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INVESTIGATIONS OF THE PHONEMES IN THE CALLS OF LITTLE OWLS USING VECTOR QUANTIZATION

Randhir Singh*, Parveen Lehana* & Gurpadam Singh***

Birds have developed excellent capabilities of using vision and hearing senses. Their temporal resolution is 10 times better than us. This allows more information to be communicated in lesser time. Bird's sounds can be divided into four categories: chip notes, calls, songs, and composite sounds. The vocal apparatus in birds consists of an oral cavity, larynx, trachea, syrinx, and lung system. The vocal tract above the larynx is very short and effectively terminates at lateral edges of an open beak. The bird larynx consists of muscular folds whose aperture can be regulated to prevent food particles from entering the respiratory system during ingestion. During vocalization the acoustic tube formed by vocal tract above and trachea below can be constricted at larynx by the action of laryngeal muscles. Trachea is terminated below by a special sound producing organ called as syrinx. It is clear that basic structure of sound production mechanism of birds is similar to that of human beings. As the human beings is composed of small units called phonemes, the bird's calls can also be assumed to be made of small units. The objective of this paper is to investigate the number of phonemes present in the little owl's calls. Scope of this research is limited to only the sounds of little owl because of their special nature to communicate during noiseless environment. This may modify their adaptation with respect to phonemes.

Keywords: Bird's Sounds, Bird's Calls, Little Owl's Calls, Call's Types, Chip Notes.

1. Introduction

Birds are excellent in using vision and hearing capabilities for detecting prey. A barn owl can hunt mice by sound alone; woodpeckers can hear insects moving under the bark of a tree; pigeons can detect the infrasonic waves (under 16 vibrations per second) that come just prior to an earthquake. But it is the auditory stimuli of other birds that is often most important. Auditory signals help birds detect and locate danger, territory, food and shelter. Birds hear a greater range of sounds than humans. The birds are able to hear and produce sounds within a few days of birth. They have developed sense of time resolution, which is about 10 times better than ours. Several separate notes in sequence may sound to us like one long note. Because of their time resolution ability they hear the note separated into the smaller segments. This allows more information to be communicated.

Bird's sounds can be divided into four categories: chip notes, calls, songs, and composite sounds. Chip notes are short and high-pitched notes given by species such as warblers and sparrows. These are used to announce a food source or stay in contact with other birds of the same species. Calls are composed of either a single emphatic note or a series of notes and may be divided into 10 main categories [1] as shown in Table 1.

Table 1
Bird's Calls

S.N.	*Type*	*S.N.*	*Type*
1	General alarm calls	6	Flight calls
2	Specialized alarm calls	7	Nest calls
3	Distress calls	8	Flock calls
4	Aggressive calls	9	Feeding calls
5	Territorial defense calls	10	Pleasure calls

The analysis of calls is very difficult because many birds use very similar calls in different contexts to convey different messages. Most birds seem to have between 5 and 15 distinct calls.

Songs are the most complex sounds of birds. Singing is a mechanism used by birds to communicate their emotions to other living beings, mostly other companion birds. These are generally used to attract a mate. Not all birds sing. Singing is limited to Passeriformes and perching birds, whose population is nearly half of the total birds in the world. Song birds came into the knowledge around 60 million years ago. Birds of some species are born with the ability to sing their unique song. Eastern phoebes, for example, can sing their raspy two-noted fee-bee, even if they have never heard another phoebe sing.

Some times the bird's sounds are complex combinations of many basic sounds. It is not necessary for all sounds to

* ECE Dept., Sri Sai College of Engineering and Technology, Badhani (Pathankot), Punjab, India. *E-mail: er_randhir81@rediffmail.com*

** Department of Physics and Electronics, University of Jammu, Jammu, India. *E-mail: lehana@iitb.ac.in*

*** ECE Dept., BCET, Gurdaspur, Punjab, India. *E-mail: gurpadam@yahoo.com*

be vocal. For example, Woodpeckers rap and several species have specialized feathers and behavior designed to send an audible message. These types of sounds may be grouped in fourth category that is composite sounds.

