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Analysis of PCG Signal using Bi-Orthogonal Wavelet Transform

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Abstract:
Heart is one of the vital components of human body, so any information related to heart is having the critical importance as far as heart signal processing is concerned. The heart sound is one of the signal which being researched by the academicians and researchers. Here an improved technique is shown on the basis of envelope detection. Here wavelet method is used for de-noising the sound is used. Also the use of wavelet transform proved as the perfect method for processing non- stationary signals without losing the significant information related to the heart sound and thus provides the complete information on non stationary signals. The study of heart sound is called as phonocardiography, and the heart sound is called the PCG signal. PCG signals are low frequency singles falling in the range of 10 Hz to 250Hz, but with noise its range can exceed up to 600 Hz also. Here a de-noising method based on threshold is used for removing the background unwanted signal called as noise. For this the analysis is done on the PCG signal and the first and second heart sounds called as S1 and S2 are being processed. The heart sound S2 is constituted by two components called A2 and P2. They can be identified by the time displacement of signal between them, and this time delay provide the significant information while working with them. Here CWT and DWT is used for determining various frequency components and for denoising & to find the best split respectively. This analysis provides the medical professionals an efficient technique to correctly identify the frequency components, best splits and other related information so as to diagnose the disease with greater accuracy and efficiency

Keywords — **Phonocardiography, Heart Diagnosis, Wavelet Transform, PCG, Segmentation, Feature Extraction etc.**

I. INTRODUCTION

The word stethoscope was invented during twentieth century and was most preferred devices used by doctors to listen to heart sound. It is formed from the Greek word “stethos”, meaning “Chest” and “skopein”, meaning "To Examine". This device provides us the input data that is the heart sound, which is to be segmented. It is processed for feature extraction, for determining the frequency components, for analyzing the frequency behavior of the sound and determining the critical information on PCG signal. The technique of phonocardiography evolved continuously to grab an important role in the accurate and proper diagnosis of the defects of heart. This method, though seemingly quite reliable for segmentation, but is quite difficult to master because with the stethoscope, it requires highly experienced professionals to read the phonocardiograph signal [1-6 One important obstacle in developing the all-automatic tool is end-pointing of cardiac cycles as well as localization of first heart sounds (S1) and second heart sounds (S2), termed by heart sound segmentation. Imprecise segmentation can place a negative impact on the Screening results relying on the fact that most of the algorithms are used on a particular segment of a cardiac cycle [22]. Normal cardiac cycle contains two key sounds: the first heart sound S1 and the second heart sound S2. S1 occurs at the onset of ventricular contraction and corresponds in timing to the QRS complex. S2 follows the systolic pause and is produced by the closure of the semi lunar valve [7]. The significance of S2 regarding diagnosis purposes has been recognized for a long time, and its significance is considered of most importance, by cardiologists, to auscultation of heart [9]. PCG may include the heart murmurs (systolic and diastolic) [2]. Heart sound consists of four components namely S1, S2, S3, and S4. The S1 (lub) and S2 (dub) are the heart sounds regarded as the normal heart sounds in a cardiac cycle. The S1and S2 heart sounds are caused by the closure of mitral and tricuspid valve, and the closure of aortic and pulmonary valve, respectively. The S3 and S4 heart sounds are caused by the rapid ventricular filling in early diastole and the ventricular filling due to atrial contraction, respectively.

Heart sounds description

The difficulty to perform an accurate pathology detection based on PCG signal is the complexity of the cardiac signal and acoustic phenomena occurred during the heart activity. Human heart can be modelled as a four chambers pump. With two superior atria that collect blood from veins and two inferior ventricles which pump blood into arteries. Its right side, called right heart, is connected to the pulmonary circuit, while the left side, called left heart is connected to the total circuit. Two sets of valves prevent blood from travelling in backward direction. They are classified as atrioventricular valves (atrioventricular and tricuspid) which regulates the blood flow between atria and ventricles, and semi-lunar valves (aortic and pulmonary) which separate the left heart from the aorta and the pulmonary artery.

- ❖ Cardiac sounds are generated by a plurality of complex mechanisms. They include sounds (or tones) of short lived burst of vibratory.
- ❖ Energy caused by contractions of cardiac valves and by the cardiac action potential.
- ❖ Murmurs are caused by turbulences of blood through atrial and ventricular valves, usually due to inborn or acquired impediments.

