Construction of A Simple Electronic Stethoscope for Chest Sound Acquisitionand Separation of Recorded Sounds Using Independent Component Analysis

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Abstract

In human chest, two kinds of sounds can be heard, one from the lungs and the other from the heart. Physician uses a Conventional Stethoscope (CS) for detecting these chest sounds in order to make a diagnosis. A unique, simple, Active Electronic Stethoscope (AES) is fabricated. In this AES, a piezoelectric ceramic plate is used for recording of chest sounds (heart and lung sounds). It is compared with two types of existing stethoscopes. It is found that AES is superior to other stethoscopeswith respect tosimplicity, better acoustic response, and ease of interface with modern devices. The signals were acquired through Labview softwarefor further analysis.Independent Component Analysis (ICA) algorithm was applied to the recorded signal which facilitated separation of heart and lung sounds.A Physician also validated the results.

Keywords: Active Electronic Stethoscope, piezoelectric ceramic plate, ICA, Labview.

I Introduction

Several factors determine quality of the detection of the heart and lung sounds. Some of them are patient's body size, obesity, chest hair, noise level in the room, proper placement of CS on the chest, hearing capacity of the physician and quality of the sounds generated inside the chest. These factors are applicable for both normal and abnormal chest sounds.

Thus the abnormal sounds produced from the body may not be transmitted with all its characteristic features. In such a situation, a physician cannot rely only on his conventional stethoscope to make final decision. Furthermore, the signal hearing by physician cannot be recorded and interpretation of sound fully depends upon his expertise. He may not be able to demonstrate these sounds for teaching purpose. In order to overcome such difficulties an attempt was made to device an electronic stethoscope with several added advantages, like the sounds could be amplified and recorded for further analysis. Moreover such amplified sounds could be used for teaching purposes in a classroom.

In this study, a prototype of anElectronic Stethoscope (ES) is designed, fabricated and finally tested its efficacy. The existing Electronic stethoscope [1]is modified with purely active components and tested with three different types of sensor configurations. The performance of the Active Electronic Stethoscope (AES) with piezoelectricsensor configuration was found to be better with respect tosimplicity, acoustic efficacy and ease of interface with modern devices.

Lung sounds and Heart sounds are considered as independent source signals [8]. However, due to the mixed signals recorded on the skin are correlated and are convolute mixtures. One solution to separate this type of mixed signals is to apply ICA on the spectrograms of the recorded signals [2]. Hence, it is necessary to investigate the application and feasibility of ICA on separation of HS and LS.

II Materials and Methods

Signal Acquisition

There are multiple types of sensors reported in literature[3] that can be used in the chest piece of an electronic stethoscope to convert body sounds into an electronic signal.Microphones, Piezoelectric ceramic plates and accelerometers are popular in chest sound recording. However, accelerometers are typically more expensive than microphones, are often fragile, and may exhibit internal resonances.

In this study,three sensor configurationsnamely, (i) Microphone Only (MES),(ii) Piezoelectric Ceramic Plate (PES)&(iii)Conventional Stethoscope coupled to Microphone (CES) are considered.

Signal Conditioning

The stethoscope system detecting chest sounds has two main blocks: Signal Acquisition and Signal Conditioning. The signal is sensed by the sensor and then preamplified, filtered and then it is given to a power amplifier, which in turn drives the output speaker and also couples the output to the PCthrough sound card(Fig 1).The signal is acquired in Labview and signal is analysed.

