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Effect of Organs in Human Body on the Frequency Spectrum of the Propagating Speech

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Abstract**—**Sound propagates as a mechanical wave and it has been widely used in medical field for imaging the details of internal organs using ultrasound. Ultrasound systems operate in 2 MHz to 20 MHz range, although some systems are approaching 40 MHz as well. Ultrasound images are generated using the reflected sound waves from the boundaries of different organs falling in the path. Although ultrasound imaging is frequently used for detecting medical anomalies, the technique has several drawbacks. The high frequency waves used in this technique are diffracted very easily and it becomes difficult to detect the problems hidden within the deeper organs. Our hypothesis is that some of the medical anomalies may be predicted from the analysis of speech naturally propagating through the body. The objective of this research is to investigate the spectral distances of the speech recorded at different external sites over the human body. The investigations were carried out with eight young subjects (four males and four females). The recording and analysis of the results showed that the spectral distances are a function of organs and subjects involved in the recording.

Keywords**—**Sound waves; pelvis cavity; sound spectra; resonance cavities; natural speech.

I. INTRODUCTION

Sound propagates as a mechanical wave of pressure and displacement through material medium. Sometimes sound refers to only those vibrations with frequencies that are within the range of hearing for human beings or other living animals. Speech, a form of sound, is a natural and efficient means of communication for human beings. The different parts involved in the generation of speech are diaphragm, lungs, wind pipe, vocal folds, epiglottis, velum, tongue, teeth, lips, and nasal cavity. The high velocity of the moving air inside the vocal folds drops the pressure. The vocal folds start moving because of Bernoulli's principle and elasticity resulting in sustained oscillations. The frequency of vibration of the vocal folds is called the pitch frequency normally in the range of 100 Hz to 600 Hz depending upon weather the speaker is a male, female, or a child. By modulating the shape of the vocal tract, different types of sounds ranging from vowels to consonants may be produced [1], [2].

Sound waves have been widely used for various applications. One of the major uses is in the security and surveillance industry. Sound detection and analysis, specifically relating to sonar technology, has been used in the military and defence sector for quite some time. But there are several non-military uses of sonar as well. Sonar is being used to provide navigational support to marine vessels and assist in avoiding collisions. Sound detection devices are also used by law enforcement agencies to determine and identify speeding vehicles using sonar based speed guns [3]. Sound waves have also been used for determining the depth of water. Fishing industry has benefitted the most from this technology. Sonar may be used for locating and detecting fishes. Another important application involves the use of ultrasonic sound waves to detect faults and cracks in pipelines [4].

Ultrasound imaging is regularly used in cardiology, obstetrics, gynecology, abdominal imaging, etc. The human body has several body cavities, the largest of which is the abdominopelvic cavity (Figure 1). The abdominopelvic cavity consists of the abdominal cavity and the pelvic cavity. It contains the stomach, liver, spleen, gallbladder, kidneys, and most of the small and large intestines. It also contains urinary bladder and internal reproductive organs such as a vagina, uterus and ovaries [5].These cavities house the various body organs including the spinal cord which also accommodates the production and flow of cerebrospinal fluid in the ventricular system of the brain. There are also many other smaller cavities throughout the body called sinuses, which have varied functions. Sinuses in general usage refers to the paranasal sinuses which are involved in the condition sinusitis. The paranasal sinuses are four pairs of vital air-cavities in the cranial bones. These air-filled spaces are paired between the eyes, above the eyes, deeper behind the eyes and around the nasal cavity [6].

Sound detectors are also used for baby monitoring systems. Ultrasound waves, also being high frequency sound waves, have been widely used in numerous industrial and medical applications. In chemical industries they are used for cleansing and controlling the rate of reactions. In robotics, these are used for obstacle detection.

