Efficient Computation of Phonocardiographic Signal Analysis with Hardware Implementation

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ABSTRACT
A prototype of a simple and non-invasive system to remotely monitor of the real-time heart rate of patients or individuals based on phonocardiography, the study of heart sounds has been developed. This system consists of five modules. The first module, namely the front-end modules is used to acquire and capture heart sound signals. This article presents a real time system for the heart auscultation monitoring and hearing. The system design comprises of a Phonocardiographic pre-amplifier circuit. The Phonocardiogram signal from there – amplifier circuits acquired and subjected to various signal processing techniques. Frequency analysis and component analysis are performed to identify the normal and pathological heart and sound patterns. To study the performance of the system, the analysis of heart sound patterns for various diseases were conducted.

Keywords
heart auscultation, murmurs, Phonocardiogram, classifier, Hardware setup

1. INTRODUCTION
Heart sounds result from the interplay of the dynamic events associated with the contraction and relaxation of the atria and ventricles, valve movements, and blood flow. They can be heard from the chest through a stethoscope, a device commonly used for screening and diagnosis in primary health care. The art of evaluating the acoustic properties of heart sounds and murmurs, including the intensity, frequency, duration, number, and quality of the sounds, are known as cardiac auscultation. The different methods and a novel analysis algorithm for dynamic assessment of cardiac acoustics signal, such as PCG but not limited to, will improve the associated researchers for better understanding of PCG signal nature and its reflection on integrative clinical diagnosis of cardiomyopathy.

2. PSYCHOACUSTICS
Psychoacoustics is the science in which the human perception of sounds is quantified. The ultimate aim is to derive a quantitative model that matches the results of all auditory experiments that can be contrived. This is quite a tall order, since, to a great extent, the human auditory system remains a “black box,” despite many years of physiological research. Each of these sound characteristics has a corresponding perceptual variable. The perception of frequency is called pitch, the perception of intensity is called loudness, and the perception of spectrum is called timbre. These human response variables are not linearly proportional to the value of the corresponding stimulus variables.

3. PHONOCARDIOGRAM SIGNAL (PCG)
The auscultation method is an important diagnostic indicator for hemodynamic anomalies. Heart sound classification andanalysis play an important role in the auscultative diagnosis. The term phonocardiography refers to the tracing technique of heart sounds and the recording of cardiac acoustics vibration by means of microphone-transducer. Therefore, understanding the nature and source of this signal is important to give us a tendency for developing a competent tool for further analysis and processing, in order to enhance and optimize cardiac clinical diagnostic approach. This approach will assist in identifying and obtaining useful clinical and physiological information. Although these PCG acquisition techniques are plain, noninvasive, low-cost, and precise for assessing a wide range of heart diseases, diagnosis by auscultation requires good experience and considerable observation ability. The PCG signal is traditionally analyzed and characterized by morphological properties in time domain, by spectral properties in the frequency domain, or by non-stationary properties in a combined time-frequency domain.

4. PHYSIOLOGY OF THE HEART SOUND
During the systolic and the diastolic phase of the cardiac cycle, audible sounds are produced from the opening and the closing of the heart valves, the flow of blood in the heart, and the vibration of heart muscles. Usually, four heart sounds are generated in a cardiac cycle. The first heart sound and the second heart sound can be easily heard in a normal heart through a stethoscope placed on a proper area on the chest. The normal third heart sound is audible in children and adolescents but not in most adults. The fourth heart sound is seldom audible in normal individuals through the conventional mechanical stethoscopes but can be detected by sensors with high sensitivity, such as electronic stethoscopes and phonocardiography systems. Sounds other than these four, called murmurs, are abnormal sounds resulting from valve problems, or sounds made by artificial pacemakers or prosthetic valves.

The third and fourth heart sounds, also called gallop sounds, are low-frequency sounds occurring in early and late diastole, respectively, under highly variable physiological and pathological conditions. Deceleration of mitral flow by ventricular walls may represent a key mechanism in the genesis of both sounds. The third heart sound occurs in the rapid filling period of early diastole. It is produced by vibrations of the ventricular walls when suddenly distended by the rush of inflow resulting from the pressure difference between ventricles and atria. The audibility of third heart sound may be physiological in young people or in some adults, but it is pathological in people with congestive heart failure or ventricular dilatation.

