A review on various Machine Learning Algorithms for Lung sound separation

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Abstract: The medical field is rapidly increasing with technology and the smart devices from IOT (internet of Things) has been influencing the devices used by medical practitioners. The devices such as blood pressure monitor, glucometer, ketones testing kits, fertility kits etc., have all been made smart by combining the software with Machine learning (ML) and Artificial Intelligence (AI). The next step for smart devices in medical field is the stethoscope. The smart stethoscope has many functions which are recording the sounds of the cardiovascular region, processing the sound for noise, analyzing the sound for abnormalities or checkups based on the way the stethoscope is designed, optimal position for stethoscope to record maximum sounds of heart or lungs. The major hindrance in this development is that the sound captured through the stethoscope is a mixture of sounds such as abdominal sounds, digestion sounds, burp sounds, bowel sounds, valve sounds etc., which mask the actual sound that needs to be recognized. This paper will review the various techniques to separate the lung and heart sounds which can be then used for analysis.

Index Terms— **Heart, Lung, Mel frequency, non-negative matrix factorization (NMF), Sound source separation, Short-term spectra, Adaptive algorithm, blind source separation;**

I. INTRODUCTION

The stethoscope has been the cornerstone of medical practitioners with the ease of use and constant evolution. The stethoscope as we know today has evolved from a cardboard piece in a cylindrical shape as the doctor found it difficult to listen to the cardiac rhythms of female patients. Because the invention of stethoscope, doctors would often keep their ears in the abdominal cavity to listen to the sounds of the valves and of the heart. The classical instrument was invented with meager materials found in one's basement by Rene Laennec around 1816. The process of listening to one's cardiac rhythm is called auscultation. During auscultation, the doctors might find some underlying medical condition which might come off as an irregular sound or sound which is out of sync. The stethoscope serves as a great tool for the doctors to identify the diseases beforehand and send the patients of further advanced consultation. It is a non-invasive way of examination which causes no pain to the patient and gives great insight into the cardiac health. The stethoscope although, gives a major insight into the cardiac sounds, it takes upon the skill of the practitioners to identify the abnormalities. The traditional stethoscope can be used by professionals. Due to the 2020 pandemic, the hospital visits for the sake of regular checkups were deemed risky as hospitals became an invariable house of infections, more so than never.

This created a storm within the automation community where stethoscope was next in line to be automated and become a smart device.

Cardiac sounds often mix with abdominal sounds, bowel sounds and sometimes burp sounds. This creates difficulty in identifying the specific sounds for analysis like the sound given by the movement of the air in the lungs. This is known as acoustic interference and must be removed using sound processing or some algorithms which can separate the different sounds.

This is quite challenging as the sounds are of similar frequency and amplitude domain. This is referred as blind source separation and this has been a driving force for fine tuning the existing algorithms to give better output. This is purely from a data scientist point of view because the doctors will not delve deep into the analysis of sound. The perspective of layman is to get a proper output. If that is met, then the process on the back end does not matter. The algorithms we will review for sound separation with respect to lung sounds are majorly of three types. Parallel source separation, High pass filter, Adaptive filter. Adaptive filter can have modifications such as adaptive filter with automatic gain control.

I. CLINICAL SIGNIFICANCE

II. The complications of the heart and lungs can occur at any stage, which often lead to death. From the analysis of World Health Organization, worldwide, an estimated 12 million deaths occur every year due to the heart disease. The main cause of mortality is no diagnosis in proper time. The diagnosis at the right stage will enhance the chance for doctors to make sure the patient gets the right treatment at the right time. The relevance and significance of respiratory sounds analysis or auscultation during operation and post operation is of critical importance as it might save the patient's life. Continuous monitoring of the lung and heart, in whole the cardiovascular system is important. Here in this paper we review the different algorithms for lung sounds separation. Even though the lung sounds are heard very much clearly through the stethoscope, the heart beats which occur in a cyclic manner continuously, it interferes with the auscultation which only focuses on lung sound analysis. This paper focuses on the lung because, in the aftermath of the COVID-19 pandemic, the most affected organ is the lung. The damage to the lungs is irreversible in many cases. Unlike some organs like liver which can regenerate itself, lungs do not have the capacity and taking care of them is of utmost importance in this polluted environment.