The first tone (S1) is generated by the deceleration of blood due to closure of atrioventricular valves when ventricular blood pressure exceeds the atrial one during heart contraction that is during systole.
S1 has four different components coming one after the other:

- Low frequency vibrations generated by muscular contraction of the left ventricle.
- High frequency vibration at the closure of mitral Valves M1.
- High frequency vibration due to tricuspid valve closure T1;
- A low frequency and low intensity vibration caused by the discharge of blood.

The second tone (S2) is generated during diastole, which closes the semi-lunar valves. S2 is constituted by two components, aortic (A2) and pulmonary (P2), both lasting less than 50ms and with almost the same frequency content, but different amplitudes (due to pressure differences between aorta and pulmonary artery). An additional tone (S3) is generated due to ventricular pressure which is lower than the atrial during the diastole, so that mitral valve opens causing the rapid flow of blood from it.

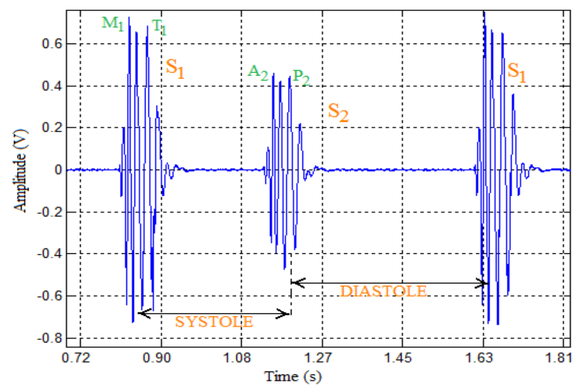

Fig.1: A normal PCG trace.

S3 is usually considered normal in case of pre-pubescent and pubescent subjects, while it is considered pathological in adults. At last, a fourth tone (S4) can be heard at the end of diastole if atria contractions make the blood to flow into relaxed ventricles. This tone is considered pathological condition of heart. Blood has a laminar flow through the heart, but some cardiac diseases can cause turbulences with associated vibrations called murmurs [17-18]. The frequency spectrum of murmurs is usually within the range from 10 Hz to 1500 Hz. They are described and catalogued on the base of their intensity, duration or their placing within the cardiac cycle. Referencing to this last criterion, common classification differentiates among systolic, diastolic and continuous murmurs [20]. Within each class, there are further and more specific distinctions among murmurs occurring at the beginning, during or at the end of each phase.

The possibility to indentify pathologies depends on the quality of the sound which can be done by reducing high levels of external noise. Electronic stethoscopes with high rejection to environmental noise [17-20] should be employed to maximize the reliability of diagnoses. Software filtering algorithms can be also applied to further enhance signal to noise ratio. It is good practice to evaluate sound quality when an electronic stethoscope is employed. A simple procedure consists in analyzing incoming data, isolated in long-time frame of 5-10 seconds, searching for some information. If the stethoscope head is not in contact with the patient body, no sound is detected and so no analysis is required for this. Even short-time spikes can reduce the quality of sounds. In this case, the problem can be fixed by pre-processing the data with interpolation algorithm [18-20]. The parameters are typically used to investigate the quality of the signal: Root Mean Square (RMS), Volume Dynamic Ratio (VDR), Zero Crossing Rate (ZCR) and Silence Ratio (SR) are some of them. Hamming window is a common choice. RMS provides information about the energy of the signal, while ZCR gives the rate at which the signal crosses the null Value and so it is linked to the energy distribution through frequencies. SR is calculated through SF that represents the number of frames with root mean square value less than 10% of the max (RMS) [17].

