ANALYSIS AND CLASSIFICATION OF HEART SOUNDS AND MURMURS BASED ON THE INSTANTANEOUS ENERGY AND FREQUENCY ESTIMATIONS

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Abstract

This paper proposes the use of the instantaneous energy and the frequency estimation in the classification of the heart sounds and murmurs for common heart diseases. It has been known that the present of the heart murmurs in one's heart sound indicates that there is a potential heart problem. Thus, the goal of this work is to develop a technique for detecting and classifying murmurs. Such a technique can be used as part of a heart diagnostic system. The analysis is performed based on a set of 102 data for various heart sounds. To discriminate the various heart sounds, the instantaneous energy and frequency estimation is used to estimate the features of heart sound. The techniques used to estimate the instantaneous frequency are the central finite difference frequency estimation (CFDFE) and zero crossing frequency estimation (ZCFE). From the instantaneous energy and frequency estimate, the energy and frequencies of the heart sounds are defined as the features of the heart sounds that can uniquely discriminate the various heart sounds.

Keywords- instantaneous energy, heart sounds, heart murmurs, central finite difference, zero crossing, frequency estimation.

1 INTRODUCTION

The current practice among the physicians is to use a stethoscope to determine the condition of the heart based on technique known as auscultation. This technique is very subjective because the records provided could be interpreted in several ways depending on how the physician interprets the sounds. Various techniques have been developed to analyze the frequency content of the heart. Examples are studies done in [1]-[4] which are based on the time-frequency analysis. The results show the direct application of the spectrum analysis is not suitable, since the heart sound signal is a non-stationary signal. This is because the spectrum cannot detect temporal variation in the signal [1]. To solve the problem authors [2][4] proposed the used of the wavelet transform technique.

The objective of this work is to develop a technique that can assist a trained physician to classify the heart sounds and murmurs. The procedure suggested would provide the graphical display of the heart sound with respect to the time, the category of the murmurs and the types of common heart disorder faced by the patient. It will also provide the permanent record of the analysis. The data collected by the electronic stethoscope is processed and analyzed. It allows early detection of the common heart disease, and a person does not need to be in the hospital to get them checked. Furthermore, a physician can monitor their patients with heart problem from remote location.

2 CHARACTERISTICS OF HUMAN HEART

Human heart is a hollow, muscular, double pump which circulate the blood through the blood vessels to all part of the body [5]. The heart is divided into two halves, the left and the right heart. The right heart is the pump that pumps blood to the lungs and this circulation is known as the pulmonary circulation. The left heart is the pump that responsible of supplying oxygen and nutrients to all the important organs and the whole body. There are four cavities that are known as the left and right atria and ventricles. Blood flow through the cavities is regulated by a set of valves: tricuspid, bicuspid (mitral), pulmonary and aortic.

The heart's pumping cycle is divided into two parts; the systole and diastole. The period of contraction of the heart muscles is called systole and the period of relaxation is the called diastole. Auscultation of the heart sounds **'lub, dub'** occur at the time of the closure of the major heart valves. The **'lub'** is known as the first heart sound, S1, and the **'dub'** sound is associated with the second heart sound, S2. A third heart sound S3 occurs after S2 has relatively lower energy. The fourth heart sound S4 occurs prior to the first heart sound S1 and has significantly lower amplitude compare to the other heart sounds. In abnormal hearts such as murmurs, are additional sounds between the real heart sounds are heard. Heart murmurs are noises created by the damaged

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valves and may also be associated with fusion of the valve leaflets.

3 MODEL OF HEART SOUND

Based on the characteristics of the heart sounds, it is appropriate to model the sound as time-varying signal that is expressed as:

$$x(n) = c(n)\cos(j\phi(n)) + w(n) = c(n)\cos\left(2\pi \sum_{\lambda=-\infty}^{n} f_i(\lambda)\right) + w(n)$$

$$0<n<N-1 \qquad (1)$$

where $f_i(n)$ is the instantaneous frequency, $c(n)$ is the amplitude and $w(n)$ is the interference due to additive white noise. To estimate its instantaneous energy and frequency, a complex form or analytical form of Equation (1) is required that can be generated by

$$z(n) = x(n) + jH[x(n)] \qquad (2)$$

where $H[\ ]$ is the Hilbert transform [6] of the signal $x(n)$ that introduce a $\pi/2$ phase shift to the original signal. Thus, the complex form Equation (1) is

