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Analysis and Synthesis of Elephant Calls Using Linear Predictive Coding

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Abstract**—** One of the most interesting features of elephant is that they use acoustic signal for both long and short distance communication. An extensive studies are carried out for African elephants and very little is known about the Asian elephants. In this research paper, elephant calls are synthesized using linear predictive coding (LPC) technique. Four different elephant calls are synthesized using LPC and perceptual evaluation of the synthesized calls are carried out. Also, the effect of prediction order in LPC on synthesized elephant calls is investigated.

Keywords**—**Acoustic signal; elephant calls; LPC; call synthesis.

I. Introduction

Elephant habitats are shrinking and their conflicts with humans are on the rise. A pressing need exists for information about the location, size, and reproduction health of existing elephant population [1]. Thick forests are the natural habitats of elephants where they sped most of their time. Old techniques like counting elephant dung piles on paths which cut through the forest are used to estimate the elephant number in that area [2]. This technique is extremely labour intensive. This constraints lead to the exploration of acoustic techniques for elephant monitoring.

Elephants are highly social animals, which have well developed communication that uses all of their senses: hearing, smell, vision and touch [3]. Communication techniques used by elephants can be categorised as:

- Visual communication: Elephants have good eye sight in dull light but it reduces to maximum range of 46m in bright light. Elephant send visual signal through heads, eyes, mouth, ears, tusks, trunk, tail, feet and even their whole body to signal messages to one another and to other species. A dominant elephant signals his/her status by appearing larger, carrying his/her head high above their shoulders. A socially excited elephant lifts and rapidly flaps his/her ears and widens his/her eyes [4].
- Tactile communication: This type of communication occurs between elephants during a broad range of contexts including aggressive, defensive, affiliative, sexual, playful, care-taking and exploratory behaviour [4].
- Seismic communication: The fundamental frequency and second harmonic of an elephant rumble produce 10 and 40 Hz signal. When elephant rumbles a replica of the airborne sound is also transmitted through the ground.Speed of elephant sounds have been measured as travelling at about 309m/s through air and 248-264m/s through the ground [5-7]. Elephants detect these seismic vibrations through bone conduction and through massive ossicles of their middle ears or possibly by mechano-receptors in the toes or feet that are sensitive to vibrations.
- Chemical communication: Animals uses this technique to communicate with each other. Elephant raise their trunks up to sniff the air, or use the tips of their trunks to explore the ground as well as to sniff the genitals, temporal glands, or mouths of other elephants. This technique of communication provides an energetically efficient and longlasting signal [8].
- Acoustic communication: Acoustic signals are omni directional and short lived signals. Environmental conditions degrade the strength of these signals by phenomenon like reflection, refraction, and absorption and these effects are greater for high frequency sound signals than for low frequency sound signals. The speciality of elephants is the production of low frequency sound signals for long distance communication. Elephants produce a broad range of sound which can be categorised as barks, roars, cries and other idiosyncratic calls. Asian elephants also produce chirps. Rumble is the most frequently used call for African elephants. Atypical male elephant rumble fluctuates around an average minimum of 12 Hz, a female elephants rumble around 13 Hz and a calf's around 22 Hz. Elephants can produce very gentle, soft sounds as well as extremely powerful sounds [9-11].

In this research paper elephant calls are synthesised using LPC technique. Comparative analyses of the synthesised calls are carried out using PESQ score obtained with respect to the originally recorded elephant calls.

II. Sound Production Mechanism

Sound is produced by elephant as air expelled from the lungs is passed over the vocal chords or larynx. Depending upon the type of sound elephant is making, the vocal cords are vibrated at particular frequency by the moving air. Elephants can control the contraction and expansion of vocal chords which enables them to produce a wide range of frequencies. The air vibrations are in the elephants vocal tract are extended

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depending upon the posture of trunk, mouth, tongue, pharyngeal pouch, and larynx, which can amplify different components of the sound.

Figure 1 shows the vocal folds of the elephants. They are attached to anteriorly, close to the broad base of the epiglottis. The vocal folds are arranged at an angle of 45° with respect to the longitudinal axis of the trachea. Only three fifth of the vocal folds are directly exposed to the passing air from the lungs due to the position of the larynx in relation to the trachea [12].The anatomical measurements of elephant larynx is given in Table 1.