Ultrasound systems operate in 2 MHz to 20 MHz range, although some systems are approaching 40 MHz as well. The ultrasound generates the image using reflected sound waves. They are reflected on every object they encounter along their propagation path. When ultrasound waves travel from one medium to another, their magnitudes, and directions get modified because of scattering. The scattering may be of three types: specular, diffusive, and diffractive. In specular scattering the scattering object is large compared to the wavelength. In this case, the reflection process can be

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approximated as an incident ray with the scattered wavefront following the shape of the object. In diffusive scattering the scattering object is small compared to the wavelength. The resulting scattering radiates in all directions within significant phase difference among reflections from the surface of the object. Diffractive scattering occurs when the object size is in between these two extremes [7-12].

Ultrasound is one of the most common methods used in detecting medical anomalies, but it faces a problem in terms of cost because the apparatus is very costly. The whole procedure of investigating through this method is very time consuming as well. This procedure does not work with natural sound. The ultrasound waves deflect very easily and so they do not detect the ailments of the deeper body parts. Our hypothesis is that some of the medical anomalies may be predicted from the analysis of speech generated within the body itself after recording at specific sites on the exterior of the body. The objective of this research is to investigate the information content of the speech recorded from different external sites over the human body. The methodology of the experimentation is presented in the following section. Results and discussions are presented in Section III.

II. Methodology

The methodology used for the investigations has been divided into six phases: recording, segmentation and labelling, parameters estimation, dynamic time warping (DTW), estimation of distance, and interpretation. The recording was carried out with four subjects, two males and two females. The age of the subjects was in the range of 18-28 years. The subjects were asked to lie down straight and pronounce /a/. The recording was carried out at seven sites in pelvic cavity and 22 sites in chest cavity taking 11 sites from front and 11 from the back. For estimating the differences in sound spectra of the sound propagating from the mouth towards the lower part of the body, sound from the mouth was also recorded using the same sensor. The signal at each site was recorded for the duration of five seconds. For recording, electronic Jabe's stethoscope was used. The output of the stethoscope was connected to a Creative sound card and the amplified output of the Creative sound card was connected to a computer through USB port for digital recording.

The recorded signals were cut into segments of one second duration for each site. The segment was selected from the most stable portion of the signal. Each segment was labelled according to the signal it carries and the subject. The entire process was manual and hence a lot of care was required to segment and label properly. For comparing the differences in the spectra of different sites, the signal was divided in to frames of 20 ms each with 50 % overlap. The magnitude of the spectra from the 512 point Fourier transform of each frame was taken and spectra were compared frame by frame for visual analysis. The average magnitude spectra and standard deviation (SD) of the entire signal were also computed. For time alignment of the signals recorded at different sites, the frames corresponding to silence intervals, detected on the basis of short-time energy, were removed. The time alignment was carried out using dynamic time warping (DTW) [13], [14]. The first coefficient, representing the dc energy, was removed before alignment to avoid any biasing due to energy fluctuations.

For estimating the closeness of the two spectra, distance between the spectra was computed. For log spectral distance (LSD) [15], the distance over a frame is calculated as

$$D(t,r)=\frac{1}{N}\sum_{i=1}^{N}\left[\frac{1}{K}\sum_{k=1}^{K}\left|\log\left(S_{t,i}(k)\right)-\log\left(S_{r,i}(k)\right)\right|^{2}\right]^{1/2}$$

Analysis was carried out of the peaks, their decay rate, presence, and absence of spectral regions.

III. Results and Discussions

Mean and SD of each site for the subjects two female subjects F1, F2 out of four and two male subjects M1, M2 out of four are plotted in Fig. 1 to Fig. 4. The sites and their codes used for plotting are listed in Table I and Table II. In case of F1, LSD (Fig. 1) was very low (<12 dB) for Liver back-front, Colon back-front, Stomach back-front, Abdominal central back-front, Right large intestine back-front, Heart back-front, Appendix back-front, Right lung back-front, and Left lung back-front.