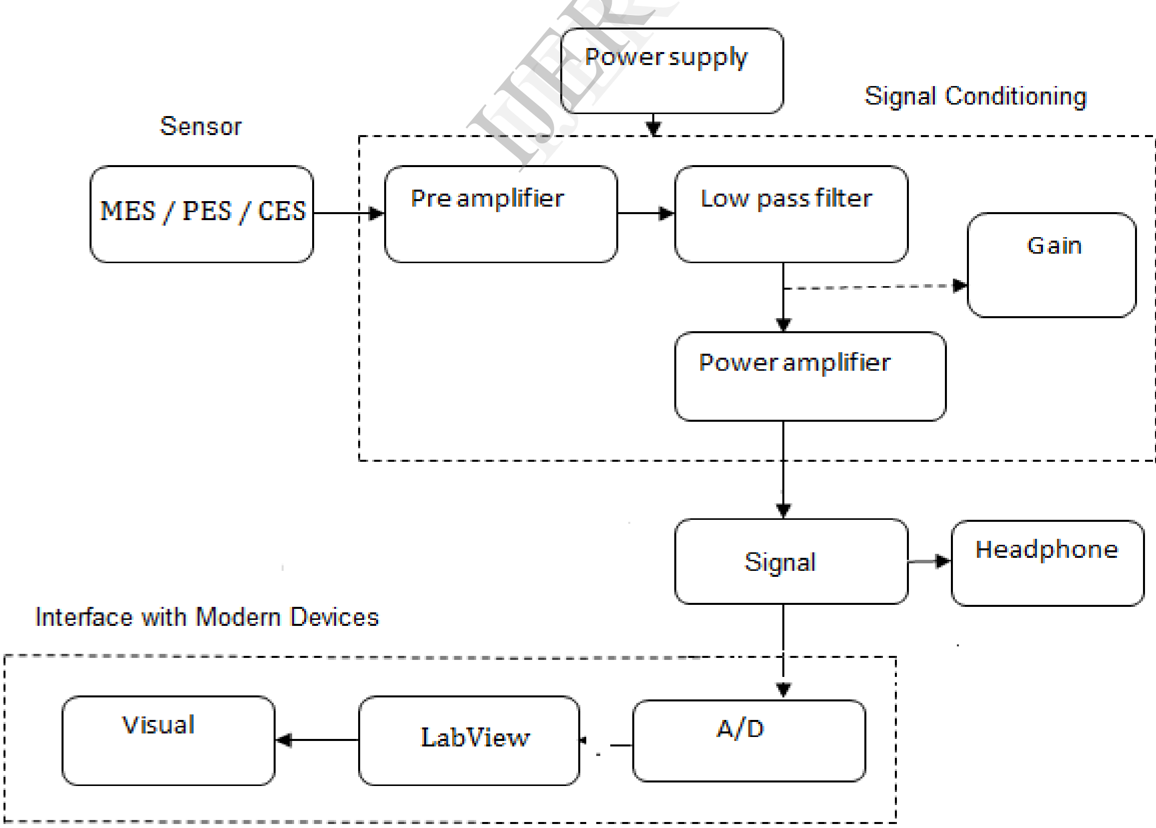

Fig 1 Complete Stethoscope System

Patient Data

Fifteen patients, those who referred to the out-patient department of a Government general hospital,were randomly selected with different age, sex and clinical symptoms. Chest sound was recorded using CS, MES, PES&CES. The recorded chest sounds were analysed with respect to the details as shown in the questionnaire.

Questionnaire

1. Patient data-Name...age.....sex
2. Equipment used = MES / PES / CES
3. Ease of operation.
4. Sound analysis
5. Noise
6. Efficacy –utility, simplicity, etc.

ICA algorithm

Recorded Chest sounds is a mixture of heart and lung sounds. Moreover it was found that the power content of both heart and lung sounds is enriched at lower frequencies. Hence traditional filtering was not successful in separation of the signals. Hence the solution to this problem was treated as a case of Blind source separation (BSS). It was found that ICA is effective BSS technique for biomedical signal processing. [2]

FastICA is an efficient and popular algorithm for independent component analysis. The algorithm is based on a fixed-point iteration scheme maximizing non-Gaussianity as a measure of statistical independence. It can also be derived as an approximate Newton iteration. FastICA was implemented in MATLAB.

III Design of the electronic Stethoscope System

The hardware design of the electronic stethoscope system is composed of the following major parts: power supply, sensor, preamplifier, low-pass filter and power amplifier. Although it is advantageous to implement operational amplifier circuits with balanced dual supplies, there are many practical applications where, for energy conservation or other reasons, single-supply operation is necessary or desirable. IC 7809 was used to regulate the input 9V, compatible with the sensor module, operational amplifierand power amplifier.

MES Sensor

The microphone is an air coupled sensor that measure pressure waves induced by chest-wall movements. Condenser microphones generally have flatter frequency responses and hence no distortion in the entire range of frequency [4]. There are two types of condenser microphones; standard condenser and electret condenser. A standard condenser microphone consists of a small diaphragm that vibrates in response to acoustic pressure. Standard condenser microphones have very high output impedance, so they are not suitable for transferring signals over even a very small distance. Hence electret microphone is considered for in this case Fig 2.