$$z(n) = c(n)\exp\left(j2\pi \sum_{\lambda=-\infty}^{n} f_i(\lambda)\right) + w(n)$$

$$0<n<N-1 \qquad (3)$$

4 INSTANTANEOUS ENERGY AND FREQUENCY ESTIMATION

In this approach, the heart sound is assumed as a time-varying signal and the method used for estimating the energy and frequency is referred as the instantaneous energy and frequency estimation (IEFE) technique. Two methods used for estimating the instantaneous frequency is the zero crossing frequency estimate (ZDFE) and the central finite difference frequency estimate (CFDFE).

4.1 INSTANTANEOUS ENERGY

A characteristic of the analytical signal is the relationship between the instantaneous energy and the signal amplitude. The instantaneous energy is required in the IEFE method to characterize the temporal behavior of the amplitude of the heart sound because the amplitude of the signal is time varying. Using the signal definition in Equation (3), the instantaneous energy is

$$E_z(n) = z(n)z^*(n) = c(n)c^*(n) \qquad (4)$$

Thus, the instantaneous energy is exactly the amplitude square of the signal.

4.2 INSTANTANEOUS FREQUENCY ESTIMATION

There are two IEFE methods that are described in this paper analyze and estimate the features of the heart sounds. Both methods estimate the instantaneous energy based on the same method described in the previous section, but the difference is in the instantaneous frequency estimation technique. One method is based on the zero crossing frequency estimation (ZCFE) and the other is the central finite difference frequency estimate (CFDFE). The first is referred as the IEFE-ZCFE and the latter is IEFE-CFDFE.

4.2.1 ZERO CROSSING FREQUENCY ESTIMATE

The amplitude of a signal changes with time according to its frequency. A zero crossing is the instant where the amplitude of the signal changes it sign from negative to positive or vice versa. From the position of the zero crossings, the instantaneous frequency of the signal can be estimated. If a signal is defined in Equation (1), then the zero crossings of the signal occurs at

$$n_{zc}(k) = n, \quad k = 0, 1, \ldots N_{zc} \qquad (5)$$

where n evaluated such that $x(n)=0$ for all time instant values. If a consecutive zero crossing pair is

$$n_{zc}(k-1),\ n_{zc}(k) \qquad (6)$$

then the instantaneous frequency estimate is

$$\hat{f}_i(n) = \frac{2}{n_{zc}(k) - n_{zc}(k-1)},$$

$$n = n_{zc}(k),\ k = 0, 1, \ldots N_{zc} \qquad (7)$$

The frequency estimate is then extended for all time instants.

4.2.2 CENTRAL FINITE DIFFERENCE FREQUENCY ESTIMATE

Assuming high signal-to-noise ratio conditions and the amplitude of the signal is nonzero, then the instantaneous frequency obtained by [6]

$$f_i(n) = \frac{1}{2\pi}\frac{d}{dn}[\arg[x(n)]] = \frac{1}{2\pi}\frac{d}{dn}[\phi(n)] \qquad (8)$$

Based on the definition of the derivative, the instantaneous frequency in Equation (8) is expressed as

$$f_i(n) = \lim_{\Delta n T_s \to 0} \frac{1}{2\pi T_s}\left[\frac{\phi(n) - \phi(n-\Delta n)}{\Delta n T_s}\right] \qquad (9)$$

where T_s is the sampling interval and Δn is an infinitesimal difference in time sample If the sampling interval T_s and difference Δn are assumed as one, the instantaneous frequency estimate is

$$\hat{f}_i(n) = \frac{1}{2\pi}\left[\hat{\phi}(n) - \hat{\phi}(n-1)\right] \quad (10)$$

where $\hat{\phi}(n)$ is the instantaneous phase estimate in Equation (8). The result in Equation (10) is known as the backward finite difference (BFD). It is based on comparing the present instantaneous phase with its previous. Depending on the choice of sample instants, the forward finite difference (FFD) and central finite difference (CFD) are defined as

$$\hat{f}_i(n) = \frac{1}{2\pi}\left[\hat{\phi}(n+1) - \hat{\phi}(n)\right] \quad (11)$$

$$\hat{f}_i(n) = \frac{1}{4\pi}\left[\hat{\phi}(n+1) - \hat{\phi}(n-1)\right] \quad (12)$$

Since the CFD is proven unbiased for time varying signal [7], it is chosen as the method for estimating the instantaneous frequency.

