Proposed Algorithm for Implementation of Shannon Energy Envelope for Heart Sound Analysis

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Abstract
In a complete cardiac cycle, the first and the second heart sounds are dominating sounds out of four high amplitude sounds. This proposed algorithm is an automatic detection of two dominating heart sounds based on 3-order normalized average Shannon energy envelope. By computation of Shannon energy envelope of heart sound signal, most of the low level murmurs and background noises get suppressed, leading to excellent detection of first and second heart sound. The performance of algorithm have been evaluated for 55 recordings (from different subjects and at all four auscultations areas) each of 2 minutes, out of which 2520 cycles were selected for analysis. Out of 2520 cycles, the 2409 cycles were correctly detected. This proposed algorithm found 95.6 % correct ratio.

Keywords
Cardiac cycle, Shannon energy, Heart Sounds, Auscultations & Shannon Envelope.

I. Introduction
The Phonocardiogram (PCG) is a Non-invasive study (diagnosis) method which provides very useful and authentic information about valve functioning of heart. Many physicians for a long time have been dependent upon heart sound auscultations for the diagnosis of different type of cardiac diseases. So the heart sound has great importance in medical science.
Mainly four types of heart sounds are associated with the opening and closing of the valves and the flow of the blood within the heart during the cardiac cycle. These sound may heard by placing a stethoscope in corresponding position on the anterior surface of the chest over the heart .The first and second heart sounds are sharp and distinct and even easily heard by untrained ear. The third heart sound closely follows the second heart sound and is of lower amplitude (muffled), which makes it hard to distinguish. The fourth heart sound is often of such low amplitude that it cannot be detected. For these reasons, the discussion of heart sound measurement often refers to only first and second heart sound [1].
In this paper an algorithm has been developed for the segmentation and detection of heart sound. This proposed algorithm is an improved version of NASA algorithm which constructs the time gate to detect the accurate boundaries of first and second heart sounds.

II. Methods
The detection algorithm is based on the calculation of envelope using three-degree normalized average Shannon energy, which attenuates the effect of low value noise and makes the low intensity sound easier to be found.

A. Acquisition and Pre-Processing of Data
The test data consists of recording of heart sounds which is recorded "MP36 System" of "BIOPAC SYS". The heart sound was recorded with at 5000 sampling frequency and 16 bit resolution.

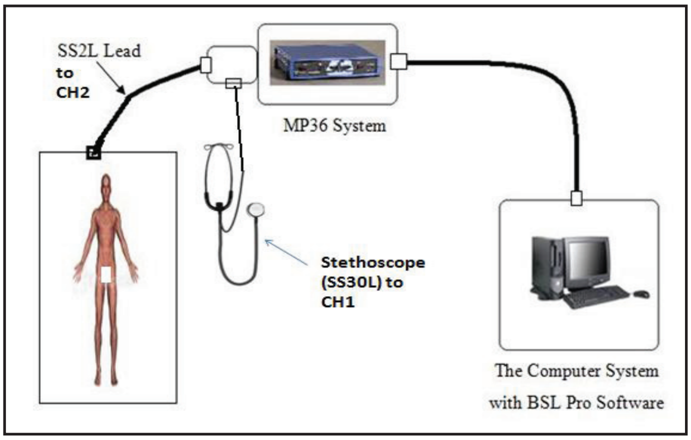

Fig. 1: Data Acquisition Using MP36 System

The original heart sound signal is acquired at 5000 samples/second and then decimated by factor 5 to 1000 sampling frequency. Now signal is normalized to absolute maximum of signal according to equation (1)

$$x(i) = \frac{x(k)}{\max(|x(k)|)} \quad (1)$$

Where, x (k) = Original heart sound signal; and x (i) =normalized signal

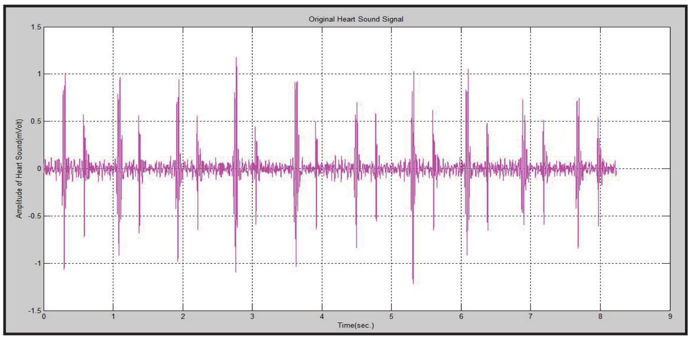

Fig. 2: Original Heart Sound Signal

B. The Normalized Average Shannon Energy
The standard definition of Shannon energy formula is as follows:

$$E_s = -\frac{1}{N}\sum_{i=1}^{N} x^2(i) * \log x^2(i) \quad (2)$$

Where, x (i) = Original Signal, and Es= Normalized average Shannon Energy
But, preliminary studies have proved that the method of normalized average Shannon energy [6] was sensitive to heart murmurs which easily lead to false segmentation. Therefore, for better computational results we can choose third order Shannon energy equation (as shown in equation no. 3).