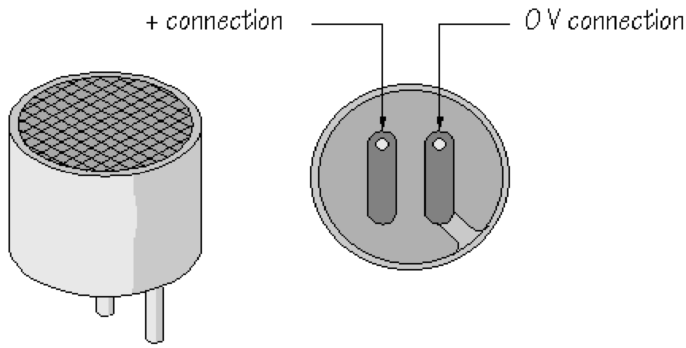

Fig 2 MES Sensor

CES Sensor

Here Conventional stethoscope coupled with microphone is used to record chest sounds. Within the device, two possible locations for the microphone were considered. The first design would place the microphone inside the tubing, some distance away from the diaphragm of the stethoscope [5]. Acoustic stethoscopes sound the way they do, because of the mechanical filtering done by the tube, prior to the sound reaching the physician's ears. The second location considered involved placing the microphone directly inside the diaphragm. This could improve the aesthetics and stability of the stethoscope, but as a compromise, the mechanical filtering done by the tube would be lost. Hence microphone was considered to be in its first location as given in Fig 3.

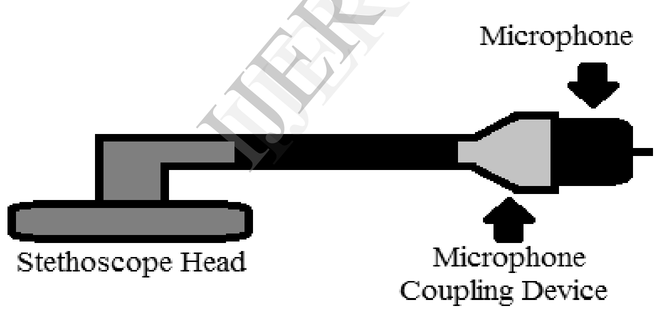

Fig 3 CES Sensor

PES Sensor

A Piezoelectric sensor (Fig 4)is an electronic device that generates a voltage when it's physically deformed by a vibration, sound wave, or mechanical strain. PES is an active sensor whereas MES is a passive sensor. Hence MES requires a power supply for the sensor. PES has an extremely high natural frequency and an excellent linearity over a wide amplitude range. Additionally, piezoelectric technology is insensitive toelectromagnetic fields and radiation.

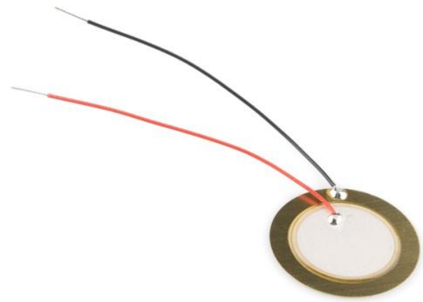

Fig 4 PES Sensor

Signal conditioning Circuit

The signal conditioning circuit employing MES / PES / CES Design is shown in Fig 5

