	25.74***	0.85 (286)	
Shimmer (%)	122.59***	4.24 (286)	
Mean Noise/ Harmonic ratio (%)	8411.99***	166.80	
Mean harmonic/ noise ratio (dB)	358.70***	6.88	

*P < 0.05 and ***P < 0.001.

represented with minus (-) sign. The overall mean variation for amplitude of Murrah individuals in present investigation ranged between -0.939 ± 0.007 to 0.936 ± 0.003 Pa. The minimum and maximum variation for amplitude in present study was observed for buffalo M-416 (-0.876 ± 0.022 to 0.899 ± 0.01 Pa) and M-454 (-0.991 ± 0.022 to 0.989 ± 0.01 Pa) respectively. The least squares mean for overall mean total energy and power for vocalizations of Murrah individuals in present study were 0.143 ± 0.003 Pa^2s and 0.00016 ± 0.000001 W/m^2 respectively. The lowest total energy (0.143 ± 0.003 Pa^2s) and mean power (0.00016 ± 0.000001 W/m^2) was observed for buffalo M-5308, while the maximum total energy (0.224 ± 0.011 Pa^2s) and mean power (0.00019 ± 0.000005 W/m^2) were observed for buffaloes M-5345 and M-442 respectively.

The average values observed for mean, minimum and maximum intensities for voice signals uttered from Murrah buffaloes were 82.42 ± 0.18, 64.75 ± 0.32 and 85.25 ± 0.04 dB respectively. The highest and the lowest mean intensity was observed for buffaloes M-455 and M-473 respectively. The highest fluctuation in intensity was observed for buffalo M-454 while the least fluctuation in intensity was observed for buffalo M-5308. Thus, the voice signals produced from buffalo 5308 were the least stable in nature.

The pitch for vocal signals of Murrah buffaloes in present experiment were investigated under median (Q50%), minimum, maximum, range and mean subclasses. The least squares variance revealed highly significant (P<0.001) effect of individuality on median, minimum, mean pitch and range of pitch (Table 1). The average values for median, minimum, maximum, mean pitch and range of pitch for voice signals articulated by Murrah buffaloes in present investigation was observed 128.47 ± 3.52, 80.05 ± 1.90, 306.88 ± 9.98, 143.48 ± 2.51 and 218.45 ± 5.03 Hz respectively. Though the values for median, minimum, mean pitch and pitch range differed significantly for many individuals but not for all. The value of Q50% and mean pitch was lowest (respectively 86.50 ± 11.16 and 103.26 ± 7.95 Hz) for buffalo M-5345, while the highest values for these acoustic features (respectively 210.30 ± 11.16 and 205.59 ± 7.95 Hz) were observed for buffalo M-5308. The highest range of pitch (252.40 ± 15.93 Hz) was observed for buffalo M-422 while the lowest pitch range (140.35 ± 15.93 Hz) was observed for buffalo M-416. At the same time, differences for median pitch, between vocal signals from each and every individual buffalo was observed to be highly significant (P<0.001). Table 1 for the least squares variance and least squares means for pitch spreading (84-50%, 50-16% and 90-10%) for Murrah buffaloes are presented in Tables 3 and 4 respectively. Least squares variance revealed a highly significant (P<0.001) difference for estimated pitch spreading (84-50%, 50-16% and 90-10%) of vocal signals from Murrah buffaloes (Table 1).

The resonant frequency was defined as the frequency at which the power reaches the local maximum value. The values for the first 5 formants (F1, F2, F3, F4 and F5) were examined for vocal signals of 10 lactating Murrah buffaloes.

The least squares variance (Table 1) revealed that vocal signals from Murrah buffaloes differed significantly ($P<0.001$) for all the 5 formants. The overall mean for F1, F2, F3, F4 and F5 formants was 900.11 ± 4.21, 2135.68 ± 10.00, 3513.96 ± 11.21, 5205.52 ± 17.76 and 6480.64 ± 8.99 Hz respectively. The overall mean of formants for 10 Murrah buffaloes indicated that F2, F3, F4, and F5 formant frequencies were almost twofold; multiple integer of fundamental frequency (F1), thus these might be considered as the harmonic overtones and may be represented as second, third, fourth and fifth harmonics or 1, 2, 3 and 4 octaves respectively. The above finding of present investigation was more or less similar to the findings of Ikeda *et al*. (2008), who reported that voice signals from both of their experimental cows were having significantly different fundamental frequencies (275 and 505 Hz) but the subsequent formants i.e. F2 and F3 of the cows were one-fold multiple integer of fundamental frequencies (F1) instead of twofold in present investigation. Moreover, the values for F1, F2 and F3 were much less as compared to that of present investigation. All the 5 formants in present investigation differed significantly for voice signals uttered by all the 10 Murrah buffaloes (Table 2), hence these formants may be used as one of the best suited descriptor for discrimination of individual Murrah buffalo.