5 SIGNAL FEATURES

The parameters of the signal are estimated from instantaneous energy and frequency of the signal. Example of heart sounds and murmurs are [5]

1) Normal First (S1) And Second (S2) Heart sound.
2) Mitral Regurgitation with third heart sound
3) Widely splitting of second heart sound (S2).
4) Mitral Stenosis.
5) Mitral Stenosis - Mitral Regurgitation.
6) Fourth heart sound (S4) Gallop.

The parameters of the heart sounds that are estimated using both the IEFE techniques are

1) E_2/E_1 - energy ratio of the S2 and S1.
2) E_3/E_1 - energy ratio of the S3 and S2.
3) E_4/E_1 - energy ratio of the S4 and S1.
4) f_2/f_1 - frequency estimate ratio of the S2 and S1.
5) f_3/f_1 - frequency estimate ratio of the S3 and S1.
6) f_4/f_1 - frequency estimate ratio of the S4 and S1.
7) E_{12}/E_1 - energy ratio of the interval between S1 and S2, and S1.
8) f_{12}/f_1 - frequency estimate ratio of the interval between S1 and S2, and S1.
9) E_{21}/E_1 - energy ratio of the interval between S2 and S1, and S1.
10) f_{21}/f_1 - frequency estimate ratio of the interval between S2 and S1, and S1.

From the set of 102 heart sounds, the both IEFE techniques are applied and the set of estimated parameters are observed to see if they can uniquely represent each of the heart sounds.

6 RESULTS

The analysis results based on the IEFE-ZCFE and IEFE-CFDFE shows that the estimated parameters of the heart sound defined in Section (5) can uniquely defined all the 102 types of heart sounds. There is no difference in terms of the accuracy of the estimated parameters if both of the methods are used. Table 1 shows the comparison of the ratio of the frequencies using ZCFE and CFDFE. Table 2 shows the ratio of the instantaneous energy for both methods. While Figure 1 show the waveforms of the two heart signals, normal and mitral stenosis. Periodogram, the power spectrum estimate was used in this analysis as indicated in both figure a) and b). Periodogram gives the range of frequencies that existed during the total duration of the signal. It has no indication as when these frequencies existed.

The estimated parameters can now be used as the input to a classifier network that can automatically diagnose potential heart problems. Compared to previous work [8] based on spectrum estimation, the parameters required to represent the heart sound is drastically reduced by a factor of 10. The next part of the work is actually to evaluate the accuracy of a classifier when used with proposed parameter estimation technique. It is expected that the performance will improve from 70% to 90%.

7 CONCLUSIONS

Analysis of heart sound based on a stethoscope that is known as auscultation is highly subjective and its interpretation may vary from one physician to another. This uncertainty can be resolved if signal analysis techniques are used as part of a heart diagnostic system. Since the heart sound is a time-varying signal, the instantaneous energy and frequency estimation (IEFE) is used to estimate the parameters of the signal. Two techniques are proposed to analyze and estimate the parameters of heart sounds: the IEFE-ZCFE and IEFE-CFDFE. Both uses the same technique for estimating the instantaneous energy but the difference is in the estimation of the instantaneous frequency. There is no significant difference in the estimated parameters of the heart sound when both methods are used. The eight estimated parameters can uniquely represent the various heart sounds. Thus, the estimated parameters can be used as input to a classifier network.