$$E_s = -\frac{1}{N}\sum_{i=1}^{N} x^3(i) * \log x^3(i) \quad (3)$$

Where, meanings of all symbols are same as those in equation (2).

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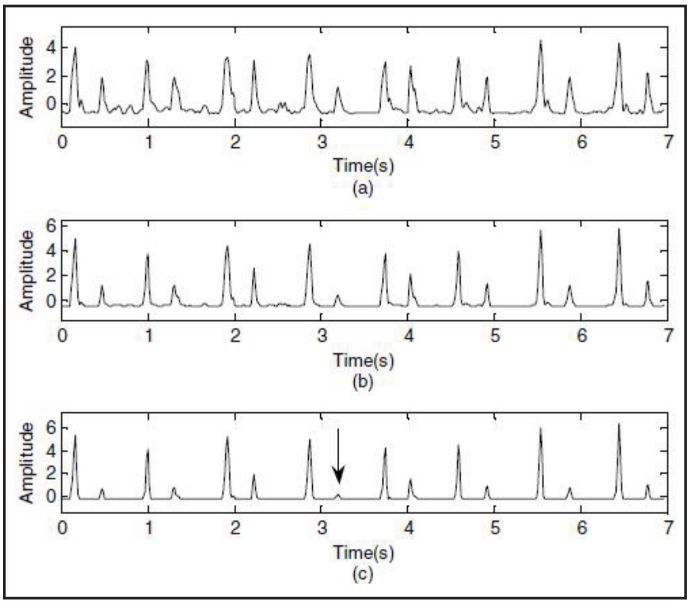

Fig. 3: Envelopes of Heart Sounds Signal Under Different Formula; (a) 2-order, (b) 3-order, (c) 4-order.
[Courtesy: Xinpei et al.]

The envelopes of signal using different computing formulae are shown in fig. 4, where (a) is the envelope using 2-order formulae, (b) is the envelope using 3-order formulae, and (c) is the envelope using 4-order formulae. As shown in fig. 4, the higher the order is, the smoother the envelope is, while the smaller the amplitude of the S_2 is. Particularly in (c), the envelope of S_2 marked with arrow can't be recognized. Considering the smoothness of the envelope and the identifiability of S_2, 3- order formula performs well [8].

Extraction of Heart sound Envelope:
The extraction of the heart sound envelope is implemented by calculating the normalized average three-order Shannon energy. The average three-order Shannon energy is calculated in continuous 32-samples segment throughout the normalized signal with 16-samples segment overlapping, according to following formula,

$$E_s = -\frac{1}{N}\sum_{i=1}^{N}|x(i)|^3 * logx|(i)|^3 \quad (4)$$

Where, x (i) = normalized signal, N= number of samples in 32-sample segment.
Then, the normalized average 3-order Shannon energy of whole heart sound signal is computed according to following formulae,

$$P_{ha}(t) = \frac{E_s(t)-M(E_s(t))}{S(E_s(t))} \quad (5)$$

Where, M (E_s (t)) = mean value of E_s (t) and S (E_s (t)) = Standard deviation of E_s (t).

D. Segmentation of Heart Sounds Envelope

After the processing a final Shannon energy envelope is obtained (as shown in Fig. 4). This envelope can reflect the approximate position of S_1 and S_2. But, due to overlapped segmentation of signal, there is deviation between the peak locations of heart sound envelope and peak locations of original heart sound signal in time axis. Therefore, to get the more accurate position of First and Second heart sounds in time axis, the time gates of S_1 and S_2 are constructed on the basis of obtained heart sound envelope. Now, the time gate can be considered as the search range to detect the accurate position of S_1 and S_2 in heart sound signal.