II. Methods

In this section, the wavelet decomposition of phonocardiogram signal is focused for the analysis the structure of the coefficients during key cardiac events. Due to the nonstationary characteristics of heart sounds and the results of previous studies, it is unlikely that a signal's fixed decomposition level can accurately capture the energy of the primary components for various types of pathologies [1]. In some cases, seven detail levels are required to properly represent the heart sound. The wavelet decomposition analysis serves as a motivation for resorting to a non-heuristic approach, namely PCA (Principle Component Analysis) in determining the combination of the detail coefficients for each point in the phonocardiogram signal. Wavelet coefficients of the signal contain important information whose amplitude is large enough, while wavelet coefficients of noise are small in amplitude [6]. Selecting an appropriate threshold in different scale, the coefficients will be set to zero if it is below the threshold, while be retained if above the threshold, so that the noise in the signal is effectively suppressed [5-6]. Finally the reconstructed and filtered signals are obtained using wavelet inverse transform.

III. Parameters

The wavelet transform provides a time localize representation of the signal while the STFT is limited to fixed resolution for all frequencies a time frequency representation, the wavelet transform employs windowing techniques [2]. That is of the variable width (a time scale representation) the width variability allows for different frequency resolution within the representation in this section wavelet analysis is introduces in the discrete wavelet transform and implementation of wavelet analysis [6-7].

For objectively comparing the de-noising effect of the three methods; signal to noise ratio (SNR), the greater the value the better the de-noising is induced. SNR is defined as: [6].

$$\mathrm{SNR} = \frac{\text{power of signal}}{\text{power of noise}} \qquad (1)$$

In signal-to-noise ratio, or SNR, is a measure of signal strength relative to background noise. The ratio is usually measured in decibels (dB).If the incoming signal strength in microvolt's is Vs, and the noise level, also in microvolt's, is Vn, then the signal-to-noise ratio, S/N, in decibels is given by the formula[15].

$$S/N = 20 \log 10\ (Vs/Vn)$$

The PSNR is most commonly used as a measure of quality of reconstruction of lossy compression codes signal in this case is the original data, echo signal noise is the error introduced by compression. When comparing compression codes it is used as an approximation to human perception of reconstruction quality [8].therefore in some cases one reconstruction may appear to be closer to the original than another, even though it has a lower PSNR. One has to be extremely careful with the range of validity of this metric; it is only conclusively valid when it is used to compare results from the same codec and same content [16].

The peak signal to noise ratio is other method of measuring the amount of noise present in a signal. PSNR is defined as the ratio between the maximum possible power of a signal and the power of corrupting noise that affects the fidelity of its representation. Because many signals have a very wide dynamic range, PSNR is usually expressed in terms of the logarithmic decibel scale [2-6].

$$PSNR = 10*\log10 (N *(x2))$$

It is the methods which find the error in the denoising process. NRMSE is defined as differences between values predicted by a model or an estimator and the values actually observed from the thing being modelled or estimated. NRMSD is a good measure of precision [6] these individual differences are also called residuals, and the root mean square difference serves to aggregate them into a single measure of predictive power.

IV. Results and Conclusion

The classical wavelets used as candidates to the most suitable wavelet for analysing the PCG signals are the Haar, Daubechies, Meyer and Morlet Wavelets. The obtained result in this process is represented in the Table 1, Table 2 & Table 3. In this case, the analyzed PCG signal was a normal PCG Signal. It can be observed that the Haar Wavelet is the best wavelet for segmentation. In order to illustrate performance of the new thresholding function for segmentation, a section of standard signals are tested by the wavelet transform, with specific Parameter shown in table1, table 2 & table 3. According to the result the value of SNR, PSNR and normalized root mean square error for standard heart sound and for other four heart sound, haar wavelet gives maximum values of SNR & PSNR [24]. In the de-noising process of PCG signal we use this wavelet and we also providing spectrogram for analyses of PCG signal. From this figure we find that pulmonary stenosis is segmented much more efficiently. Compare the both row and column for every types of value and calculate maximum level value and bold the highest value.