8 REFERENCES

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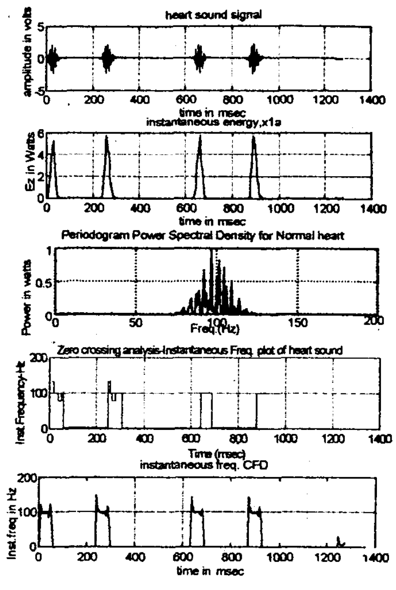
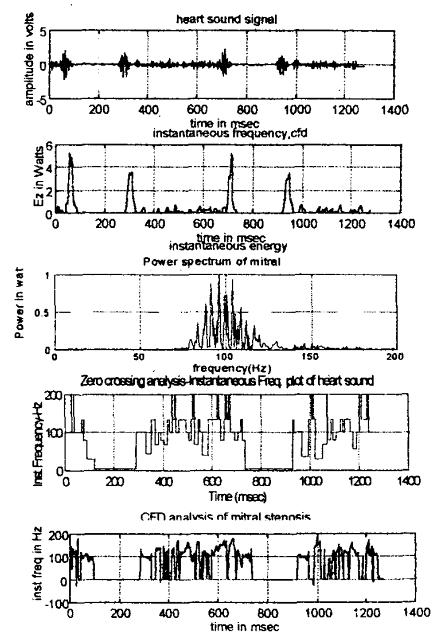


a) Good heart



b) Mitral stenosis

Figure a) and b) show the comparison of the normal heart sound a) and mitral regurgitation and mitral stenosis using central finite difference and zero crossing frequency estimates. The instantaneous energy for both the heart sound signals are shown.

Heart class	Mtd	f4/f1	f12/f1	f2a/f1	f2b/f1	f21/f1	f3/f1
MR +3^{RD} 56A	cfd	0	0.1439	0.9870	0	0	0.7954
	zc	0	0.6164	0.8135	0	0	0.6901
MR +3^{RD} 55A	cfd	0	0.0823	1.0051	0	0	0.7764
	zc	0	0.3958	1.0872	0	0	0.8526
MS63a	cfd	0	0	0.9673	0	0.8322	0
	zc	0	0	0.9357	0	1.2114	0
MS64a	cfd	0	0	0.9948	0	1.0451	0
	zc	0	0	0.8700	0	1.1343	0
MS-MR65a	cfd	0	0	0.9080	0	0.9158	0
	zc	0	0	0.9747	0	1.2126	0
MS-MR67a	cfd	0	0.0291	0.9949	0	0.9002	0
	zc	0	0	1.0091	0	1.0841	0
Normal S1-S2-1a	cfd	0	0	0.9830	0	0	0
	zc	0	0	0.9958	0	0	0
Normal S1-S2-3a	cfd	0	0	1.0170	0	0	0
	zc	0	0	1.0217	0	0	0
S4 GP-S1-11a	cfd	0.7700	0	0.9909	0	0	0
	zc	0.7533	0	1	0	0	0
S4 GP-S1-12a	cfd	0.7833	0	1.0064	0	0	0
	zc	0.8262	0	0.9895	0	0	0
WS-S2-8a	cfd	0	0	1.0067	0.9996	0	0
	zc	0	0	1	1	0	0
WS-S2-9a	cfd	0	0	0.9818	0.9943	0	0
	zc	0	0	1	1	0	0

Table1: The comparison of the instantaneous frequency using central finite difference analysis and zero crossing analysis

Heart class	e4/e1	e12/e1	e2a/e1	e2b/e1	e3/e1	e21/e1
MR +3^{RD}56A	0	0.0098	1.1463	0	0.7532	0
MR +3^{RD}55A	0	0.0083	1.2313	0	0.9024	0
MS63a	0	0	0.6511	0	0	0.0345
MS64a	0	0	0.8973	0	0	0.0466
MS-MR65a	0	0	0.7034	0	0	0.0405
MS-MR67a	0	0.0049	0.6629	0	0	0.0533
Normal S1-S2-1a	0	0	1.1134	0	0	0
Normal S1-S2-3a	0	0	1.3715	0	0	0
S4 GP-S1-11a	0.2455	0	1.1897	0	0	0
S4 GP-S1-12a	0.1964	0	1.1770	0	0	0
WS-S2-8a	0	0	1.2120	1.1816	0	0
WS-S2-9a	0	0	1.1218	1.2096	0	0

Table 2: The ratio of the heart sounds energy with respect to first sound

**Notes: MR+3^{RD} -Mitral Regurgitation with 3^{rd} heart sound
MS-Mitral stenosis
MS-MR-Mitral Stenosis and Mitral regurgitation
Normal-Normal heart sound
S4 GP-S1 - S4 gallop preceding S1
WS-S2 - Widely splitting of S2