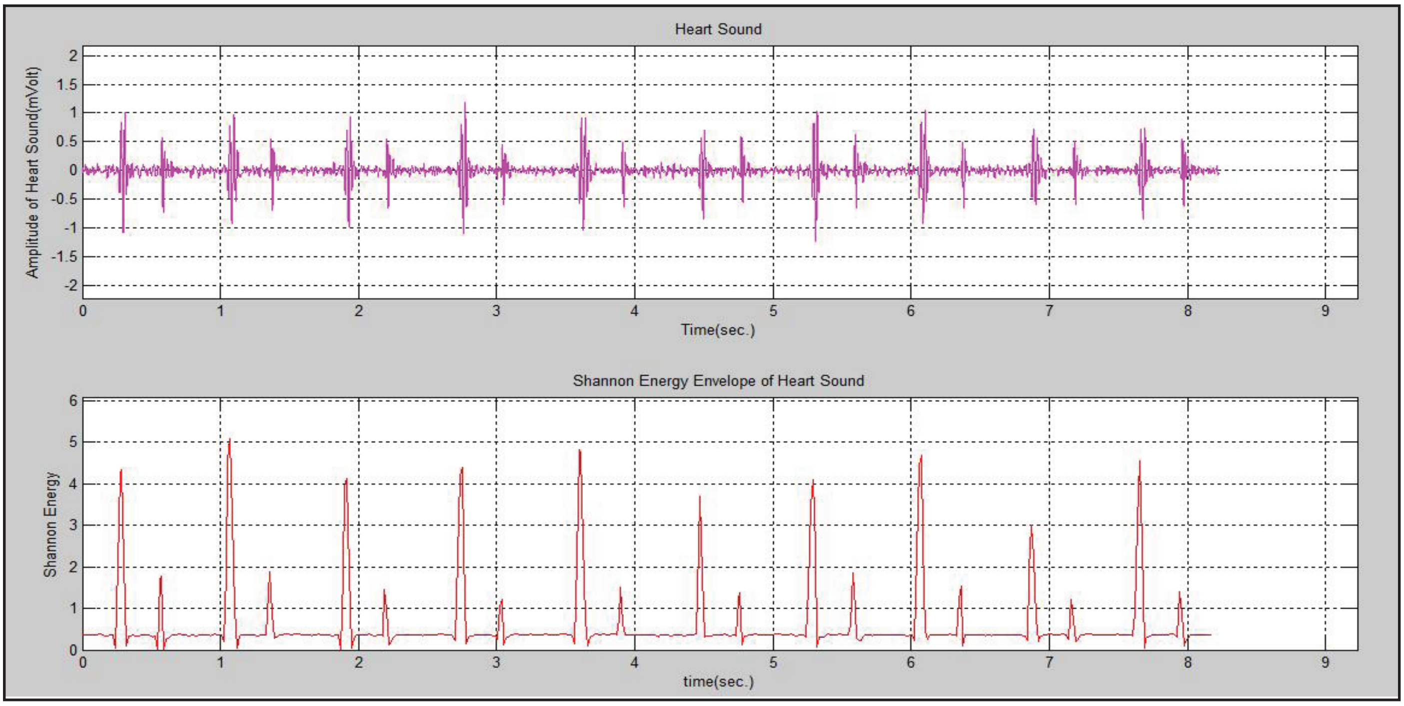

Fig. 4 : Heart Sound and its Shannon Energy Envelope

Now, according to the amplitude of envelope, a soft-threshold "Th" has to obtain. Then, time gate of S_1 and S_2 is constructed by Threshold "Th".