level / Wavelet	Normal heart sound (7) db	Atrial septal defect (7) db	Aortic insuffii-ency (7) db	Patent ductus atrocious (7) db	Pulmo-ary stenosis (7) db
Haar	17.3320	25.3340	28.2589	15.4427	**30.6087**
Db2	17.8360	20.3737	21.8954	15.1476	23.7744
Db4	17.1432	19.2651	20.2295	15.4940	22.3689
Db6	17.1198	19.1035	20.1231	15.4479	22.0549
Db8	17.0651	19.0457	20.1992	15.4257	21.9073
Db10	17.0047	19.0006	19.9768	15.3898	21.9124
Coif1	18.0154	20.5229	21.9233	15.1569	23.8120
Coif2	17.1588	19.1269	20.3771	15.4764	22.2737
Coif4	17.1447	18.9994	20.1842	15.4014	22.0449
Sym2	17.8360	20.3737	21.8954	15.1476	23.7744
Sym4	17.1510	19.0908	20.3761	15.4858	22.2812
Sym6	17.1009	19.0374	20.2003	15.3909	22.1612
Sym8	17.1339	19.0277	20.1238	15.4075	22.0110
Bior1.3	20.2627	24.6172	27.3100	17.4267	29.5236
Bior2.8	17.0819	19.4100	22.2644	15.4620	24.0671
Bior3.9	15.8404	18.3277	19.6040	15.5884	21.8740
Bior6.8	16.9968	18.9263	20.0512	15.3813	21.8740
Dmeyer	17.0068	18.9946	20.0908	15.3661	21.9458

Table 1- Signal to noise ratio for decomposition value in seven levels

The result of the peak signal to noise ratio is the major criteria which needs to get special attention while working with the segmentation of PCG signal, which is shown below:

level / Wavelet	Normal heart sound (7) db	Atrial septal defect (7) db	Aortic insuffii-ency (7) db	Patent ductus atrocious (7) db	Pulmo-ary stenosis (7) db
Haar	35.5619	39.5510	47.0588	35.3694	**51.2643**
Db2	35.6038	37.8422	46.3097	34.7324	50.2781
Db4	35.4821	37.4400	45.9779	35.6398	49.9388
Db6	35.5221	37.3604	45.9257	35.556	49.8916
Db8	35.3897	37.4011	45.8812	35.3707	49.7819
Db10	35.4923	37.3242	45.8422	35.3807	49.8111
Coif1	35.5533	37.8326	46.2177	34.8244	50.2384
Coif2	35.5497	37.3519	45.9587	35.5677	49.8759
Coif4	35.4773	37.2796	45.7994	35.4028	49.7493
Sym2	35.6038	37.8422	46.3097	34.7324	50.2781
Sym4	35.5227	37.3316	45.9911	35.5933	49.8425
Sym6	35.5164	37.3466	45.8096	35.4113	49.8113
Sym8	35.5281	37.3044	45.8088	35.4425	49.7620
Bior1.3	35.6773	39.5258	47.0786	35.5317	51.2562
Bior2.8	34.2734	37.1374	45.3781	35.5400	49.4076
Bior3.9	33.0919	36.4420	44.0813	35.9567	49.6375
Bior6.8	35.2704	37.0815	45.7004	35.4921	49.6375
Dmeyer	35.5093	37.2845	45.8666	35.4465	49.8030

Table 2 - Peak Signal to noise ratio for decomposition value in seven levels.

The normalized Root Mean Square values generated for various pathological signals are shown below, and it can be observed that the minimum value is generated by Haar wavelet for Pulmonary Stenosis at level 7. The result is shown below:

level / Wavelet	Normal heart sound (7) db	Atrial septal defect (7) db	Aortic insuffii-ency (7) db	Patent ductus atrocious (7) db	Pulmo-ary stenosis (7) db
Haar	0.0306	0.0109	0.0131	0.0207	**0.0086**
Db2	0.0306	0.0132	0.0143	0.0223	0.0096
Db4	0.0311	0.0140	0.0150	0.0204	0.0100
Db6	0.0312	0.0141	0.0151	0.0205	0.0101
Db8	0.0313	0.0141	0.0150	0.0207	0.0102
Db10	0.0311	0.0141	0.0151	0.0208	0.0102
Coif1	0.0308	0.0133	0.0145	0.0222	0.0097
Coif2	0.0311	0.0140	0.0150	0.0204	0.0101
Coif4	0.0314	0.0141	0.0152	0.0207	0.0101
Sym2	0.0306	0.0132	0.0143	0.0223	0.0102
Sym4	0.0312	0.0141	0.0150	0.0203	0.0096
Sym6	0.0312	0.0141	0.0152	0.0207	0.0102
Sym8	0.0312	0.0142	0.0152	0.0206	0.0103
Bior1.3	0.0303	0.0109	0.0131	0.0203	0.0086
Bior2.8	0.0356	0.0144	0.0159	0.0203	0.0107
Bior3.9	0.0357	0.0156	0.0185	0.0198	0.0104
Bior6.8	0.0321	0.0144	0.0154	0.0207	0.0104
Dmeyer	0.0313	0.0142	0.0151	0.0208	0.0102

Table 3 - Normalize root mean square for decomposition value in seven levels.