The least squares variance (Table 1) revealed that differences for B1 ($P<0.05$), B3 and B4 ($P<0.001$) bandwidths of vocal signals from different Murrah buffaloes were significant. Overall mean of these bandwidths for Murrah buffaloes were 300.20 ± 40.81, 1182.37 ± 48.78, 927.83 ± 33.53 and 1295.34 ± 45.06 Hz respectively. These bandwidths were significantly different only for few animals under study and not for all. Therefore, bandwidths could not be considered as a suitable feature for discrimination of individual Murrah buffalo.

Pulse is a short transient signal, which includes a complete waveform of definite shape and one which is repeated at a regular interval of time is called a periodic pulse. The least squares analysis of variance (Table 1) revealed that differences in vocal signals from Murrah buffaloes for number of pulse, number of period and mean period was highly significant ($P<0.001$). The overall mean for number of pulse, number of period and mean period in present investigation for Murrah buffaloes were observed to be 192.99 ± 5.97, 183.95 ± 5.84 and 0.0076 ± 0.0001 s respectively. Overall periodicity of buffalo voice in present

Table 2. Least squares means (±SE) for acoustic features of individual Murrah buffalo showing significant difference between the 10 individuals

Animal Id.	Formants					Degree of voice breaks (%)	No. of pulse	No. of periods	Mean noise/ harmonic ratio (%)	Mean harmonic/ noise (dB)
	F1	F2	F3	F4	F5					
Overall	900.11	2135.68	3513.96	5205.52	6480.64	20.78	192.99	183.95	42.51	6.82
mean	±4.21	±10.00	±11.21	±17.76	±8.99	±0. 89	±5.97	±5.84	±0.74	±0.15
Buffalo	939.36^{g}	2200.45^{f}	3502.43^{e}	5081.44^{d}	6452.14^{d}	4.29^{a}	320.56^{j}	317.86^{j}	15.34^{a}	±0.47
-0416	±13.33	±31.65	±35.46	±56.16	±28.44	±2.82	±18.89	±18.47	±2.35	11.96^{j}
Buffalo	829.03^{c}	2212.99^{g}	3554.91^{f}	5189.12^{e}	6319.85^{a}	21.19^{f}	181.00^{d}±	169.36^{d}	54.61^{g}	4.24^{d}
-0422	±13.33	±31.65	±35.46	±56.16	±16.50	±2.82	18.89	±18.47	±2.35	±0.47
Buffalo	731.38^{a}	1794.75^{a}	3427.31^{d}	5312.89^{h}	6611.57^{j}	34.48^{i}	221.20^{g}	203.40^{g}	56.46^{h}	4.07^{c}
-0442	±13.33	±31.65	±35.66	±56.16	±28.44	±2.82	±18.89	±18.47	±2.35	±0.47
Buffalo	914.39^{f}	2126.78^{d}	3640.37^{h}	5552.78^{j}	6586.73^{i}	11.17^{c}	198.13^{f}	192.93^{f}	26.44^{c}	±0.47
-0453	±13.33	±31.65	±35.46	±56.16	±28.44	±2.82	±18.89	±18.47	±2.35	10.46^{h}
Buffalo	818.42^{b}	1920.02^{b}	3361.41^{b}	4979.17^{b}	6405.78^{c}	39.80^{j}	266.66^{h}	247.66^{h}	59.61^{i}	±0.47
-0454	±13.33	±31.65	±35.46	±56.16	±28.44	±2.82	±18.89	±18.47	±2.35	3.68^{b}
Buffalo	952.20^{h}	2232.05^{h}	3384.20^{c}	4938.93^{a}	6520.61^{f}	16.72^{e}	65.40^{b}	61.73^{b}	43.64^{e}	6.14^{f}
-0455	±13.33	±31.65	±35.46	±56.16	±28.44	±2.82	±18.89	±18.47	±2.35	±0.47
Buffalo	1002.64^{i}	2187.46^{e}	3301.37^{a}	5060.29^{c}	6459.58^{e}	29.41^{g}	193.76^{e}	182.60^{e}	49.85^{f}	4.91^{e}
-0473	±13.33	±31.65	±35.46	±56.16	±28.44	±2.82	±18.89	±18.47	±2.35	±0.47
Buffalo	1087.21^{j}	2041.33^{c}	3744.48^{j}	5243.40^{f}	6330.98^{b}	30.13^{h}	56.96^{a}	52.36^{a}	62.83^{j}	2.86^{a}
-5308	±13.33	±31.65	±35.46	±56.16	±28.44	±2.82	±18.89	±18.47	±2.35	±0.47
Buffalo	845.12^{d}	2248.71^{i}	3582.03^{g}	5513.82^{i}	6579.42^{h}	14.97^{d}	273.30^{i}	264.46^{i}	30.83^{d}	8.50^{g}
-5345	±13.33	±31.65	±35.46	±56.16	±28.44	±2.82	±18.89	±18.47	±2.35	±0.47
Buffalo	881.37^{e}	2392.29^{j}	3691.02^{i}	5283.41^{g}	6539.75^{g}	5.64^{b}	152.93^{c}	147.16^{c}	25.50^{b}	11.43^{i}
-5725	±13.33	±31.65	±35.46	±56.16	±28.44	±2.82	±18.89	±18.47	±2.35	±0.47