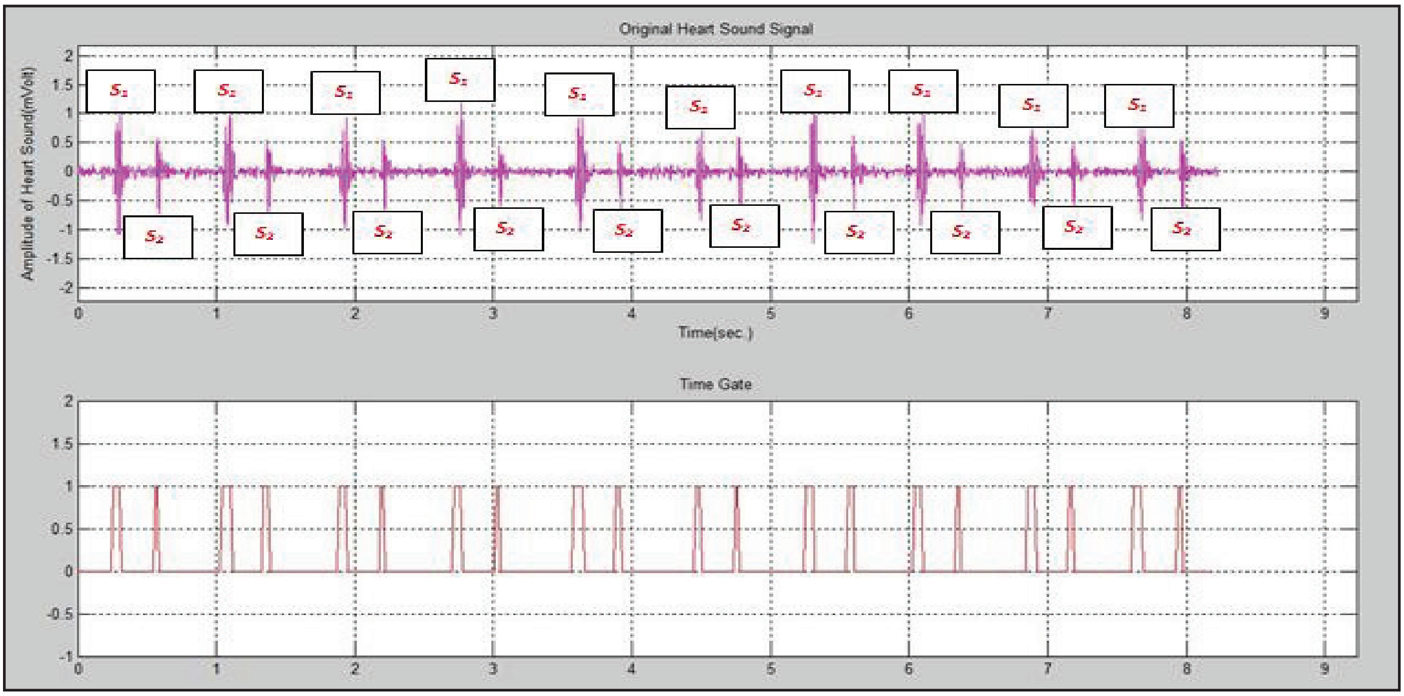

Fig. 5: Final Marking of S_1 and S_2

The S_1 and S_2 are identified on the basis of following facts:

1. The longest time interval between two consecutive peaks is the Diastolic period (i.e. from the end of S_2 to beginning of S_1) [5].
2. After finding the longest interval, the starting and ending of interval is marked as S_1 and S_2 respectively. And in the same way all peaks are marked.

If there is no splitting or murmurs in the heart sound, then all peaks can be detected very correctly (as shown in fig. 5).