Three mechanisms are used by the birds to learn the production and recognition of the sounds. Some birds are born with the inherent capabilities. Most young birds learn sounds from their parents. Some of birds learn these skills from other adult males of their kind. By the following spring, all the males need to perform the song well if they hope to attract a mate. The chipping sparrow learns its simple series of musical chips from another male chipping sparrow nearby. Some male birds, such as the song sparrow, learn a repertoire of two or three songs, which they sing over and over. Birds of the same species may have different accents depending on their geographical location.

The vocal apparatus in birds consists of an oral cavity, larynx, trachea, syrinx, and lung system. The vocal tract above the larynx is very short and effectively terminates at lateral edges of an open beak. The bird larynx consists of muscular folds whose aperture can be regulated to prevent food particles from entering the respiratory system during ingestion. During vocalization the acoustic tube formed by vocal tract above and trachea below can be constricted at larynx by the action of laryngeal muscles. Trachea is terminated below by a special sound producing organ called as syrinx. It is clear that basic structure of sound production mechanism of birds is similar to that of human beings.

Klatt [2] has shown that mynah can imitate human speech very effectively using its tongue. Other birds are not so efficient, but they can produce limited number of phonemes by modulating the behavior of the syrinx. The objective of this paper is to investigate the number of phonemes present in the little owl's calls. It is very difficult to collect and analyze the sounds of all birds; hence, scope of this research is limited to only the sounds of little owls because of their wide spread population obtained from different sources. The detailed explanation of sound producing mechanism in birds is explained in the following section. The methodology and results & conclusions are presented in the subsequent sections.

2. Mechanism of Sound Production

Birds do not have a larynx like human beings. Instead they have an organ called a syrinx (Figure 1) [3]. Syrinx may be located at the junction of the two primary bronchi and the trachea or entirely in the trachea or in the bronchi. Syrinx resembles human vocal cords in function, but it is very different in form. Also the vocal tract, whose main parts are trachea, larynx, mouth and beak, interacts to the sound of birds [4]. When a bird is singing, airflow from lungs makes syringeal medial tympaniform membrane (MTM) in each bronchi to vibrate through the Bernoulli effect [5]. The membrane vibrates nonlinearly opposite to the cartilage wall. Voice and motion of the membrane is controlled by a symmetrical pair of muscles surrounding the syrinx. Membranes can vibrate independently to each other with different fundamental frequencies and modes.

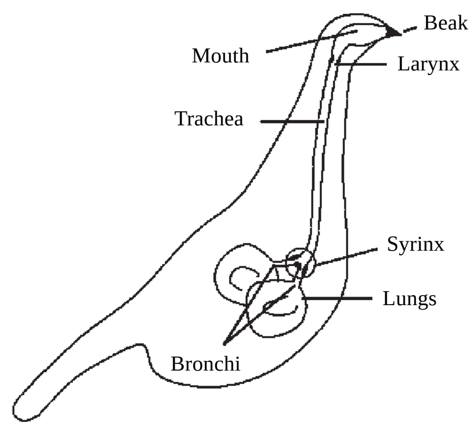

Figure 1: Sound Producing Mechanism in Birds

Membranes are pressure controlled like a reed in woodwind instruments, but membranes are blown open while the reed in the woodwind instruments is blown closed.