\# Data with different superscript in the same column differs significantly from each other ($P<0.001$).

investigation was observed to be 95.31% (i.e. 183.95 periodic pulses out of 192.99 pulses). The voice from buffalo M-416 was most periodic with a periodicity of 99.16% (i.e. 317.86 periodic pulses out of 320.56 pulses) while the voice from buffalo M-5308 was least periodic with a periodicity of 91.92% (i.e. 52.36 periodic pulses out of 56.96 pulses) (Table 2). As a significant difference in number of pulse and number of periods for voice signals from all the buffaloes were observed in present investigation hence these acoustic features or periodicity in voice signals might be considered as one of the best suited acoustic feature in individual identification. Besides it was observed that mean period for buffalo M-5345 was highest (0.0094 ± 0.0003sec) and lowest for buffalo 454 (0.0059 ± 0.0003 sec).

These acoustic features indicate how harsh or soft a sound signal is. The least squares analysis of variance revealed that vocal signals from Murrah buffaloes differed significantly ($P<0.001$) for various acoustic features viz. unvoiced frames, degree of voice breaks, jitter, shimmer, mean noise to harmonic ratio and mean harmonic to noise ratio (Table 1) and the overall mean for these acoustic features in present study was observed to be 16.40 ± 0.48%, 20.78 ± 0.89%, 1.83 ± 0.05%, 7.40 ± 0.11%, 42.51 ± 0.74% and 6.82 ± 0.15 dB respectively. As the value of unvoiced frames (4.66 ± 1.53%) and degree of voice breaks (4.29 ± 2.82%) were lowest for buffalo M-416 hence her voice was considered to be most periodic out of all the 10 individuals. The jitter values (0.48 ± 0.16%) for buffalo no. 416 was lowest out of the 10 individuals; it implied that this particular buffalo was least nervous. At the same time highest shimmer (9.91 ± 0.37%) and highest jitter (2.89 ± 0.16%) for buffalo 442 revealed that her voice was softest one among all the other buffaloes, even after extreme nervousness. The highest mean noise to harmonic ratio (62.83 ±2.35%) and lowest mean harmonic to noise ratio (2.86 ± 0.47 dB) for buffalo 5308 reflected that her voice was least harmonic or musical while the reverse values of these features (15.34 ±2.35% and 11.96 ± 0.47 dB) for buffalo 416 indicated that its voice was most musical. As the differences for degree of voice breaks mean noise to harmonic ratio and mean harmonic to noise ratio was found to be significant for all the 10 individual buffaloes thus it was obvious that these acoustic features could be used as one of the best suited features in discrimination of individual Murrah buffaloes.

Thus it is obvious from above that vocal signals changed significantly from one buffalo to other which is helpful in discrimination of individual buffalo. Similarly Jahns *et al.,* (1997), reported that individual cows could easily be differentiated by analyzing the power spectrum density (PSD) of their voice signals but it was not sufficient to identify the meaning of the calls. Ikeda and Ishii (2008), could differentiate four cows by mapping the power spectrum density vectors of their 99 voice samples in 2D space and observed that PSD vectors for the different cows were concentrated in different regions of 2D map.