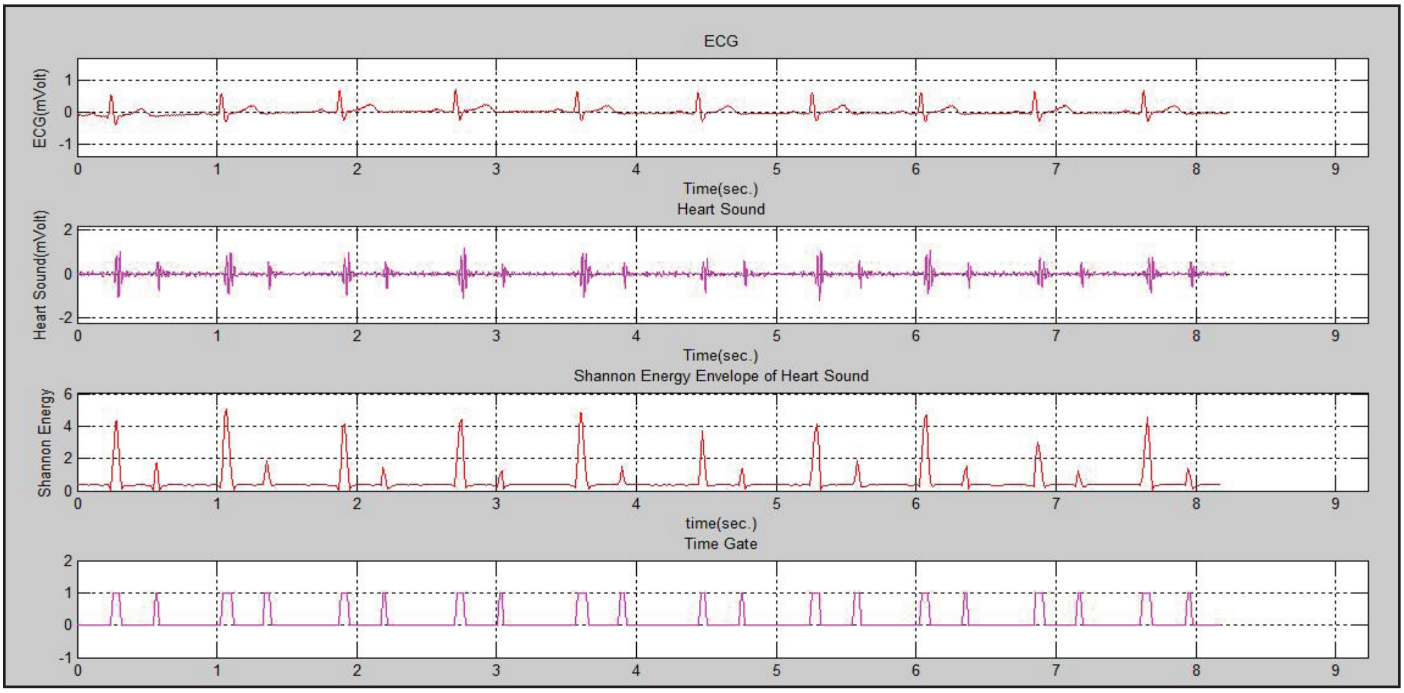

Fig. 6: Whole Process at a Glance

E. Evaluation of functioning of Heart valves by correlating the number of S_1/ S_2 detected and number of R-peaks detected in selected ECG signal segment:

Since, we acquire ECG signal simultaneously for verification of our results. Now, we detect the number of R-peaks obtained in the selected ECG signal segment and also count the number of S_1/S_2 obtained in selected heart sound signal segment, simultaneously (The signal should be always selected in complete cycle segment, i.e. from P to P cycle of P-Q-R-S-T). Then, we can predict the following facts:

1. If no. of R-peaks in ECG signal segment are equals to half the number of time gates detected in Heart Sound signal (false detection must be avoided), then heart valves are working properly.
2. If the above condition does not occurs then there are possibility of either heart sounds splitting and presence of murmurs or

due to lost peaks or extra peaks the number of actual time gates are not properly detected.

The algorithm of this decision process is shown in fig. 7.

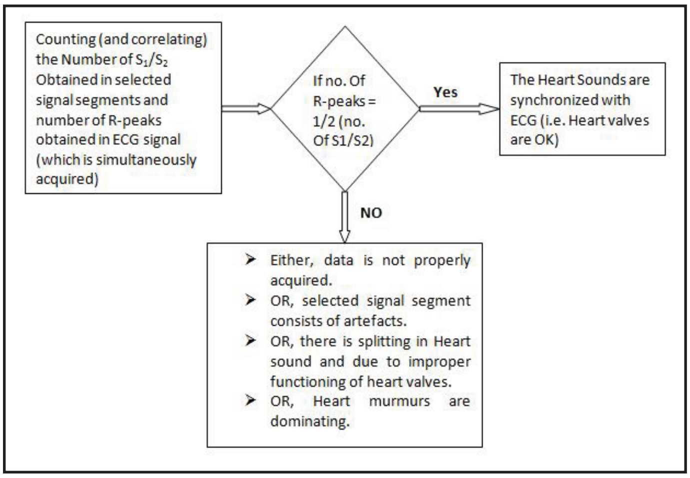

Fig. 7: Algorithm for Prediction of Situation of Heart Valves on Basis of Detected no. of R-peaks and S_1/ S_2

III. Results

Since, Heart sound signal reflects the mechanical valve functioning of heart and it can't be acquired as accurately as ECG signal. Because ECG reflects the electrical changes in heart, therefore its rather accurate than heart sounds. Therefore, in order to evaluate the proposed 3-order Shannon energy algorithm and verify the results, the ECG signals are recorded synchronously. This proposed algorithm detects S_1 and S_2 very accurately. The location of S_1 is after R-wave of ECG Signal and the location of S_2 is approximately at the end of T-wave of Electrocardiogram signal, which is consistent with the physiology knowledge [9].

The performance of the algorithm is also evaluated for 55 recordings (from different subjects and at all four auscultations areas) each of 2 minutes, out of which 2520 cycles were selected for analysis. The achieved results are summarized in Table 1.

This algorithm gives better results even if we acquire the signal from any of the four auscultations areas (i.e. Aortic, Pulmonic, Tricuspid and Mitral), but the best performance is achieved if data is acquired from Pulmonic position on chest. At the end of algorithm the detected number of S_1/ S_2 time gates is correlated with number of R-peaks detected in selected simultaneously acquired ECG signal segment, automatically. It provides better explanation to results obtained.