In contrast to the MTM theory recent studies with endoscopic imaging have shown that MTM would not be the main source of sound [6]. Goller suggests that sound is produced by two soft tissues, medial and lateral labia (ML and LL), similar to human vocal folds. Sound is produced by airflow passing through two vibrating tissues. Further evidence to this comes from a study where MTM's were surgically removed [7]. After removal birds were able to phonate and sing almost normally. Small changes in song structure however were found, which indicates that MTM's have a function in sound production. However it is possible that birds may be able to compensate the loss of MTM. Also, because of large diversity in structure of avian syrinx and also in sounds, it is possible that the MTM theory is correct for some species. For example Goller and Larsen limited their study only to cardinals (Cardinalis cardinalis) and zebra finches (Taeniopygia guttata). In contrast in [8] ring doves (Streptoperia risoria) were studied as evidence for the MTM theory. Furthermore in [9] it was found that the main source of sound in pigeons and doves is the tympaniform membrane. However this membrane is located in the trachea and not in the bronchi.

The anatomy of the syrinx and the avian vocal tract vary considerably among different orders of birds and sometimes even in different families within the same order. Syrinx may act as a double instrument for generating two different notes at the same time, or even sing a duet with itself. For example thrushes use this mechanism; they are even capable of singing a rising note with one side and a falling note with the other. It is this sort of ability that allows some birds to sing as many as 30 separate notes per second.

Stucture of bird song has large diversity. Typical song may contain components which are pure sinusoidal, harmonic, nonharmonic, broadband and noisy in structure [10]. Sound is often modulated in amplitude or frequency or even both together (coupled modulation) [11]. Frequency range is relatively small, typically fundamental frequency lies between 3 and 5 kHz. A well-established way to divide song into four hierarchical levels is: elements or notes, syllables, phrases, and song [12]. Elements can be regarded as elementary building units in bird song [13] whereas phrases and songs often contain individual and regional variation. Duration of one syllable ranges from few to few hundred milliseconds.

3. METHODOLOGY

A. Characteristics of Little Owls

The Little Owl is a bird which is resident in much of the temperate and warmer parts of Europe, Asia east to Korea, and North Africa. Latin name of little owl is Athene noctua. This small owl was introduced to the UK in the 19th century. Little owls have a wingspan of 54-58 cm and are 21-23 cm long. The males weigh an average of 170g and the female's average 174g. Their back and wings is a deep grey-brown, spotted with white. The underside is white with broad, broken streaks of grey-brown. The face is marked by dark areas around the yellow eyes that give a frowning look. Extremely acute eyesight, sees well night or day. Eyes fixed in sockets, can only look straight ahead, turns head to see surroundings, head can swivel 270°. It will bob its head up and down when alarmed. They feed on a wide variety of prey-mostly small mammals, such as mice, voles, shrews, even small rabbits, as well as insects, earthworms, snails, slugs and small fish. They can be found all year round, during the day. It hunts at night and dawn. The environment at this time is generally quite and this may modify the adaptation of owls to communicate using the whole available spectrum. This is a sedentary species which is found in open country such as mixed farmland and parkland. Little owls also occupy woodland, fields, coastal areas and semi-desert areas. They nest in tree holes, pollarded willows, walls of old buildings, rabbit burrows and cliff holes. The female lays 3-5 eggs in early May and incubates the eggs for 29 days. Only the male feeds the chicks at first, but later the female helps. After 26 days, the chicks leave the nest. If living in an area with a large amount of human activity, Little Owls may grow used to man and will remain on their perch, often in full view, while humans are around. It can be seen in the daylight, usually perching on a tree branch, telegraph pole or rock. Little owls are not considered to be at threat, and there is a population of 9,000 pairs in the UK [14]-[17].

B. Recording Material

The main call of a Little Owl is a ringing kiew, kiew, repeated every few seconds. The second is a rapidly repeated, yelping wherrow. Little owls use a variety of chattering notes at the nest and in particular during the breeding season a loud hoo-oo note. We have taken five calls of little owls from [18], [19] of Athene noctua or Civetta. These calls were recorded at Poderone near Magliano in Toscana (Latitude: 42°36' N, Longitude: 11°17' E). The detail of these calls is given below.