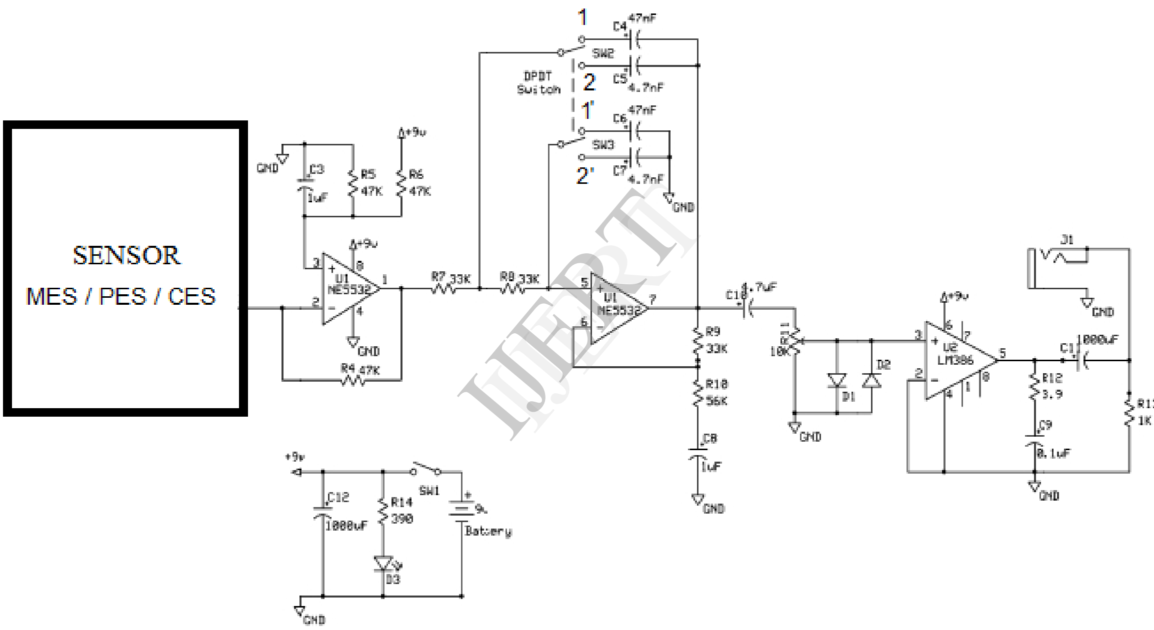

Fig 5 Signal Conditioning Circuit

9V single-supply biasing method is chosen since it is compatible with the microphone, operational amplifier and power amplifier. Three operational amplifiers OPA2134, TL072&NE5532 were recommended in literature [6] for signal conditioning the sensor. Hence NE5532 is chosen because of its availability and has lower noise as compared to TL072. The NE5532 is an internally compensated dual low noise OP-AMP. The high small signal and power bandwidth provides superior performance. It is also a low-power device that can be operated from a single voltage supply, therefore appropriate for battery-operated circuits.

A two stage low pass Sallen-key architecture is employed for filtering the output signal of preamplifier.

When Heart sounds are measured (DPDT Switch position 1-1') the Sallen key configuration is described by the following transfer function.

$$G(s) = \frac{415696.53}{s^2 + 1289.49s + 415696.53}$$

The cut off frequency for heart sounds is 102.6 Hz.

When Lung sounds are measured (DPDT Switch position 2-2') the Sallen key configuration is described by the following transfer function.

$$G(s) = \frac{41569653.49}{s^2 + 12894.91s + 41569653.49}$$

The cut off frequency for lung sounds is 1026 Hz.

The chest sounds recorded with stethoscope has both heart and lung sound segments mixed. The aim of this study is to record chest sounds particularly to study both heart and lung sounds.Hence two recordings, with one heart sound dominant (switch 1 – 1') and other lung sound dominant (switch 2 – 2') is required.

Filtered output is given to audio amplifier. The LM386 circuit is an audio amplifier designed for use in low voltage consumer applications which provides both voltage and current gain for signals. There are many other audio amp ICs on the market, but the LM386 is sufficient for the purposes. Another benefit about the LM386 is that the gain-frequency curve can be shaped with some external feedback components, so it is a very flexible device.

IV Software Design

The dynamic range of the heart and lungs is 20Hz to 1 kHz. In order to preserve sound quality during recording, sampling should be done at a rate that is at least twice the highest frequency of Interest (5 kHz in the case of the heart and lungs).

Sound is acquired directly using the sound VI's designed in Labview 12. The front panel and block diagram of the sound card interface is shown in Fig 6 & Fig 7.