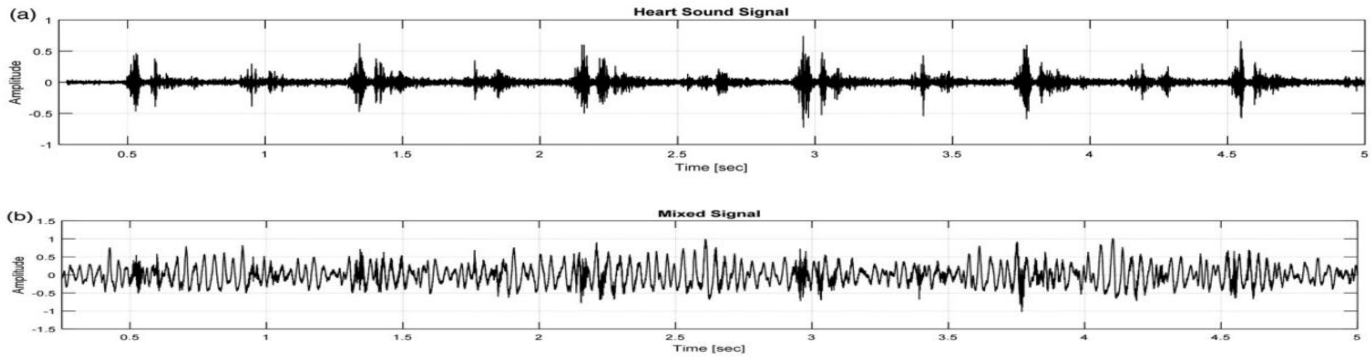

Figure 1. (a) Pure heart sound recorded from the chest. (b) Mixed (heart sound and bronchial breath sound) input signal.

The above two images depict the different sound waves, the diagram (a) is that of the heart sounds signal (HSS), and the second diagram (b)

III. Literature Review

IV. M T Pourazad et al. [1] has come with up an algorithm using independent component analysis (ICA). The heart beat is the strongest sound signal in the abdominal area and cannot be discounted when analyzing the lung sounds. The disturbance of sound from Heart Sound (HS) is more significant when the patient breathes moderately as the breath in and breath out matches with the working of the valves opening of the heart. In this study, the independent component analysis (ICA) is used where in the approach is novel. Two different recordings of the cardio-vascular sound is done in parallel. Since the stethoscope is placed at different locations, the amplitude and frequency of the recordings are different. This is done by implementing the Inverse Short Time Fourier Transform (ISTFT). Data acquisition is done by taking volunteers who are healthy without much medical history and then taking the sound recording. The breath sounds are below the hearing range when separated and hence are amplified with band pass filter to fit the frequency from 50 to 2500 Hz.

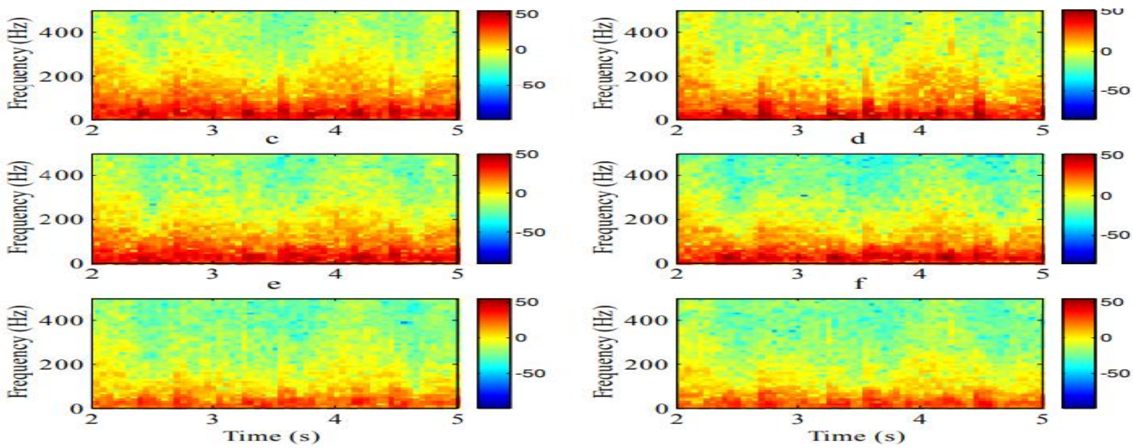

Figure 2: Spectrograms of the recorded signals at Right and Left location. The left side is towards the left side of the abdomen. The right-side set is of the recording from the right side of the chest. The heart signal is less amplified, as it is located on the left side.

The spectrogram ICA-based methodology will reduce the heart signal yet not cancel it completely and hence needs fine tuning. The independent component analysis is the main analysis. The implementation of the Inverse Fourier Transform is when signals are separated by the time domain and the results are also calculated the same way. The accuracy of the results is around 80% which is enough for some decent analysis of the lung sound and with fine tuning, more can be achieved.