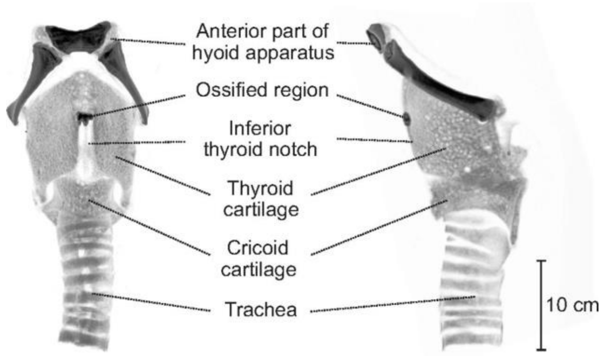

Fig. 1. Anatomy of the excised elephant larynx using 3D computed tomography [12].

Table 1. Measurements of elephant larynx.

Structure	Dimensions
Thyroid cartilage width	112 mm
Thyroid cartilage angle	31 degree
Cricoid cartilage width	80 mm
Maximum vocal fold thickness	32 mm
Maximum vocal fold length	104 mm
Vocal fold length (inferior edge)	88 mm
Vocal fold length (superior edge)	97 mm
Maximum vocal fold width	29 mm

III. Linear Predictive Coding (LPC)

It was first introduced by Gauss in 1795 [13]. Since then it has found wide range of applications. It's been implemented in neurophysics to describe the spectra of EEG signals [14], used to model seismic traces to determine the traces of oil [15], and used to model speech waveform to estimate the speech parameters [16]. LPC model predicts the speech signals by estimating the present instant value from previous values. The basic equation used in LPC is given as:

$$s'(n) = \sum_{k=1}^{p} \alpha_k{}^{s(n-k)}$$

where s'(n) is the estimated sample of the actual sample s(n) from the linear p combination of samples with α_kas the coefficients.

In order to have accurate prediction, the prediction error must be minimized. The prediction error given below should be minimized.

$$E = \sum_n e^2(n)$$

where E is the short time average predication error

$$e(n) = s(n) - s'(n)$$

e(n) = individual error.

IV. Methodology

Research work is carried out to synthesize and analyses elephant calls using LPC technique. Also the effect of the prediction order in LPC on synthesised elephant call is investigated. Objective evaluation method i.e. Perceptual Evaluation of Speech Quality (PESQ) is used for the comparison of the original and synthesized elephant calls. The block diagram of the methodology is shown in Fig. 2. A high quality sound recording system is used to record the sound produced by Asian elephant. Four sound signals are subjected to be synthesized using LPC techniques. Various prediction orders ranging from 10 to 80 is taken in LPC algorithm and sound signals are synthesised.

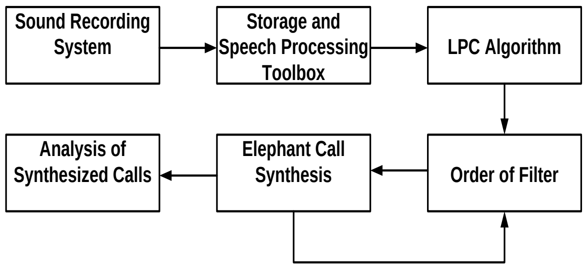

Fig. 2. Schematic of methodology.

V. Results

Figure 3(a)-(d) shows the normalized recorded elephant calls and their respective spectrogram. The computed PESQ score of synthesized elephant calls I, II, III, and IV with respect to original elephant calls are given in Table 1. Figure 4 shows the pictorial view of the PESQ score of synthesized elephant calls with different order of prediction in LPC. In the graph x-axis represents the prediction order in LPC ranging from 10 to 80 and y-axis is the magnitude of the PESQ score. The inference drawn from the results is that at lower prediction order i.e. M=10, the PESQ score obtained is below 2 which represents very poor quality of synthesized call. As the order is increased the PESQ score reaches a magnitude of approximately 2.5 at order 40, which is acceptable range of PESQ. Further increasing the prediction order increase the PESQ score increases and saturates.