The fourth heart sound occurs in late diastole and just before first heart sound. It is produced by vibrations in expanding ventricles when atria contract. Thus, fourth heart sound is rarely heard in a normal heart. The abnormally audible fourth heart sound results from the reduced distensibility of one or both ventricles. As a result of the stiff ventricles, the force of atrial contraction increases, causing sharp movement of the ventricular wall and the emission of a prominent fourth heart sound. Most murmurs are the result of turbulent blood flow, which produces a series of vibrations in the cardiac structure. Murmurs during the early systolic phase are common in children, and they are normally heard in nearly all adults after exercise. Abnormal murmurs may be caused by stenosis and insufficiencies (leaks) at the aortic, pulmonary, or mitral valves. It is important from a diagnostic point of view to note the time and the location of murmurs. The identification of murmurs may assist the diagnosis of heat defections like aortic, stenosis, mitral and tricuspid regurgitation, etc.

5. MURMURS AND ITS TYPES

Heart sounds are caused by turbulence in blood flow and vibration of cardiac and vascular structures. Murmurs are caused by turbulent blood flow and there are a number of different murmurs which may be detected by cardiac auscultation. Table 1.1 shows the principle characteristics of the heart mummers which derived spatially and have clinical importance in diagnosis in heart valve abnormalities and describe the different heart sound and the origin of each one. Heart sounds and murmurs are small amplitudes, with frequencies from 0.1 to 2000 Hz.

Table 1.1 Spatial characteristics of diagnosing valve disease from heart murmurs

Heart sound murmurs	Heart valve abnormalities	Clinical importance
S_1	is volumetric contraction	mitral and tricuspid valves Closure
S_2	is volumetric relaxation	aortic and pulmonary valves vlosure
S_3	early ventricular filling	normal in Children, in adults, associated with ventricular dilation (e.g., ventricular systolic failure)
S_4	atrial contraction	associated with stiff, low compliant ventricle (e.g., ventricular hypertrophy)

6. HEART MURMUR's (SOUND) RECORDINGS

To record heart sounds, very sensitive amplifiers are used. These amplifiers are provided specially designed microphones, which will pick up not only the sounds /and murmurs at the body surface, but also all extraneous noises and vibrations in the immediate vicinity of the patient. This fact emphasizes the importance of having a quiet area for a phonocardiography. Many sources of noise can contribute to the overall background level in a room. External noises, such as air conditioners, typewriters, machinery, street noises and voices from radios and television sets create vibrations within the same frequency range of the heart sounds and murmurs and will result in artefacts which can mask faint heart sounds and murmurs. Therefore, it is important to select a room for phonocardiography where the external background noise level is already low. In addition, some soundproofing measures can be taken, if necessary. The walls and ceiling of the room can be covered with acoustic tile such as the perforated fiber type. The floor can be covered with a thick carpet or cork and the window closed off or heavily draped. The door can be heavily padded and also draped, or perhaps a double door utilized. Any noise making apparatus within the room, such as a room air conditioner or fan should be disconnected during the examination. To check whether the environment is adequate for phonocardiography, place a microphone connected to the instrument on a table near the recording area. Set the amplifier controls at typical sensitivity settings and at the various filter positions you will be using. Room temperature must not be allowed to become too cool, for this can induce shivering in the patient, and the resultant muscle tremors, could interfere with good sound. The block diagram of PCG processing scheme is shown in figure 1.