The developed system is represented best via the Graphical User Interface, and hence the GUI has been developed for the comparison purpose and result displayed. Following snapshot shows the developed GUI for the system representation.

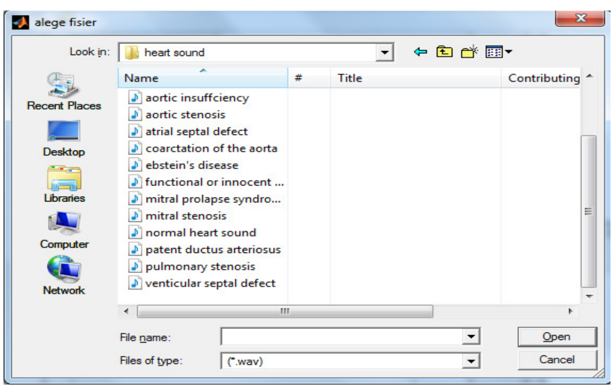

Fig. 2: GUI for selecting the PCG Signal.

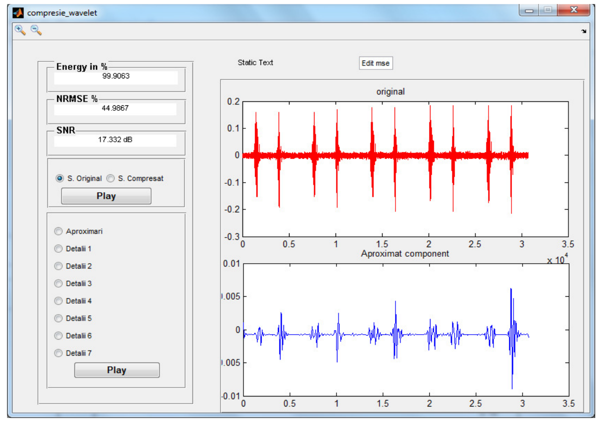

Fig. 3: GUI for display of Energy, NRMSE and SNR of the selected PCG Signal.

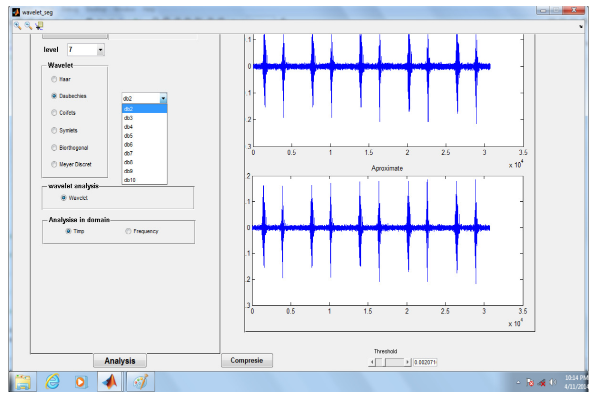

Fig. 4: GUI for selecting the Wavelet to be used with level.

The result is also produced at the command prompt parallely and the figure below shows the snapshot of such a situation of generating the result.

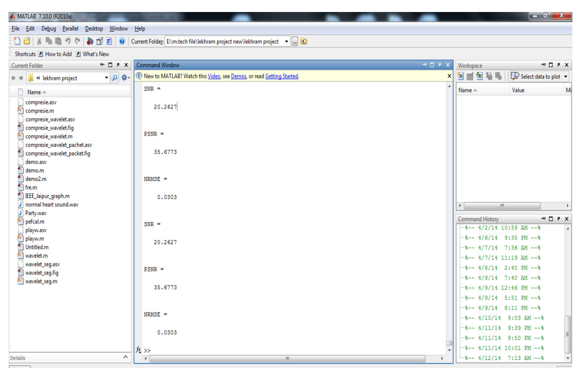

Fig. 5: Result displayed on the Command Prompt.

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