The basic concept behind present investigation was that an individual could be easily identified only by hearing it from a large distance even without seeing. It reflected that certainly there existed some qualitative difference in the voice of one individual from other. Moreover, as the basic anatomy, physiology, endocrinology and mechanism of voice production in animals are quite similar to that of human beings; hence there must be the similar kind of differences between the vocal signals of dairy buffaloes. Thus, it may play a vital role in differentiation of individual buffaloes, as have been experienced by many farmers closely engaged in animal husbandry practices.

The waveform and spectrogram (Fig. 1) of voice signal reflected the identifiable differences for various acoustic features of individual buffalo. As none of the amplitude related acoustic features could significantly differentiate the vocal signals uttered by all the 10 Murrah buffaloes, hence these could not be considered as one of the best suited acoustic feature in discrimination of individuality of dairy buffaloes. The peak energy (gain) of voice signals from 5 different Murrah buffaloes also reflected significant difference in their vocalization patterns (Fig. 2). Voice signals from different individuals received their energy peaks at different time period and for different duration (Fig. 2). An identifiable difference was also observed for the number energy peaks gained in a definite time window for different animals. Fig. 2 also presented an obvious difference in the total energy (area under curve) of a voice signal from 5 different Murrah buffaloes. It revealed visible demarcations between the vocal signals articulated from different Murrah buffaloes. Despite identifiable demarcations in peak energy of Murrah buffaloes, the present study could not establish a significant difference for total energy and mean power of voice signals from all the 10 Murrah buffaloes. It reflected that these features could not be considered to be much effective in quantitative discrimination of Murrah buffaloes from each other.

As the pitch variables for the voice signals from different buffaloes did not reflect a significant difference for all the 10 individuals, hence could not be considered suitable acoustic feature for individual discrimination. The least squares mean reflected higher right side skewing (84-50%) of pitch for voice signals almost from all buffaloes as compared to that of left side skewing (50-16%) from median

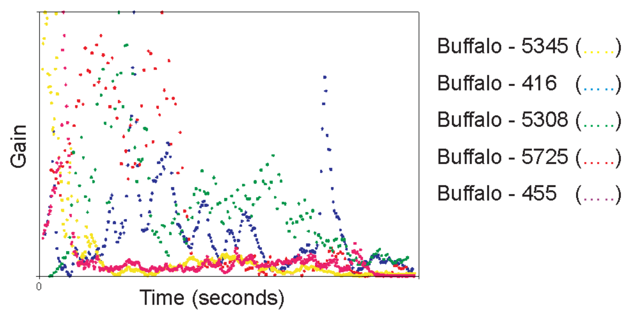

Fig. 2. Energy peaks (gain) of a voice signal from five different Murrah buffaloes.

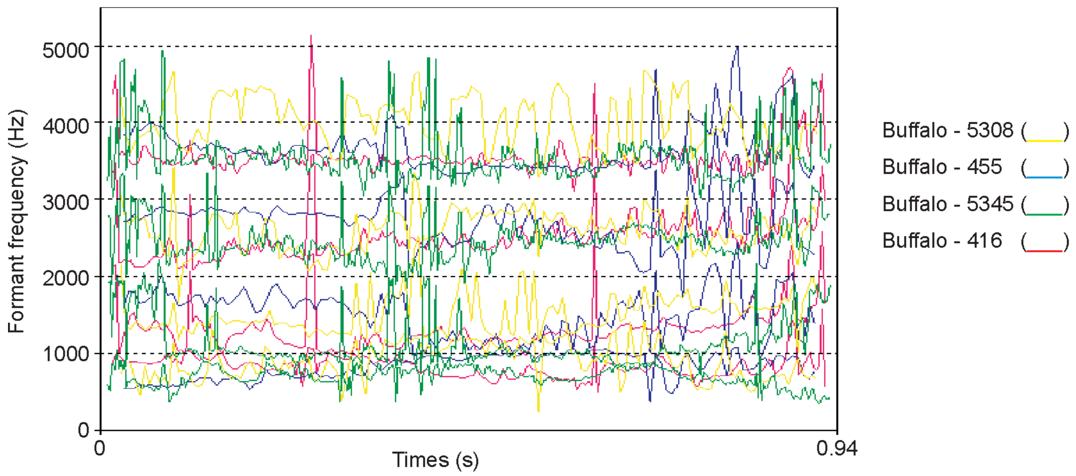

Fig. 3. Tracks of formants for a voice signal from four different Murrah buffaloes.