Sensor specifications	
Frequency response	Flat in the frequency range of the sound Maximum deviation allowed 6 dB
Dynamic range	>60 dB
Sensitivity	Must be independent of: frequency; static pressure; and sound direction
Signal-to-noise ratio	>60 dB (S=1 mV·Pa^{-1})
Directional characteristic	Omnidirectional
Coupling	
Piezoelectric contact	
Condenser air-coupled	Shape: conical Depth: 2.5–5 mm Diameter at skin: 10–25 mm Vented
Fixing methods	
Piezoelectric	Adhesive ring
Condenser	Either elastic belt or adhesive ring
Noise and interferences	
Acoustic	Shielded microphones Protection from mechanical vibrations
Electromagnetic	Shielded twisted pair or coaxial cable
Amplifier	
Frequency response	Constant gain and linear phase in the band of interest
Dynamic range	>60 dB
Noise	Less than that introduced by the sensor
High-pass filtering	Cut-off frequency 60 Hz Roll-off >18 dB·octave^{-1} Phase as linear as possible Minimized ripple
Low-pass filtering	Cut-off frequency above the upper frequency of the signal Roll-off >24 dB·octave^{-1} Minimized ripple

*: applied for piezoelectric or condenser sensors

Figure 3: Summary of recommendations

In this study [2], L. Vannucini and others have provided a detailed description when the sound captured is analog. The sub sonic range of the sounds prove to be a hindrance to the research of the signals and normally the signals are amplified to a range of 60-2k Hz. The analog processing will consist of sensors, which sense the sound, amplifier which amplifies the sound which is captured through the abdomen. The system also contains the filters which condition the signal before the analog-to-digital (AD) conversion and then a combination of low-pass filters is used. The chest wall is quite good in containing the vibrations and hence we need to amplify it.

A piezoelectric mic is used so that the pressure of the valves will create the electricity to power the mic and the sound is captured. The signal-to-noise ratio (SNR) is the ratio between the output voltage and the noise. This determines the quality of the sound captured. The SNR should be 60dB for optimal placement.
Through this algorithm [3], Vijay and others arrive at an algorithm using the adaptive filter which is used in different configurations. The cancelation of the aggregate interference and the digital implementation configuration is used.

Lung sounds here recorded from different people, around five volunteers, with no known cardiac history. The signals were recorded on a frequency-modulator (FM) mic. This is to preserve the frequency of the sound. The adaptive filtering procedure is known through this experiment to completely separate heart and lung sounds. This hybrid methos is also found that it is above some traditional methods.

According to L. Yip and Y.T.Zhang [3], they have used an automatic gain control along with adaptive filter to cancel out the noise and amplify the sound we need. The research done prior to this paper indicates that the Laplacian electrocardiographic signals (LECG) give more insight in to the deeper parts of the sound rather than the normal electrocardiogram (ECG). Automatic gain control (AGC) (Figure-5) is combined with the stethoscope which is then given to the adaptive filter algorithm. The AGC algorithm mainly allows the simplification of the LECG signals when taken at the right side of the chest. The right side mainly gives better lung sounds since the heart signals is weaker and the lung sound is more prominent. The experiment with this approach shows that the accuracy went up from 43% to 75% which is a good sign for the analysis of the lung sounds.

The AGC algorithm stands for a closed loop feedback algorithm, which regulates the circuit for an amplifier or chain of many amplifiers. The AGC does the work of reducing the volume effectively when the signal is strong and increases the volume when the signal goes weak. It is taken from the detector stage and then gain control is done for the signal of the Radio frequency. This helps when the sounds are mixed in the signals as shown in Figure-5

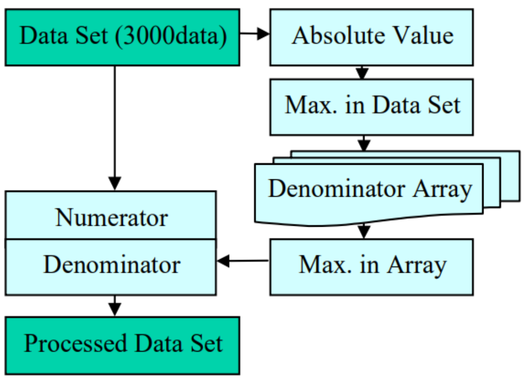

Figure – 5: Block Diagram of the Automated Gain Control (AGC)

In this research [4], the authors Fatma Ayari, Mekki Ksouri and Ali T Alouani implemented the enhanced version of Independent Component Analysis (ICA) and implemented the FAST-ICA algorithm. Lots of methods prior to this paper have attempted to separate the sounds but with much interference from the heart sounds. In this paper they have introduced FASTICA and using the Signal-to-Noise (SNR) ratio is good and found to be within 70 dB which is well within the boundary to have a good analysis. This method employed using the enhanced ICA is found to successfully separate the heart sounds and lung sounds with good accuracy. The one limitation is that the noise level in the output which masks the lesser peaks in the sound.