BLOCK DIAGRAM

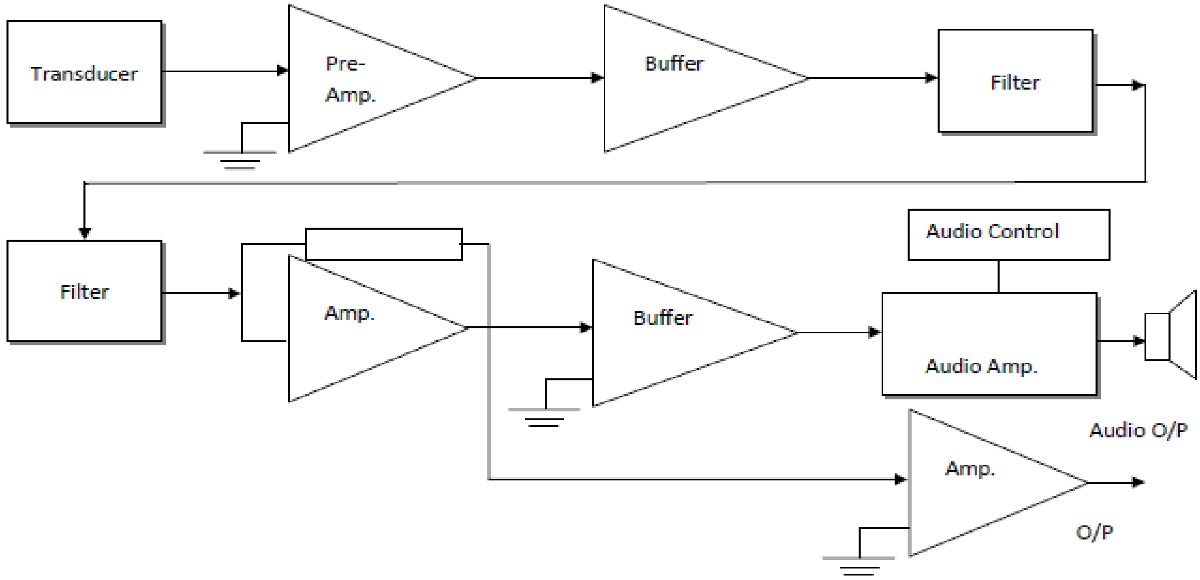
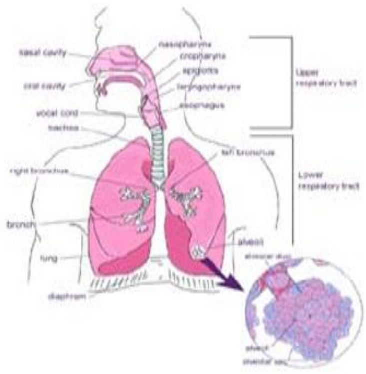


Figure 1 Block Diagram of PCG amplifier

The block diagram of PCG machine shown in figure 1, consists of following blocks:

- Transducer
- Pre-amplifier
- Filter
- Audio phone Amplifier
- Heart Sound Indicator
- Heart Sound Amplifier

The input section receives the heart signals from the microphone on the patient’s heart (chest) and feeds the heart sound preamplifier. Dynamic microphones are used for phonocardiograph. The dynamic microphone has frequency response from 20 Hz to 2000 Hz. The heart sound preamplifier amplifies the heart sound to the desired level. An audio phone amplifier and audio phone output section further amplify these sounds to drive the headphone. The five-step filter employed here passes the selected band of heart sounds to the heart sound amplifier. The heart sound amplifier amplifies the heart sound to the desired level and via output level control feed the records or CRO, which can be connected to the output socket directly. The heart sound indicator senses each heard sound & murmur & display as light flashes through the LED. Heart sound & murmurs contain the frequency 20Hz to 2000 Hz. A standard galvanometer recorder can record the frequencies which are 100 Hz. In phonocardiograph a direct writing hot stylus galvanometer is used to record heart sound & murmurs which are below 100 Hz. Using standard galvanometer. To record the higher frequency signals special types of galvanometer are used. The front panel appearance of the PCG unit is shown in figure 2. The technical specification is given in table 2. The complete PCG module is given appendix 1.



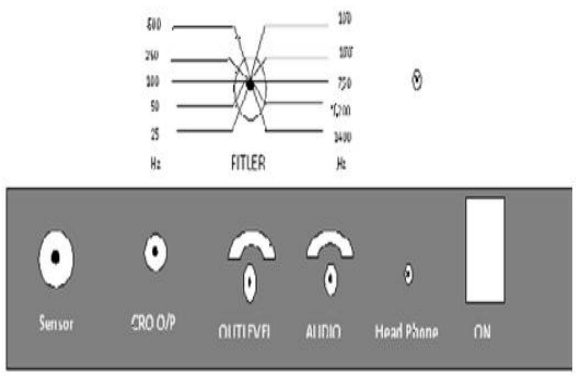


Figure 2 Front Panel

Sl. No.	Features	Remarks
1	Filter	100,250,500,750 and 1000 Hz
2	Heart Sound Indicator	LED
3	Frequency response	20-2000 Hz
4	Transducer type	Dynamic
5	Indication	Heart Beat & Power
6	LPF	100,200,500 & 1000 Hz
7	Gain	Variable
8	Amplifier	LNA

7. RESULTS AND DISCUSSION

The heart sound murmurs were recorded from different subjects along with other measured signals. From these observations, different features were extracted and these features were applied to a classifier network for further classification.