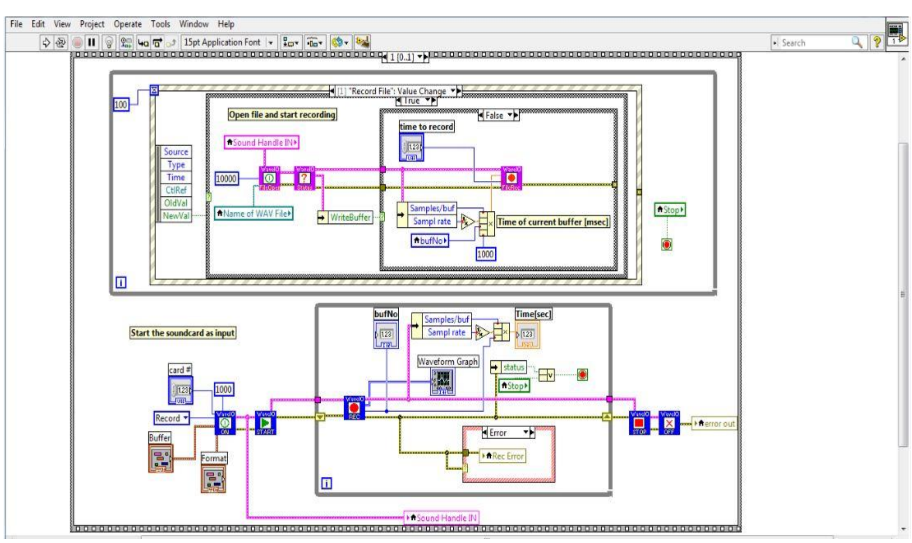

Fig 6 Block Diagram of Sound Card interface

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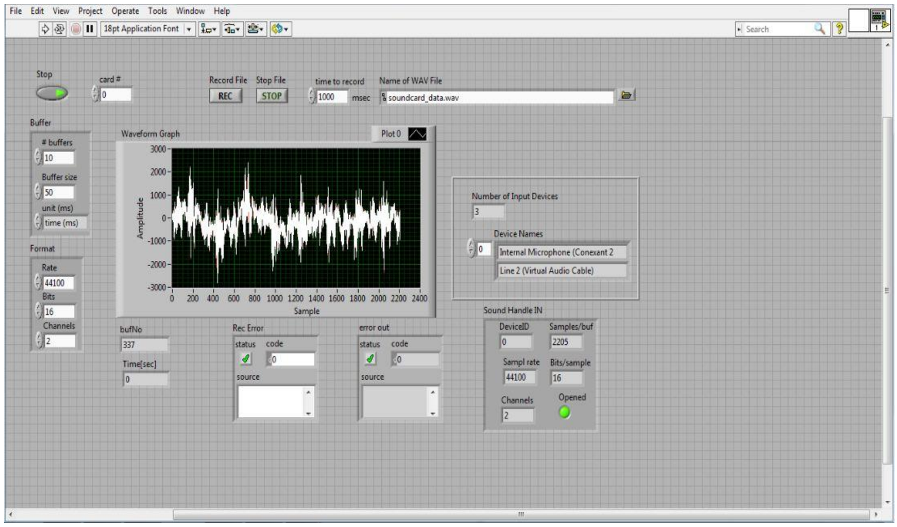

Fig 7 Front Panel of Sound Card interface

Time Frequency Analysis

Signal acquired using Soundcard interface VI are analysed in time and frequency domain [7]. The Signal had peaks of 50 Hz noise and harmonics. The signal was notch filtered and amplified for further display and analysis. The VI for this purpose is shown below in Fig 8 & Fig 9.