In this paper [5], Hong Tang and Ting Li studied the noise of the signal. Studying what needs to be eliminated is more useful. Noise is unavoidable in day-to-day life and also in recording instruments in medical field. Noise reduction is done when the noise is analyzed. The reduction is done through joint cycle frequency and time – frequency domains. The atoms of the heart sound captured through the stethoscope result in signals congregate joint domains. Heart signal was completely separated from the lung sounds and chest motion helps the separation as the sound waves maximize as the diaphragm which is solid acts as amplification of the sound. Correlation co-efficient is normalized residue which is used to indicate the closeness of the constructed noise-free heart signal as shown in Figure- 6

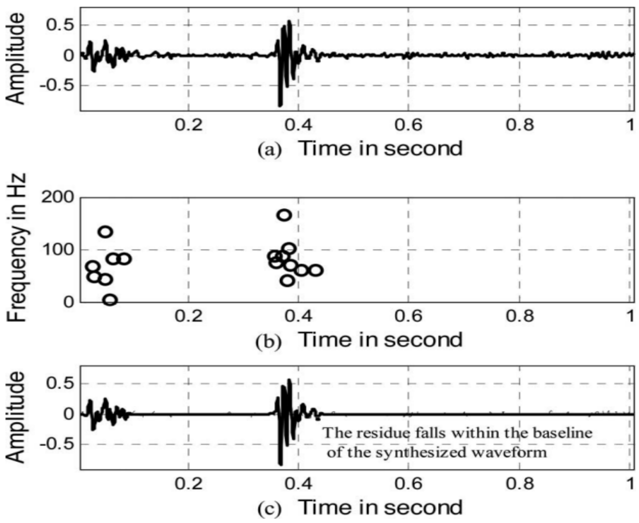

Figure-6: Heart signal of one cardiac cycle which constitutes to lub-dub of the heart. The taking of deoxygenated blood and re-pumping the oxygenated blood to different parts of the body.

With this paper [6], L.J. Hadjileontiadis and S.M. Panas there is an incessant noise which is recorded due to the beating of the heart. This paper does heart noise reduction which is employs a method of fourth order statistic. Order statistics have sample values which are then placed in ascending order. This also differs with rank order statistics which uses only the ranks of the statistical values.

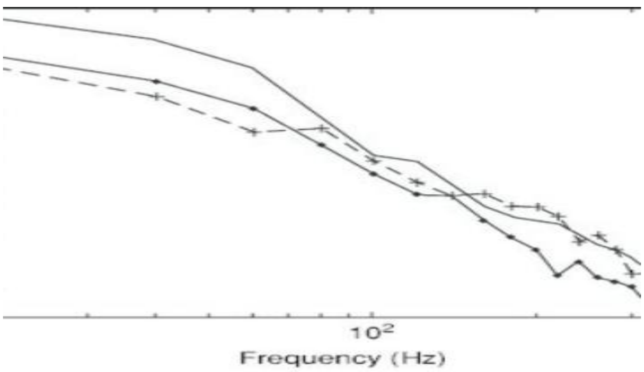

Figure 7: PSD of the original lung sounds including heart sounds (solid line), original lung sounds free of heart sounds (dashed line), and reconstructed lung sounds (dotted line) at low flow

With this paper, the authors [7], J.Gnitecki, Z.Moussavi, and Pasterkamp, they have a perspective that the lungs sound will never be completely void of other sounds. They have adopted recursive least squares (RLS) which is a adaptive noise cancellation technique which was applied for heart signal cancellation. The lung sounds is recorded on the anterior right chest from many healthy men with little or no cardiac history. Here they have used four different frequency bands within the range 20 to 300 Hz. Similar to above methods, the piezoelectric equipment is used to capture the lung sound noise. Three target flows of 7.5, 15 and 22.5 mL/s which are low, medium and high respectively. Selective PSD calculation is also used in this work to reduce the noise and get the lungs sound with more amplification with the system as shown in Figure-8

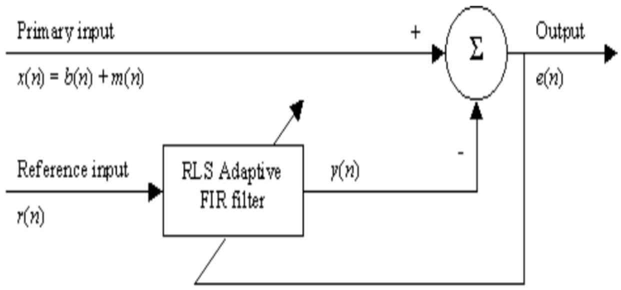

Figure-8: A diagram of RLS-ANC filter method

V.CONCLUSION

The experiments give good separation for the lungs sound from the heart sound. These algorithms use the sound which is recorded and then processed to remove the heart sounds along with other sounds like abdominal sounds. The digestive sounds also interfere as the diaphragm acts as an amplifier for certain frequencies. More fine tuning is required to get accuracy around 95% while separating the sounds. Better separation ensures better analysis for the smart stethoscope.

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