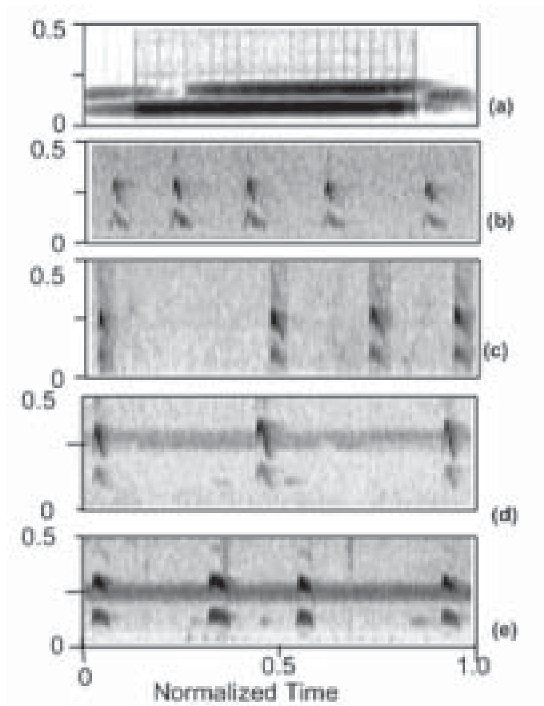

Figure 2: Spectrograms of the Five Calls Described in Section3-B.

CALL 1: One male sings (not seen) perched somewhere in a cultivated field with scattered olive trees (Date: 01 Feb'04, Time: 6.00 p.m., Altitude: +130 m).

CALL 2: One bird (not seen) is perched somewhere in a cultivated field with scattered olive trees. It seems to answer to the male hoots of call 1. Might be a female answering to her mate (Date: 01 Feb'04, Time: 6.00 p.m., Altitude: +130 m).

CALL 3: One bird (not seen) is perched on a pine tree over a camping area, which is full of tourists; zone with cultivated fields and farms. A slightly different "kew" call, maybe less excited compare with Call 2 (Date: 23 Aug'04, Time: 10.30 p.m., Altitude: +17 m).

CALL 4: One bird (not seen) is perched on a pine tree near the border of Patanella pinewood. A third different example of "kew" call. Maybe the bird is slightly anxious, because sound recoder quite close to its perch (Date: 24 July'05, Time: 0.30 a.m., Altitude: 0 m).

CALL 5: One bird (not seen) is perched on an oak tree in a zone with cultivated fields, vineyards and woods. A plaintive cry, not unlike Call 3, but less bisillabic (Date: 4 July'07, Time: 11.30 p.m., Altitude: +130 m).

C. Signal Processing

The five calls were analyzed individually and collectively for obtaining 21 order mel frequency cepstral coefficients (MFCC's) using a hamming window of 10 ms with 1 ms shifting. The calls were analyzed at sampling frequencies of 8 kHz and 44.1 kHz. The MFCC's of each individual call were used to get the centroids of the calls. The centroids were obtained by using vector quantization. Total of 2, 4, 8, 16, 32, and 64 centroids were used for estimating the number of phonemes. For calculating the MFCC's the windowed signal was used to obtain 1024 point FFT. The process for this is shown in Figure 3.