For Left large intestine back, Chest central back-front, Chest central front, Right lung front, Chest central back, Left lung back, Right lung back, Heart back, Left lung front, Heart front, Stomach back, Liver back, Appendix front, Abdominal central front, Left large intestine front, Right large intestine back, Liver front, Stomach front, Abdominal central back, Colon front, Right large intestine front, Appendix back, Colon back, and Left large intestine back-front LSD was more than 13 dB. Minimum LSD was shown by Liver back-front and maximum by Left large intestine back-front. Minimum SD was shown by Liver back-front and maximum by Chest central back.

Table I. Sites and their codes.

Code	Site
C1	Heart front
C2	Right lung front
C3	Chest central front
C4	Left lung front
C5	Liver front
C6	Stomach front
C7	Right large intestine front
C8	Appendix front
C9	Abdominal central front
C10	Large intestine left front
C11	Colon front
C12	Heart back
C13	Right lung back

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C14	Chest central back
C15	Left lung back
C16	Liver back
C17	Stomach back

In case of F2, LSD (Fig. 2) was very low (<12 dB) for Liver back-front, colon back-front, Appendix back-front, Right large intestine back-front, Stomach back-front, Chest central back-front, Left large intestine back-front, Heart back-front, Abdominal central back-front, Left lung back-front, Stomach back, Colon front, Right large intestine back, Appendix front, Appendix back, Left large intestine back, Heart front, Liver back, Heart back, and Colon back. For Abdominal central front, Stomach front, Left lung front, Right lung back, Chest central front, Right lung back-front, Liver front, Left large intestine front, Chest central back, Right lung front, Abdominal central back, Right large intestine front, and Left lung back LSD was more than 13 dB. Minimum LSD was shown by Liver back-front and maximum by Left lung back. Minimum SD was shown by Stomach front and maximum by Left lung back.

In case of M1, LSD (Fig. 3) was very low (<12 dB) for Colon back-front, Appendix back-front, Right large intestine back-front, Left large intestine back-front, Stomach back-front, Abdominal central back-front, Chest central front, Chest central back-front, Left lung-front, Left lung back-front, Right lung front, Right lung back-front, Liver front, Abdominal central front, Left large intestine back, and Abdominal central back. For Right lung back, Appendix front, Right large intestine front, Liver back, Left large intestine front, Appendix back, Colon back, Right large intestine back, Colon front, Stomach front, Left lung back, Heart back, Stomach back, Liver back-front, Central back, Heart back-front, Heart front LSD was more than 13 dB. Minimum LSD was shown by Colon back-front and maximum by Heart front. Minimum SD was shown by Appendix back-front and maximum by Right lung back-front.

Table II. Sites and their codes.

Code	Site
C18	Right large intestine back
C19	Appendix back
C20	Abdominal central back
C21	Left large intestine back
C22	Colon back
C23	Heart back-front
C24	Right lung back-front
C25	Chest central back-front
C26	Left lung back-front
C27	Liver back-front
C28	Stomach back-front

C29	Right large intestine back-front
C30	Appendix back-front
C31	Abdominal central back-front
C32	Left large intestine back-front
C33	Colon back-front

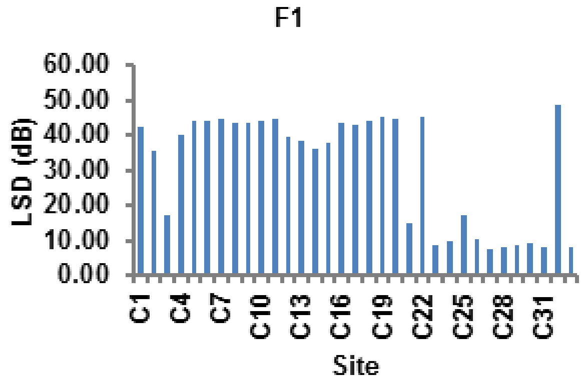

Fig. 1. Mean and SD of the LSD of subjects F1.