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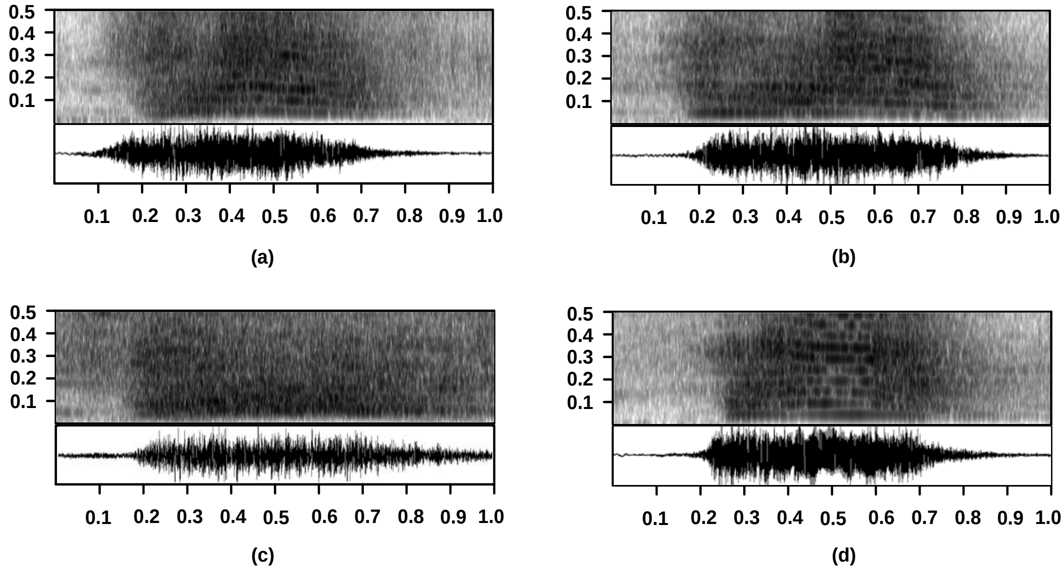

Fig. 3. (a)-(d) Normalized signal and spectrogram of four different calls of elephant.

Table 1.PESQ score of I-IV elephant calls w.r.t. original elephant calls.

LPC Prediction Order (M)	PESQ Score Call I	Call II	Call III	Call IV
10	1.3894	1.4339	1.9816	1.478
20	2.0441	1.9844	2.2649	1.9161
30	2.4644	2.2799	2.3278	2.1642
40	2.5553	2.3621	2.3107	2.3423
50	2.6688	2.6059	2.4497	2.4994
60	2.6199	2.5206	2.5137	2.5316
70	2.6174	2.5295	2.5216	2.5342
80	2.6184	2.5252	2.527	2.5322

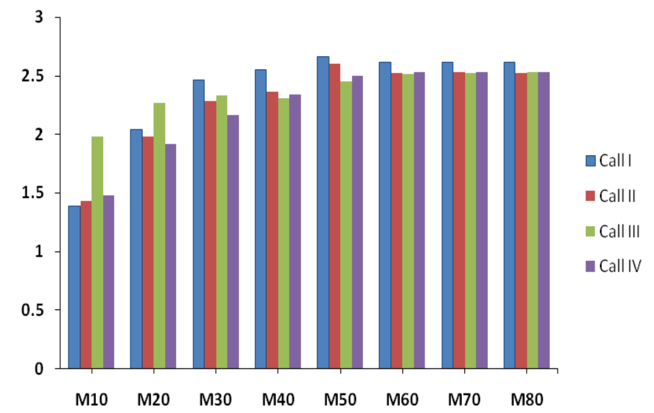

Fig. 4. PESQ score with different prediction order.

VI. Conclusion

A preliminary investigation of Asian elephant calls synthesis using LPC technique has been presented. The effect of prediction order in LPC has been evaluated and it is observed that with order M = 10 the PESQ score is around 1 which gives poor quality of elephant calls and fair quality is obtained for M ranging from 20-40. PESQ score for M ranging from 50-80 is more than 5.6, which is good quality of synthesized calls. Future studies are required to gain insight of acoustic signals generated by Asian elephants and different techniques to synthesis the calls.

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