7.1 CLASSIFICATION OF HEART SOUNDS

Totally 2048 samples of heart murmurs were given as input. The artifacts in the acquired samples were filtered and the filtered heart sound signals (wave signals) were classified using SVM technique. The confusion matrix for five different heart sound signals is given in Table 3 to Table 6 for different signal to noise levels. The five different heart sound murmurs were classified from the filtered 2048 samples.

Table 3 Heart sound murmurs classified for SNR=0 dB

0dB, 2048 samples
Correctly classified HB diastolic rumble Signal 38 %
Correctly classified SYSTOLIC AORTIC STENOSIS 74.5 %

Correctly classified TRICUSPID REGURGATION 97.25%
Correctly classified EJECTION MURMUR 83.25%
Correctly classified DIASTOLIC VENTRICULAR GALLOP 99.75%
CLASSIFICATION/MISCLASSIFICATI ON MATRIX

152.0000	0	3.0000	0	0	98.0645
0	298.0000	0	60.0000	0	83.2402
245.0000	0	389.0000	7.0000	1.0000	60.5919
3.0000	102.0000	6.0000	333.0000	0	75.0000
0	0	2.0000	0	399.0000	99.5012
38.0000	74.5000	97.2500	83.2500	99.7500	78.5500

TABLE 4 Heart sound murmurs classified for SNR=1 dB
1dB, 2048 samples
Correctly classified HB diastolic rumble Signal 79%
Correctly classified SYSTOLIC AORTIC STENOSIS 78.5%
Correctly classified TRICUSPID REGURGATION 95%
Correctly classified EJECTION MURMUR 88.5%
Correctly classified DIASTOLIC VENTRICULAR GALLOP 100%
CLASSIFICATION/MISCLASSIFICATION MATRIX

316.0000	0	20.0000	2.0000	0	93.4911
0	314.0000	0	42.0000	0	88.2022
80.0000	0	380.0000	2.0000	0	81.5451
0	86.0000	2.0000	354.0000	0	80.4545
0	0	0	0	400.0000	100.0000
79.0000	78.5000	95.0000	88.5000	100.0000	88.2000

Table 5 Heart sound murmurs classified for SNR=5dB
5dB, 2048 samples
----------Classification Rate-----------------

Correctly c lassified HB d iastolic r umble Signal 100%
Correctly classified SYSTOLIC AORTIC STENOSIS 99%
Classification/MISCLASSIFICATI ON MATRIX

400.0000	0	64.0000	0	0	89.8876
0	397.0000	0	23.0000	0	96.8215
0	0	336.0000	0	0	100.0000
0	3.0000	0	377.0000	0	98.9770
0	0	0	0	400.0000	100.0000
100.0000	99.2500	84.0000	94.2500	100.0000	96.9000

TABLE 6 Heart sound murmurs classified

10dB, 2048 samples

Signal 99.75%

Correctly classified SYSTOLIC AORTIC

STENOSIS 100%
ICUSPID
Correctlv classified TRICUSPID

REGURGATION 100%
JECTION
Correctlv classified EJECTION

MURMUR 100%
IASTOLIC
Correctlv classified DIASTOLIC

VENTRICULAR GALLOP 100%

399.0000	0	0	0	0	100.0000
0	400.0000	0	0	0	100.0000
4.0000	0	400.0000	0	0	99.7506
0	0	0	400.0000	0	100.0000
0	0	0	0	400.0000	100.0000
99.7500	100.0000	100.0000	100.0000	100.0000	99.9500

The self-classification and average cross-classification efficiency plots corresponding to different heart sound murmurs obtained using the SVM classifier scheme is shown in figure 3 and figure 4.