In case of M2, LSD (Fig. 4) was very low (<12 dB) for Left lung back-front, Right large intestine back-front, Colon back-front, Left large intestine back-front, Left lung back, Heart back-front, Appendix back-front, Liver back-front, Stomach back-front, Stomach back, Right lung back-front, Abdominal central back-front, and Abdominal central front. For Appendix front, Heart front, Chest central front, Right lung front, Liver front, Stomach front, Left large intestine back, Heart back, Left large intestine front, Appendix back, Right large intestine back, Chest central back, Abdominal central back, Colon back, Colon front, Left lung front, Liver back, Right lung back, Right large intestine front, and Chest central back-front LSD was more than 13 dB. Minimum LSD was shown by Left lung back-front and maximum by Chest central back-front. Minimum SD was shown by Left large intestine back-front and maximum by Heart front.

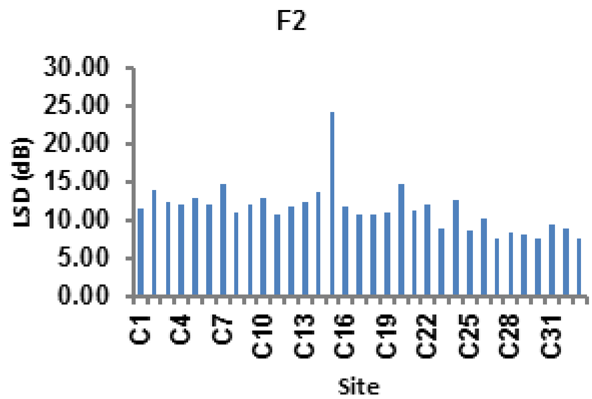

Fig. 2. Mean and SD of the LSD of subjects F2.

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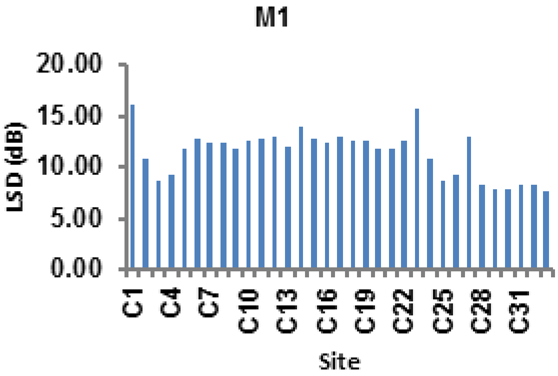

Fig. 3. Mean and SD of the LSD of subjects M1.

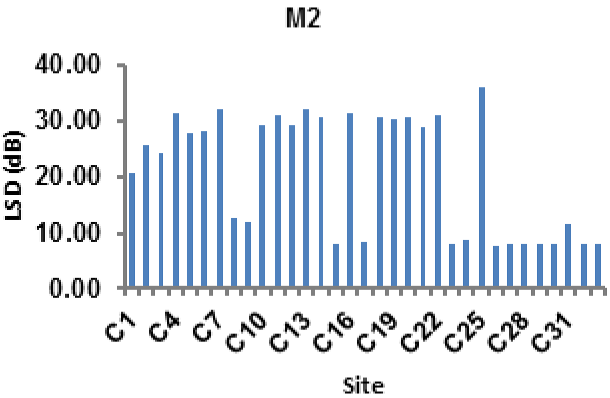

Fig. 4. Mean and SD of the LSD of subjects M2.

The analysis of the results showed that there is a specific relation between the organs involved and the spectrum of the recorded sounds. The results may be useful for predicting the anomalies in the human body on the basis of spectral differences as the LSD depends upon the subject and site involved.

Presently, we are working with different anomalies in the human bodies and their effect on the transmission of sound waves. Preliminary investigations indicate that prediction of anomalies is possible using natural sound waves generated within the human body. The research may be very beneficial for quick prediction of ailments from the recorded speech at an economical price. Although the proposed research indicated that medical anomalies may be detected but detailed investigations of the spectra for normal and medically unfit subjects need to be carried out.

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