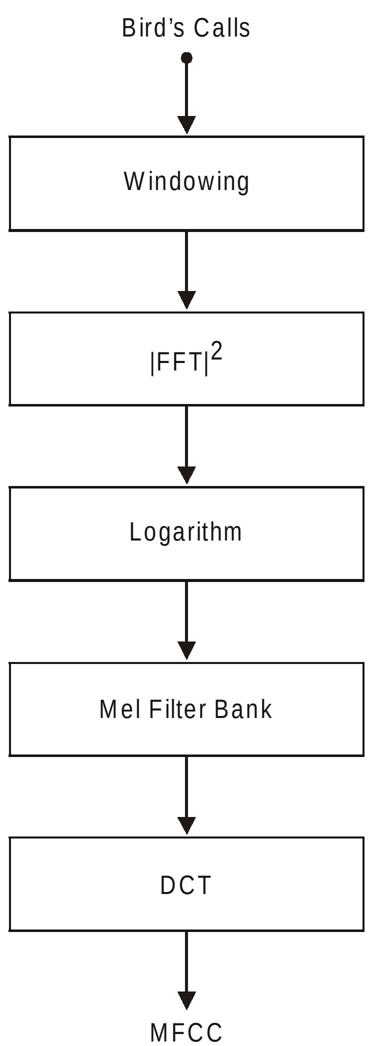

Figure 3: Estimation of MFCC's from Bird's Calls

After estimating the energy Em in each critical band in the spectrum by using a triangular function [20], MFCC's were calculated as

$$c_m = A\sum_{m=0}^{M-1}\cos\left(j\frac{\pi}{M}(m+0.5)\right)\log_{10}E_m \qquad (1)$$

The factor A was taken as 100 [21]. The order of MFCC's , M, is taken as 21.

The Euclidean distances among the centroids were found and plotted as 3-D plots using multiple colours. Each colour represented a specific range of distances. The 3-D plots were analyzed at different viewing angles to estimate the total major shades of the colours. The number of shades indicated the number of phonemes in the little owl's calls.

The other mathematical model to estimate the total number of phonemes can be derived from statistics of the Euclidean distances for all recorded calls of the owls. If we assume that the approximate distance between two consecutive phonemes in 20 dimensional plots is around 10% of the average value of all the distances among centroids, the equation for estimating the number of phonemes can be written as

$$p = 2\sigma / (0.1m) \qquad (2)$$

where σ is the standard deviation and m is the mean of the 64 centroids of all calls.

4. RESULTS AND CONCLUSIONS

The spectrograms of some segments of the calls used for these investigations are shown in Figure 2. The analysis of the spectrograms show that in each call, there are some finite variations of duration, silence, formants, randomness of spectral structure, and amplitudes. It is difficult to say whether each call is composed of a single phoneme or multiple phonemes.

The plots in Figure 4 show the centroids estimated for the five calls of little owls, described in Section 3-B. The first column is for sampling frequency of 8 kHz and second column is for 44.1 kHz. It can be observed that there is a definite effect of sampling frequency on the centroids. Hence, for further analysis, only sampling of 44.1 kHz was taken to take in to acound the high resolusion of birds.

Further, from the analysis of the centroids of individual calls, it was observed that there were considerable differences in the single centroids and multiple centroids. It tells us that each call may be composed of more than one phoneme. As the number of centroids are increased from 8 to 32, the plots become very confusing after 16 centroids (Figure 4). Many centroids strats coming close to each other. It means, the total number of phonemes may be expected less than 16. For deriving a solid conclusion, the centroids for all the five calls were analyzed.