(Q50%) value and similar trend was also observed for overall mean of 10 buffaloes for estimated pitch spreading. Thus, pitch related acoustic features were suitable only in qualitative differentiation of vocal signals from different individual buffaloes.

Least squares mean table for resonance frequencies clearly reflected that all the 5 formants differed significantly for voice signals from all the 10 Murrah buffaloes; indicating that these 5 formants could be used as one of the most preferred acoustic features for individual identification through vocal signal processing. Plot for resonance frequency tracks against time (second) also revealed an identifiable difference between vocalization patterns of Murrah individuals (Fig. 3). Four different formant tracks were clearly visible in picture window for a single voice signal from four different Murrah buffaloes. Moreover, distribution of F1 and F2 formants for all frames of one voice signal from above 4 Murrah individuals in a 2-D space were found to be concentrated in different identifiable regions (Fig. 4). Similar to the results of present experiment, Ikeda and Ishii (2008) also reported that lower formants were more stable as compared to that of higher ones. The second, third, fourth and fifth formants in present investigation could not be observed to be absolute twofold multiple integers of the fundamental frequency it might be due to the fact that wind pipe or trachea of animals are not rigid in nature but are flexible. As the trachea is surrounded with many cartilaginous rings, its diameter may change in different time domain, more precisely many times in single call duration. But as this variation in diameter remains very little the higher formants were observed to be almost twofold multiple integers of the fundamental frequency. From present investigation it was also observed that calls from different individuals consisted of one fundamental frequency which is referred as first harmonics and many other smaller notes called as overtones and sum of all the harmonics was the waveform which denoted the quality of sound signals. As the values of these tones and overtones for voice signals from different individuals were specific hence these could be considered to be an efficient acoustic feature for differentiation of individual buffaloes.

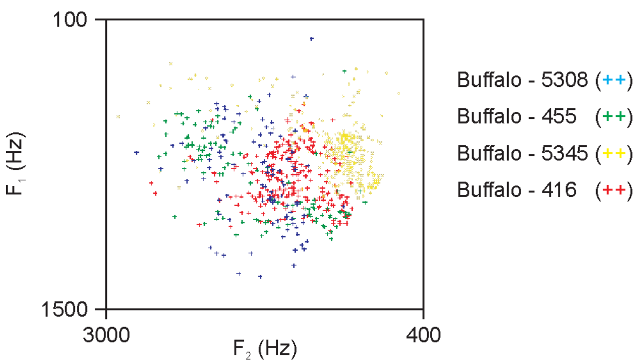

Fig. 4. Discrimination of four Murrah buffaloes with the help of 2D plot of F1 and F2 formants.

The waveform and spectrogram (Fig. 1) of sound signals from buffaloes in present investigation consisted pulses which were mostly periodic i.e. sound waves uttered from these buffaloes do repeated themselves at regular interval, which indicated that voice signals from these buffaloes were musical. The concentration of periodic pulses was higher from beginning and abruptly low in the end. Thus, the buffaloes in present investigation started with a musical sound which usually abruptly ended into a harsh sound with low intensity and loudness. Moreover, degree of voice breaks, mean noise to harmonic ratio and mean harmonic to noise ratio also represented that the voice signals from buffaloes consisted of more harmonic or pleasant signals. The findings of present investigation were quite similar to those reported by Singh *et al*. (2013) in which it was observed that acoustic features from voice signals of dairy cattle was significantly affected by their individuality.

Out of so many acoustic features considered in present investigation, it was observed that almost all the acoustic features reflected a significant effect of individuality on vocal signals from Murrah buffaloes but only few of them viz. formants (F1, F2, F3, F4 and F5), degree of voice breaks, number of periods, number of pulse, mean noise to harmonic ratio and mean harmonic to noise ratio, could be found to show a significant difference for vocal signals uttered by all the 10 individual buffaloes, hence only these features could be selected as the best suited descriptors in discrimination of individual buffalo from its herd and other features could be used in qualitative differentiation of individual buffalo.

Thus from above results it could be concluded that vocal signals uttered from different buffaloes, changed significantly for many acoustic features from one to other individual. As the values of all the 5 formants, degree of voice breaks, number of pulse, number of period, mean noise to harmonic ratio and mean harmonic to noise ratio differed significantly for voice signals from all the 10 individual dairy buffaloes, hence these acoustic features might be considered as the one of the most preferred features to discriminate individual buffalo through acoustic sensing technology. Identification and discrimination of dairy buffaloes through acoustic sensing thus seems to be possible by using above said acoustic features.

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