Acoustical Analysis of Pain Cries' in Neonates: Fundamental Frequency

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ABSTRACT
Infant crying comprises a rhythmic alternation of cry sounds (utterances) and inspiration. A method for knowing the reason of baby's cry is proposed using frequency analysis of the recorded voice. The analysis has been done by using Welch's method and performing Fast Fourier Transform (FFT). The frequency analysis helps in finding the different tendencies of the Fourier spectrum for different causes. To find the cry type, fundamental frequency is considered. The acoustical analysis of cry, it is found that the fundamental frequency f_0 for cry due to pain is found to be around 400Hz. The male cry f_0 is higher than the female cry mean f_0.

Keywords
Frequency Analysis of cries, Neonates, .

1. INTRODUCTION
A Neonate or newborn infant refers to an infant in the first 28 days of life. Crying is the only communication means that the baby has in the first month of life; before the use of signs or words. They express their needs and feelings through cry. Babies cry due to various causes such as hunger, sleepiness, pain, loneliness, discomfort, wetting of cloth, etc. It is often difficult to know the exact cause because they can express by cry only.

During crying, the volume, the pitch (i.e., the fundamental frequency) and the tone-color change [1]. The period associated with the fundamental f_0 is usually known as pitch. Fundamental frequency is median frequency in Hz of vocal fold vibration heard as voice pitch [2]. The present work explicitly refers to this quantity. The effectiveness of such an approach can be enhanced significantly using advanced signal processing technology in infant cry study [3].

Several studies have demonstrated that infant cry is a powerful tool that can be used to decipher the needs of the baby or for making medical diagnoses of pathologies at the early stages of life. The studies on quantitative analyses of babies' cries were first established by Truby and Lind [4] and some fundamental frequency characteristics were clarified for babies' cries from pain. Wolff [5] categorized babies' cries into two groups such as hungry cries (basic cries) and angry cries (mad cries). Xie and Laszlo [3] proposed a practical system to estimate the babies' emotion from their cries, but the method just estimates the level of distress, and no work was done on reasons such as hungry state, a sleepy state, etc. Mima and Arkawa [6] proposed a method for finding reason for babies' cry using frequency analysis of the voice for three causes, hunger, sleepiness, and discomfort. They worked on babies aged from 2 to 4 months. No significant work has been done on infants below 1 month of age.

Nevertheless, our knowledge of the infant cry remains limited, and no applications of cry analysis have found wide clinical acceptance. This is at least partly due to the fact that the focus of studies so far has been primarily to gain fundamental knowledge on topics such as cry generation, rather than the design of an automatic cry analyzer. The second reason is that the limitation of the instrumentations in the past has often imposed restrictions on the analytical techniques used.

In this paper, we report an application-oriented investigation of normal, or clinically healthy infant cries due to stimulated pain and a method is proposed for finding the fundamental frequency of baby's voice using frequency analysis. The cause of cry under study is pain due to BCG vaccination. Cries of around 100 neonates, both male and female, aged from newborn to 1 month have been collected. Frequency analysis is done to find the fundamental frequency.

2. INFANT CRY
The crying wave is generated in the Central Nervous System, that's why the cry is thought to reflect the neuropsychological integrity of the infant and may be useful in the early detection of the infant at risk for adverse developmental outcome. Two kinds of crying are considered: normal and pathological crying. A cry from a healthy baby is considered normal cry [7].

Infant's cry is in the most sensitive range of the human auditory sensation area, if any disorder occurs with the infant, the cry may differ. This issue is main idea in recognition systems based on infant's cry [8].

The first stage of the cry production mechanism is initiated in the infant's brain upon external or internal stimuli (hunger, pain, etc.). In the second stage, the brain command is translated into series of commands through the nervous system to the speech and respiratory limbs, which are responsible for the creation of acoustic signals at the physiological level. This process continues with the ejection of air from the lungs to the vocal tract and the nasal tract. Thus, the cry is produced in the form of radiation. These radiations can be used for analysis as shown in Fig.1.

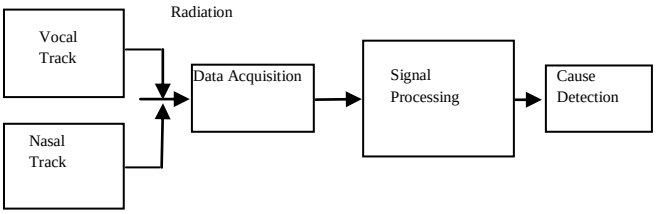

Fig. 1 Block Schematic for cry analysis.