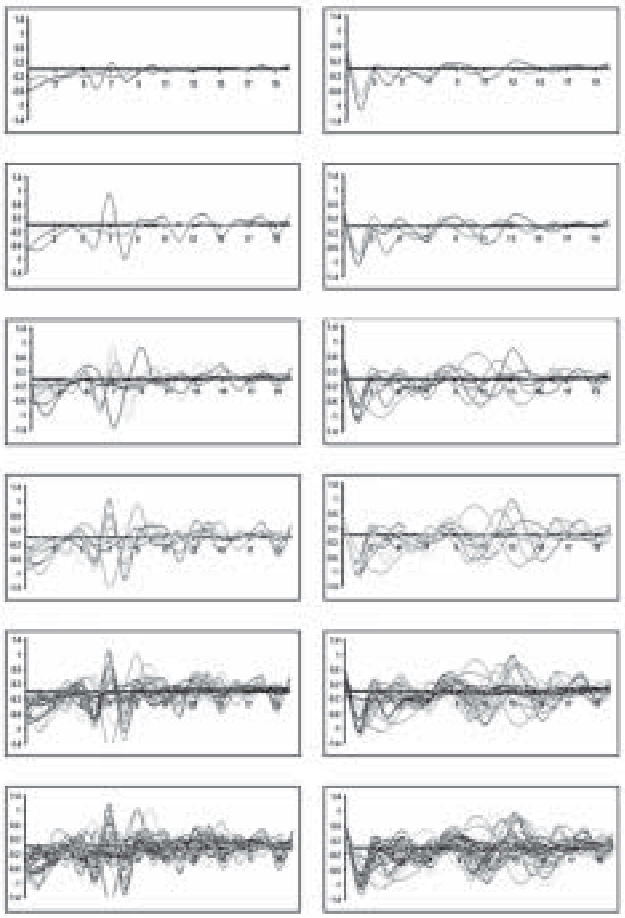

Figure 4: Comparison of MFCC's of all the Five Calls of Little Owls Collectively Analyzed. The First Column is for Sampling Frequency of 8 kHz and the Second Column is for 44.1 kHz. The Numbers of Centroids for these Plots are 2, 4, 8, 16, 32, and 64.

Three dimension plots of the distances between 64 centroids are shown in Figure 5. Each plot is taken for different viewing angle for observing the total number of phonemes. It can be concluded from these plots that the total numbers of colours in all the plots viewing at different angles fall in the range of 9 to 10. It means, the total number of phonemes for little owls may be around 10. It should be noted that total number of messages communicated by the little owls may be more as the silence duration also plays a major role in deciding the meaning of the calls.

The statistical analysis of the calls showed that the standard deviation and average values of the Euclidean distances among the 64 centroids is 2.09 and 4.45, respectively. If we estimate the total number of phonemes from (2), it comes as 10. This number is in close agreement with the results obtained from 3-D plots. Hence, total number of phonemes in the calls of little owls may be around 10. It should be noted that the number and types of phonemes may be slightly different for little owls belonging to different habitats.

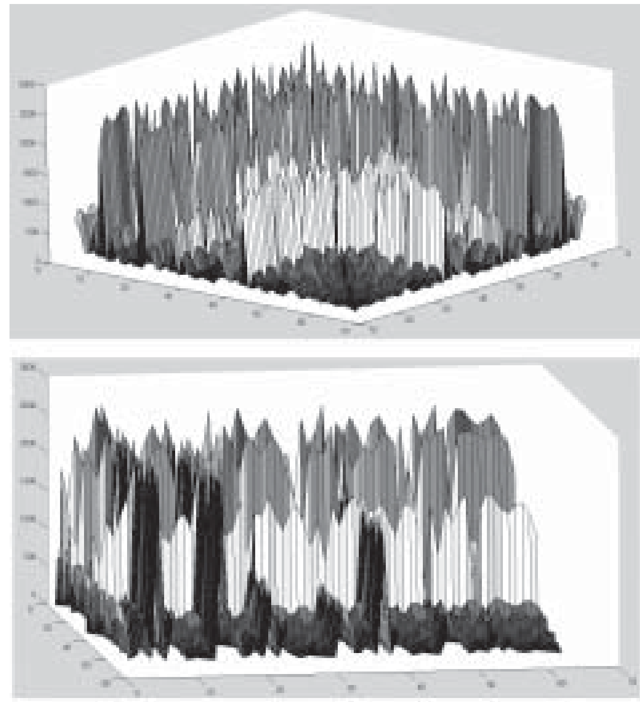

Figure 5: Three Dimension Plot of the Distances between Different Centroids of all the Five Calls of Little Owls. Each Plot is taken for Different Viewing Angle for Observing the Total Number of Phonemes (Basic Sound Elements). The Total Number of Centroids are taken as 64. The Sampling Frequency is Fixed at 44.1 kHz. (View 1 and View 2).

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