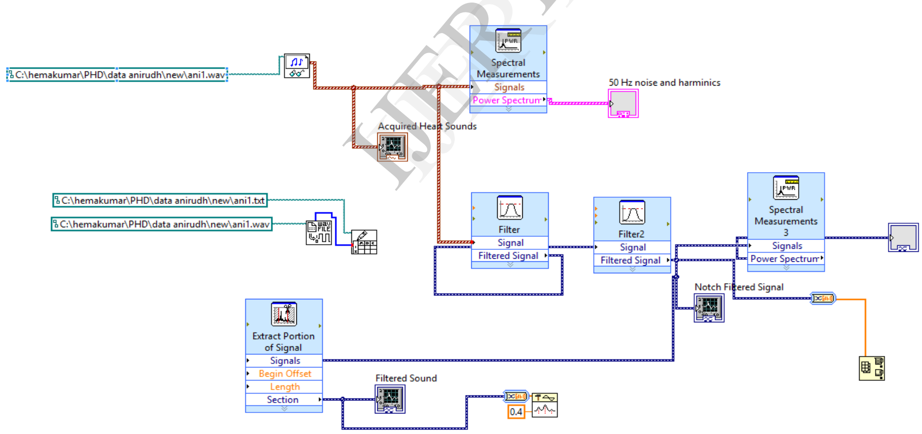

Fig 8 Block Diagram of Filtering Chest Sounds

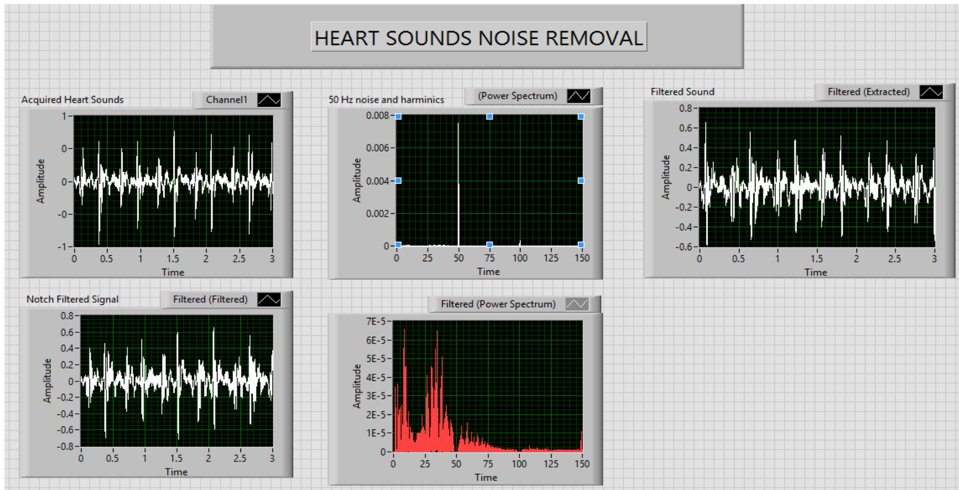

Fig 9 Front Panel of Filtering Chest Sounds

V ICA algorithm for separation of Heart and lung Sounds

The data matrix X recorded from stethoscope is considered to be a linear combination of non-Gaussian (independent) components i.e. X = SA where columns of S contain the independent components (heart and lung sounds) and A is a linear mixing matrix. In short ICA attempts to 'un-mix' the data by estimating an un-mixing matrix W where $XW^{-1} = S$.

Under this generative model the measured 'signals' in X will tend to be 'more Gaussian' than the source components (in S) due to the Central Limit Theorem. Thus, in order to extract the independent components/sources we search for an un-mixing matrix W that maximizes the nongaussianity of the sources.

In FastICA, non-gaussianity is measured using approximations to neg-entropy (J) which are more robust than kurtosis-based measures and fast to compute.The approximation takes the form

$$J(y) = [E\{G(y)\} - E\{G(v)\}]^2$$

Where v is aN (0, 1) r.v.

First, the data are centered by subtracting the mean of each column of the data matrix X. The data matrix is then 'whitened' by projecting the data onto its principal component directions i.e. X -> XK where K is a pre-whitening matrix. The number of components can be specified.

The ICA algorithm then estimates a matrix W s.t XKW = S . W is chosen to maximize the negentropyapproximation under the constraints that W is an orthonormal matrix. This constraint ensures that the estimated components are uncorrelated. The algorithm is based on a fixed-point iteration scheme for maximizing the neg-entropy.

V Results and Discussion

Stethoscope Sound Quality

MES Design incorporated Electret Microphone was able to pick up the sounds. But it is also sensitive to human voice. MES is highly sensitive to heart sounds.

CES Design using conventional chest piece with microphone had better sound quality in par with MES design. The signal clarity was good. But basically it produces humming sound and few echos. A third order Sallen Key filters can be used to suppress to some extent.

PES Design which incorporated Piezo ceramic plate was more sensitive compared to electret microphone It was able to pick up both heart and lung sounds effectively.

In conclusion PES and CES Design sound quality was more or less comparable.