These radiations are extracted using some recording device in data acquisition block and is given to the signal processing block for analysis. In this block frequency analysis of the cry is done to find the fundamental frequency and finally the cause detection is done by obtaining a melody contour by plotting the fundamental frequencies.

3. METHODOLOGY AND OBSERVATIONS
A. Data Acquisition
Hundred cry episodes have been recorded in the outpatient department of Jehangir Hospital (Pune) from hundred babies aged from new born to one month old. The cry episode is the result of

stimulus situation; pain due to BCG vaccination. The crying voices have been acquired with a Sony ICD-UX200F stereo IC recorder with a bi-directional microphone, digitized in 44.1 kHz-16 bits. The recordings, which had cry episodes of at least 6 seconds from the moment of stimulus event, have been used for the present study. The microphone was located about 15 cm from the babies' mouth and care was taken to minimize noise by recording at low cut frequency mode. In general, the environment was peaceful with minimum external disturbances. Out of the 100 neonates, 62 are male and 38 female infants. Fig. 2 shows a typical infant cry (Cry1) as recorded.

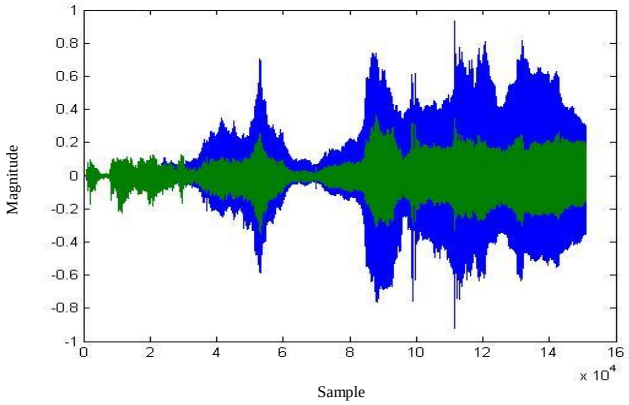

Fig. 2. Original infant cry'babycry01.wav

B. Frequency Analysis of Cries

The collected samples files are in mp3 format. The samples were saved on the hard disk of computer for further analysis. MATLAB7.1 has been used as a software tool for analyzing the cry samples. As the analysis is carried out in MATLAB, so the mp3 files are converted to .wav files using mp3 to .wav converter. Algorithms are developed for reading the wave files, filtering the voice samples and frequency analysis. First the voice samples in wave format are read using an algorithm and are then filtered so as to get a significant cry sample. Filtering removes the noise from the sample. Subsequently, cry sample is analyzed using Welch method to get the rough power spectrum and finally 256 point FFT is done to get the fundamental frequency for the sample. The approximation is done by applying 256 point FFT on the spectrum obtained from Welch method. Hamming window is used.

4. RESULTS

The preliminary characteristics are obtained by using an algorithm based on Welch's method. The curve is a plot between frequency-power spectrum density. Power spectral density shows the strength of the signal and frequency represent the pitch of cry signal. Characteristic curve typically for a subject is shown in Figs 3 and 4.

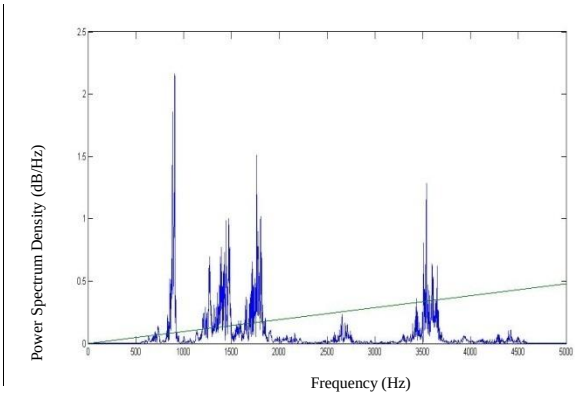

Fig. 3. Power spectrum density curve using Welch's method for cry1.

