Received: 19/03/2022 *Accepted: 25/04/2022*

International Journal of Advances in Biomedical Engineering
Open Access Peer-reviewed Journal
ISSN: 2822-2237
www.ijabe.online
Volume:1, Number:2, Pages:(78-86)
Year:2022

Spectral Characteristics of Intestinal Sounds

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Abstract

In today's modern medical practice, many imaging techniques are used for diagnosis or treatment. Some of these methods directly and some indirectly provide information about the target organ or region. At that point, it would be possible to accept that the acquisition of information about the internal parts of the body may be critical for diagnosis. In addition to the capabilities of medical imaging techniques, acoustic monitoring is also accepted as one of the supportive medical approaches today. Accordingly, thanks to the increased processing power of computers and developed algorithms, the analysis of sounds obtained from the heart, lungs and abdomen has become more detailed and accurate day by day. In this study, an acoustic instrument was developed and sounds were collected from the abdomen with the help of this device. Acoustic data on intestinal activity were obtained by filtering the collected sounds on the computer. The spectral characteristic of this data is revealed with various features for further diagnostic studies.

Keywords: Acoustic; Intestinal; Spectral; Features

1. Introduction

It has been accepted today that bowel sounds carry data about the functioning of internal organs, just like heart or liver sounds [1]. Accordingly, it would be possible to accept that the sounds of the intestines originate from vital processes for humans and that the acoustic characteristic will change in case of an abnormality. Extracting the numerical characteristic of the functionality of the intestines will be useful in many medical practices today, from understanding the time of feeding in the postoperative period to the early diagnosis of a wide range of intestinal disorders. However, today, brief clinical auscultation is most likely preferred for diagnosis rather than computer aided diagnosis and classification systems [2, 3]. Rapidly developing computing technologies can produce fast solutions to many diagnostic problems that require complex numerical solutions [4, 5]. Utilization of computer-assisted automatic analysis and diagnostic systems in cooperation with the conventional auscultation approach would improve the medical practice [6]. Accordingly, intestinal sounds originating from bowel activity are captured and analysed in this study as a starting point. Spectral characteristics of the captured acoustic data is revealed for forming a basis for further diagnosis and classification studies.

2. Methodology

2.1. Acquisition of Gastrointestinal Sounds

a non-invasive acoustic instrument was implemented for the acquisition of gastrointestinal sounds from subjects. The instrument is designed to record acoustic activity from the abdomen of the patient so that further analysis can be completed at digital environment. Acoustic data, including bowel sounds, are collected from the abdomen via a diaphragm and sent to the electret microphone. In this study, mentioned acoustic data collection is achieved via a 3M Littmann, Classic II S.E model stethoscope head. Which has a tunable diaphragm (with a diameter of 4.44 cm) and open bell that allows device collect sound-waves with high sensitivity. Before recording raw acoustic data a pre-amplication is applied to analog signal for adjusting signal to noise ratio to an optimum rate. Low-noise and wide-spectrum pre-amplification is achieved by a ”jfet” input type ”op-amp”. Preferred integrated circuit for the purpose is TL082 instrumentation operational amplifier which provides high reliability and efficiency. It is known that the sound waves to be collected from the abdominal region also include other sounds coming from the heart, lungs and outside [7]. In previous studies, the recommended spectral range for gastrointestinal activity to be separated from these noise sources is 200-500 Hz [8]. This filtering operation is applied to raw digital data after recording. Additionally tension of the diaphragm is tuned for intestinal acoustic waves which means diaphragm is also serving as a mechanical pre-filter that eliminating irrelevant data out of the focused frequency range.

Intestinal sound recordings were made with a T60 brand original 8gb voice recorder. Raw data is recorded as dual channels with a sampling frequency of 44100 and a bit rate of 1536 Kbps. Average recording length is 97.26 seconds. A total of 20 subjects are participated. Age and body mass averages are given in Table 1.