Correctly classified HB diastolic rumble

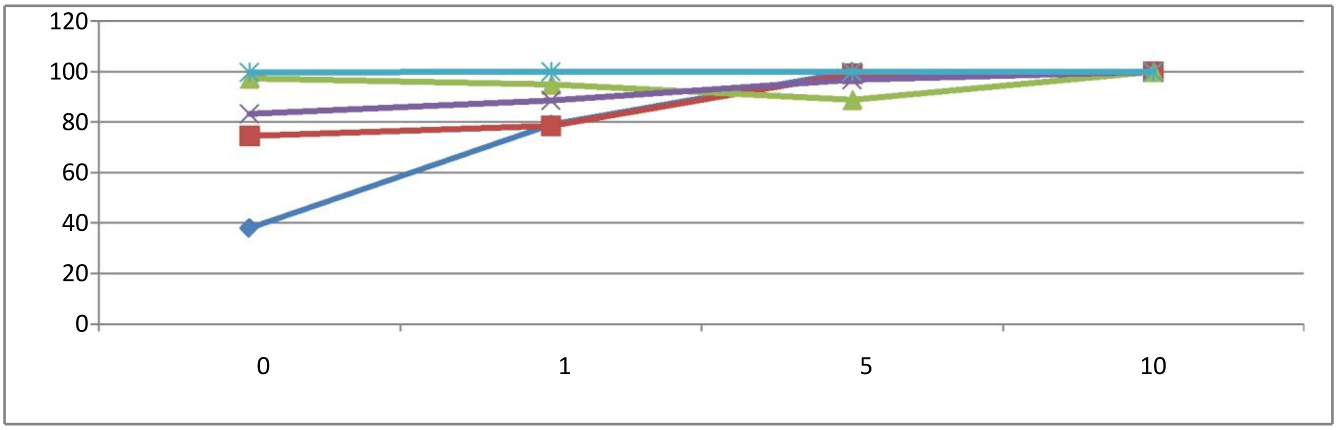


Figure 3 Self-Classification efficiency of different heart sound murmurs Vs SNR (dB)

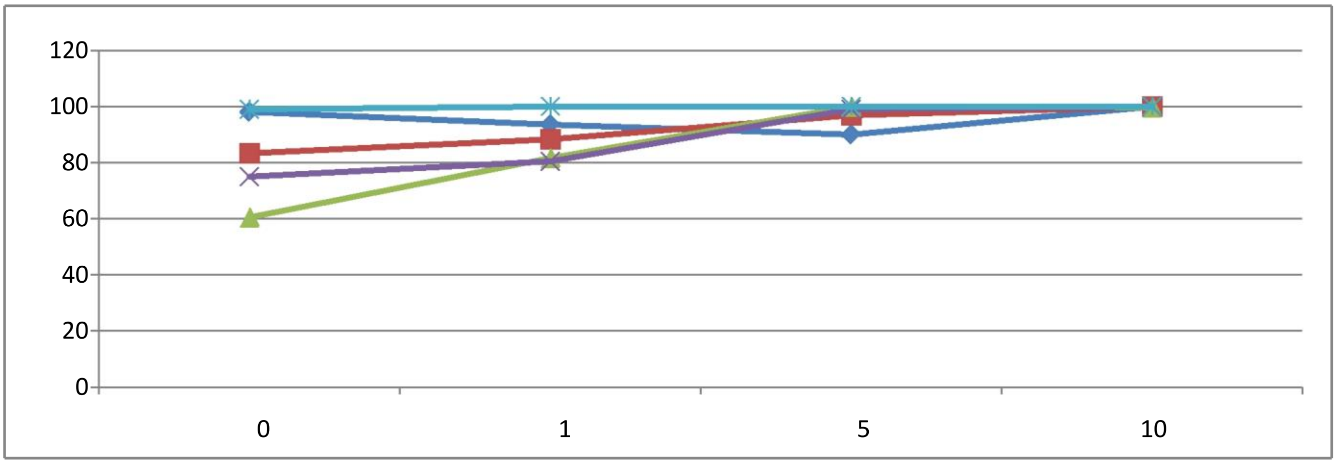


Figure 4 Average cross-classification efficiency of different heart sound murmurs Vs SNR (dB)

8. CONCLUSION

This paper presents a hardware setup to perform the signal analysis of heart sounds and murmurs. A large number of, partly nonlinear, features can be extracted and used for distinguishing innocent murmurs from murmurs caused by Aortic Stenosis using recurrence quantification analysis. The work is a noninvasive investigation of blood pressure changes and an integrated heart monitor with ECG and PCG will offer improved clinical decision making. Traditionally heart auscultation is an initial and fundamental procedure toinspect a patient. Applying these diagnostic procedures in routine clinical practices would results in efficient and accurate diagnosis of the disease at an early stage

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