It is reported that the fundamental frequency of babies' cry typically lies between 200 to 500 Hz [2]. In Fig. 3 the frequency on the x-axis ranges from 0-5000 Hz for cry1. It shows that at different frequency we have different power spectral density but no sharp and significant peaks are seen below 500 Hz as for a neonate the value of f_0 usually extends from about 200 to 500 Hz.

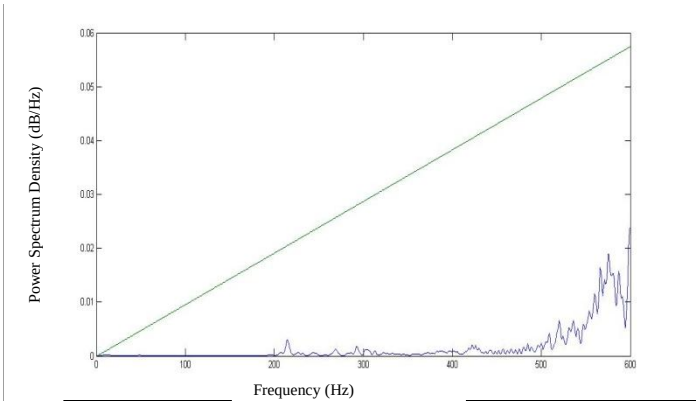

Fig. 4. Power spectrum density curve using Welch's method for cry1.

In order to get the fundamental frequency a blurred characteristics curve is obtained on reducing the scale. As can be seen in Fig. 4, even on reducing the scale no significant peak can be noticed in fundamental frequency range.

So, the fundamental frequency cannot be detected simply by using the Welch method, as sharp peaks cannot be obtained and seen for frequencies below 1000 Hz. Hence, to find the value of f_0, approximations have been made by applying 256 point FFT on the above results.

Figs. 5-9 show fundamental frequency for cries' due to pain. By using 256 point FFT we obtained curve showing frequency from 0-500 Hz.

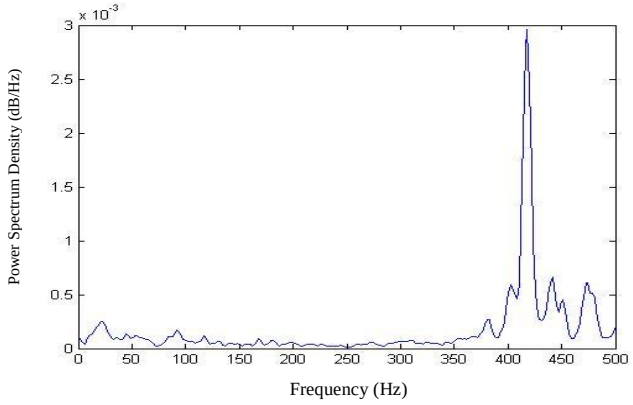

Fig. 5. Power spectrum density curve using 256 point FFT for cry1 (Male).

Cry1 is a cry of a male infant. Fig. 5 shows the power spectrum density curve for cry1, which a male infant cry. In the above figure we can see a sharp, distinct and first peak around 420 Hz. It is the fundamental frequency for cry1 (male).

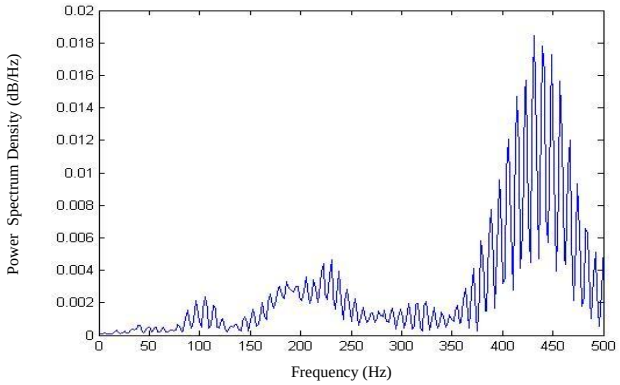

Fig. 6. Power spectrum density curve using 256 point FFT for Cry2 (Male).

The frequency-power spectrum density curve for Cry2 is also a male infant's cry sample and it shows a lot of peaks between 400-500 Hz. But the highest peak is seen between 400-450 Hz and is considered as fundamental frequency. The considerable peak is around 430 Hz. Rest all peaks are seen due to disturbances, i.e., the noise present in the environment.