Table 1: Average values of age and body mass index of subjects

Age	Body Mass Index
34.5 ± 10.8	26.3 ± 3.2

2.2. Segmentation Stage

Recorded audio data is likely to contain various noises and distortions along with characteristic sounds associated with the intestinal activity. These include friction sounds caused by the movements of the patient, unusual sounds transmitted from the environment through the patient's body, and electronic noise caused by electronic interference. Additionally, patient's respiratory sounds, sound of blood flow, and heartbeat can be seen scattered across a wide frequency spectrum of the raw data. In this study it was aimed to extract spectral features characterizing the bowel activity. Accordingly bowel activity regions are segmented empirically by two experts for further feature extraction process. A total of 40 region is segmented from different subjects.

2.3. Feature Extraction

2.3.1. Spectral Centroid

This feature extracted for measuring the location of the center of mass of the spectrum. It is calculated by:

$$Centroid = \frac{\sum_{k=b_1}^{b_2} f_k s_k}{\sum_{k=b_1}^{b_2} s_k} \tag{1}$$

where f_k and s_k are indicating frequency corresponding to bin k and spectral value at bin k. b1 and b2 are denotes band edges [9].

2.3.2. Spectral Entropy

Spectral entropy can be defined as spectral power distribution of a signal. It is one of the widely used features for biomedical signal processing [10]. If Fourier transform of signal $x(n)$ is $X(m)$ then power spectrum would be calculated by:

$$S(m) = |X(m)|^2 \tag{2}$$

Accordingly, formulation of the probability distribution P(m) is:

$$P(m) = \frac{S(m)}{\sum_i S(i)} \tag{3}$$

where the spectral entropy is:

$$H = -\sum_{m=1}^{N} P(m) log_2 P(m) \tag{4}$$

Finally, the normalization is calculated by:

$$H_n = -\frac{\sum\limits_{m=1}^{N} P(m) log_2 P(m)}{log_2 N} \tag{5}$$

Here, N is standing for the the total frequency points and $log_2 N$ represents the maximal spectral entropy of white noise.

2.3.3. Spectral Flux

It would be possible to define spectral flux as change in consecutive spectrums. [11] which is formulated by:

$$flux(t) = \left(\sum_{k=b_1}^{b_2} |s_k(t - s_k(t-1)|^p \right)^{\frac{1}{p}} \tag{6}$$

Where k, b1 and b2 are value of spectrum at bin k, and band edges respectively. It should be noted that P indicates the norm type which would be valued as double or single.

2.3.4. Energy

In the study, the energy is accepted as area under the squared magnitude of the signal.

2.3.5. Zero Crossing Rate

The zero crossing rate (ZCR) is accepted change rate of the signal from positive to negative.[12].

2.3.6. Spectral Rolloff

It is accepted as frequency value where the 85% of the signal distribution is located.[13].

3. Results

A total of 6 features are extracted from 40 intestinal activity region. Cluster centers of features and standard deviations are given in Table 2.

Table 2: Calculated spectral features of the intestinal activity regions on recorded audio data.

	Cluster Centroid	**Standard Deviation**	**Maximum Value**	**Minimum Value**
Spectral Centroid	0.028722	0.008823	0.069692	0.020148
Spectral Entropy	0.000530	0.001310	0.008243	0.000011
Spectral Flux	2.55164E-26	2.12718E-26	7.47678E-26	2.64092E-27
Energy	0.029381	0.022451	0.100320	0.006531
Zero Crossing Rate	0.015856	0.000758	0.018110	0.014869
Spectral Roll-off	0.014545	0.001023	0.017007	0.012634

4. Discussion and Conclusions

Many studies in the literature show that with the evaluation of acoustic data, it is possible to make accurate classifications about the abnormality in the abdominal region [14]. It would be possible to conclude that, objective assessment of activity would contribute to daily surgical practice in evaluating intestinal motility that may develop in the postoperative period, determining the feeding time, and diagnosing ileus. In this study, as a first step in the automatic diagnosis of intestinal activity, the spectral features characterizing the activity were extracted from the sound recordings and presented numerically. Presented results would be helpful for further studies on automated or semi-automated decision making systems.

Competing interests

The authors declare that they have no conflict of interests.

Ethics approval and consent to participate

The authors declare that this study does not contain any personal information that could lead to the identification of the patients and Informed consent was obtained from all participants. The work described has been carried out in accordance with the ethical approval of the Cukurova University Faculty of Medicine, Non-Interventional Clinical Research Ethics Committee.

Consent for publication

All authors read and approved the manuscript.

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