Physician Validation Report (On a Scale of 5)

Number	Sound Characteristics	MES	PES	CES
1.	Type	HS	HS,LS	HS,LS
2.	Intensity	3	5	5
3.	Quality	3	5	4
4.	Clarity	3	5	4
5.	Noise	2	-	2
6.	SNR	2	4	3

HS – Heart Sounds, LS – Lung Sounds, SNR – Signal To Noise Ratio

Based on the physicians report tested on 15 patients of different age and gender groups, the stethoscope using MES design was good to detect first and second heart sounds. The stethoscope with PES design had better performance in both heart and lung sounds acquisition. The design with CES system was having good performance in par with PES design. But the system suffered from having low SNR.

Separated heart and lung sounds

FastICA algorithm was applied to the recorded chest sounds andthe source-to-interferences ratio (SIR) was evaluated using the whole separated signals. Fig 10 shows the results of heart and lung sounds separation using ICA. It was observed that ICA algorithm is better in speed of convergence measured in terms of number of iterations and has a higher SIR.

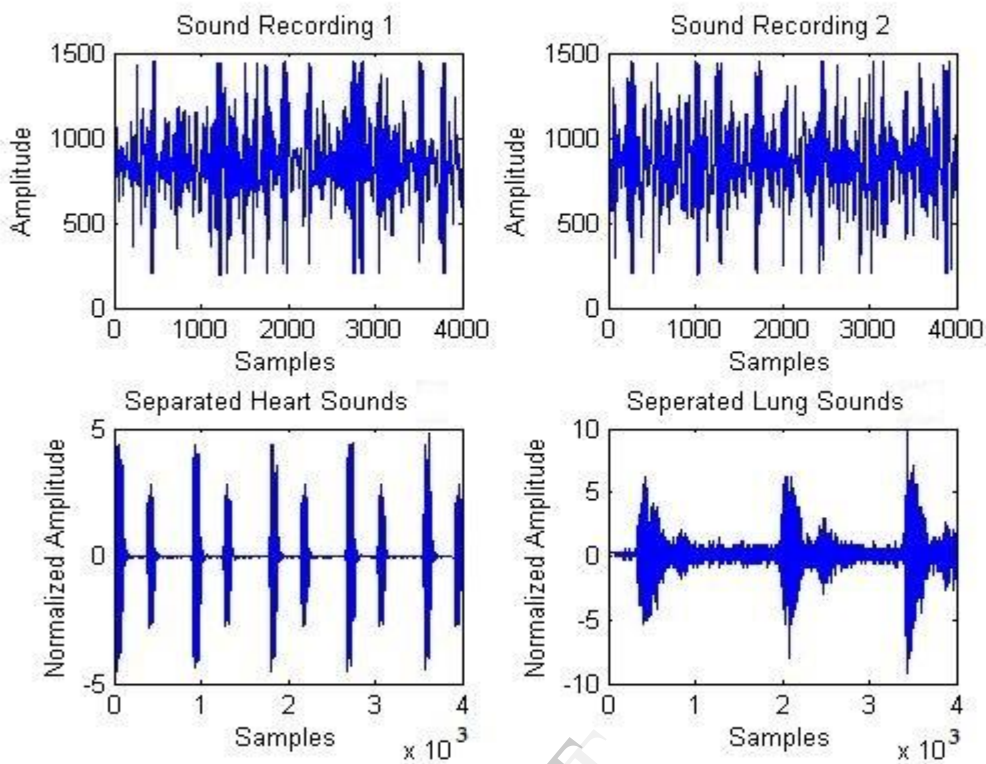

Fig 10 Separation of Heart and Lung sounds

VI Conclusion

Chest sound recordingusing stethoscope remains an important diagnostic tool, when performed skilfully, can provide clinicians with a wealth of information regarding patients' cardiac health. However, the standard acoustic stethoscope which has been useful for more than century, cannot process, store, and play back sounds or provide visual display, and teaching is hindered because there is no provision to record and playback the recording.

Hence an Electronic stethoscope using three different sensor configurations was designed and validated the performance of the stethoscope with a physician and found that the design with PES configuration gave better clarity, acoustic stability & simplicity. ICA was applied on the recorded output and its components viz Heart and Lung Sounds were separated.

Hence if PES is incorporated by practitioners, they can rely less on their subjective judgment and own hearing ability to gain an accurate representation of sounds using the electronic version.

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