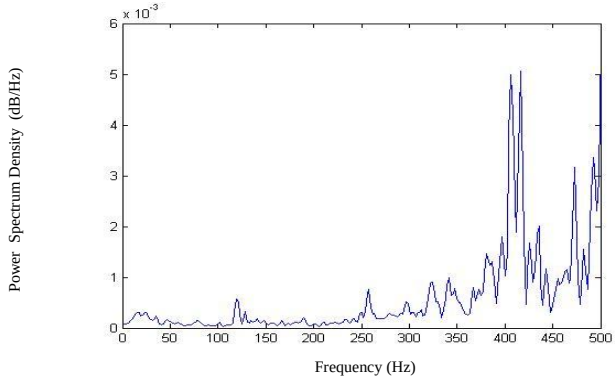

Fig. 7. Power spectrum density curve using 256 point FFT for Cry3 (Male).

Cry3 is again a male infants' cry. For Cry3, we can see two parallel peaks in Fig. 7. The peaks are between 400-450 Hz but the considerable peak is around 420 Hz. Rest all peaks are noise.

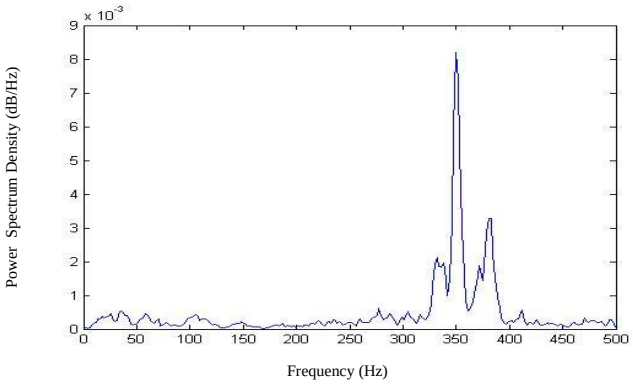

Fig. 8. Power spectrum density curve using 256 point FFT for Cry4 (Female).

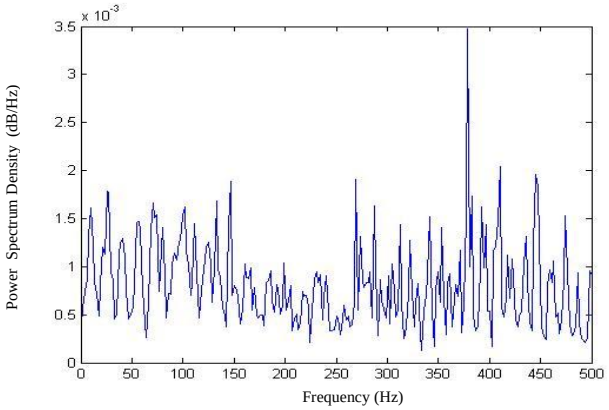

Fig. 9. Power spectrum density curve using 256 point FFT for Cry5 (Female).

A clear peak can be seen around 360 Hz for Cry4 in Fig. 8. Cry 4 is a female infant cry and has a fundamental frequency lower than a male infant.

The frequency-power spectrum density curve for Cry5 of a female infant is shown in Fig. 9. It shows a lot of peaks. But a sharp peak is seen approximately at 370 Hz and is considered as fundamental frequency. Rest all peaks are seen due to disturbances, i.e., the noise present in the environment.

The output obtained from FFT as shown in Figs. 3-4, does not give significant information. So, to understand the cry pattern the analysis has been carried out using 256 point FFT to find out the fundamental frequency. It can be clearly see in Figs. 5-9, that an averaged peak is obtained near 420 Hz for a male infant and 370 Hz for a female infant. Thus the averaged fundamental frequency of cry due to pain in neonates is approximately 400 Hz. Out of the hundred collected samples, 70 samples were of good quality and similar results have been obtained for these samples also.

5. CONCLUSIONS

A method for analyzing a babies' cry to find the fundamental frequency is proposed in this paper. The cause of cry considered here is pain. Welch method and 256 point FFT has been used for determining the fundamental frequencies. By performing frequency analysis on the voice samples, it is shown that the averaged fundamental frequency is obtained approximately at 400 Hz. In case

of male infant the fundamental frequency is around 420 Hz and in female infants' is around 370 Hz. The results are promising.

6. ACKNOWLEDGMENT

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