Table 1: The Statistics Results of S_1/S_2 Detection

	No. of cycles	Percentage (%)
Correct Detection	2409	95.59
Incorrect Detection	111	4.41
Total	2520	100

Most of the reasons for incorrect detection are as following:

1. Abnormal heart sound splitting.
2. High level interfering signal like speech, crying, gastric sound etc.
3. Presence of high level murmurs, which get mixed with major heart sounds.

But, still the background noises and low level murmurs have no effect on the detection results due to efficient suppression of noises in pre-processing and envelope calculating.

IV. Conclusion

This presented automatic detection and analysis algorithm can overcome the interferences of noises i.e. heart murmurs and background noises, and efficiently detects the primary heart sound (i.e. First heart sound and Second heart sound). It suppresses the low level murmurs and background noises due to pre-processing of signal and envelope calculation. The detected time gates are accurate boundaries of S1 and S2. The performance result shows that it's nearly 95.6% successful. In the final step, the number of detected S1/S2 are correlated with number of R-peaks in ECG signal which is simultaneously acquired, which gives a better explanation to our results. Although, this algorithm have the excellent performance for detecting S1 and S2 in heart sound, this method still fails to detect the high level of heart murmurs which are the major symptom of prosthetic valve dysfunction and heart disease.

References

[1] "Lesson 17: Heart Sound", Biopac Student Lab 3.7.6.

[2] Lehner RJ, Rangayyan RM.,"A three-channel microcomputer system for segmentation and characterization of the phonocardiogram", IEEE Trans. on Biomedical Engineering 1987.

[3] Groch MW, Domnanovich JR, Erwin WD,"A new heart sounds gating devices for medical imaging", IEEE Trans. On Biomedical Engineering 1992; 39, pp. 307-310.

[4] Iwata A, Ishii N, Suzumura N.,"Algorithm for detecting the first and the second heart sounds by spectral tracking", Med. & Biol. Eng. & Comput. Jan 1980: pp. 19-26.

[5] Y. Lin, X. F. Xu,"Segmentation algorithm of heart sounds based on empirical mode decomposition," Chinese Journal of Biomedical Engineering, Beijing, Vol. 27, pp. 485–489, August 2008.

[6] H. Y. Liang, L. Sakari, H. Iiro,"A heart sound segmentation algorithm using wavelet decomposition and reconstruction," 19th IEEE International Conference on Medicine and Biological Society, USA, Vol. 4, pp. 1630–1633, October 30 – November 2 1997.

[7] T. Oskiper, R. Watrous,"Detection of the first heart sound using a time-delay neural network," Computers in Cardiology, USA, Vol. 29, pp. 537–540, September 2002.

[8] Xinpei Wang, Yuanyang Li, Churan Sun, Changchun Liu, "Detection of First and Second Heart Sound Using Heart Sound Energy", IEEE Conference, 2009.

[9] C. B. Xu,"The Theory of Phonocardiogram", Science Press, Beijing, 1982.

[10] F. Debiais, L. G. Durand , P. Pibarot, R. Guardo.,"Time-frequency analysis of heart murmurs. Part1: Parametric modelling and numeric simulations", Med. Biol. Eng. Comput., 1997, 35, 474-479.

[11] P. Hult, T. Fjallbrant, K. Hilden, U. Dahlstrom, B. Wranne, P. Ask,"Detection of third heart sound using tailored wavelet approach: method verification", Med. Biol. Eng. Comput., 2005, 43, pp. 212-217.

[12] J. Herold, R. Schroeder, F. Nasticzky, V. Baier, A. Mix, T. Huebner, A. Voss,"Diagnosing aortic valve stenosis by correlation analysis of wavelet filtered heart sounds", Med. Biol. Eng. Comput., 2005, 43, pp. 451-456.

[13] Henrici Peter,"Applied and computational complex analysis", Vol. 1, John Wiley & Sons, Inc., New York, 1988.

[14] A. N. Pelech,"The physiology of cardiac auscultation," Pediatr Clin North Am, Vol. 51, pp. 1515-1535, 2004.

[15] Maton, Anthea; Jean Hopkins, Charles William McLaughlin, Susan Johnson, Maryanna Quon Warner, David LaHart, Jill D. Wright,"Human Biology and Health". Englewood Cliffs, New Jersey: Prentice Hall, 1993.