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Advancements of Electronic Stethoscope: A review

HSH Perera

Deparment of Electrical,Electronic and Telecommunication Engineering, Faculty of Engineering, General Sir John Kotelawala Defence University, Sri Lanka

hshperera99@gmail.com

Abstract— Auscultation is one of the most popular methods of disease diagnosis and stethoscope has been an integral device of medical examination as it is used to listen to internal body sounds. But it inherits many limitations in traditional conventional stethoscope. Hence, an electronic stethoscope provides a much more advanced and modern solution for those limitations, and it increases the accuracy of different internal body sound recognition, assisting medical professionals to make a proper disease diagnosis. Despite the conventional stethoscope, electronic stethoscope amplifies the auscultation sound captured at the chest piece and converts it to an electrical signal which is then transmitted through an advanced designed circuitry to apply further signal processing techniques. The main objective of this review is to analyse the evaluation of medical stethoscope and the advancements that have been done using modern technology to improve electronic stethoscope by adding various features including noise reduction techniques and real time visualization techniques. Further, the paper discusses how wireless data transmission techniques have been included in electronic stethoscope, making it is possible to provide graphical analysis of the sound signal and the advanced mathematical techniques applied to make denoising and feature extraction process in an accurate way. It further reviews the alternations and modifications that have been possible due to electronic stethoscope enhancing the quality of healthcare sector.

Keywords: ***auscultation, electronic stethoscope, real time visualization techniques, feature extraction***

I. INTRODUCTION

In a rapidly developing world, technology has affected almost all the fields in the world over the years. In the field of medicine, there has been many advancements with the arrival of new technologies. Electronic stethoscope is one such improved medical device which make auscultation process easier and more accurate. Stethoscope plays a vital role in the field of medicine to hear internal sounds of the body mainly cardiac and respiratory sounds. Internal body sound auscultation is one of the basic ways to assess the diseases diagnosis. Modern technology has introduced many newer methods such as ultrasound imaging and doppler techniques for diseases diagnosis. But despite other methods of detecting most of the diseases including cardiac diseases, auscultation method is widely practiced in the world using conventional stethoscope due to its easiness to detect health problems.

In 1816, French physician René Laennec invented the medical stethoscope by placing a wooden hollow cylinder between patient's chest and physician's ear to detect auscultation of heart and lungs (Swarup and Makaryus, 2018). After adding many improvements for Laennec's stethoscope, conventional stethoscope which is also known as traditional acoustic stethoscope was introduced as a noninvasive acoustic diagnostic tool which is simple, light weight, easily available, affordable. Hence, it is widely used by doctors, and it has become the sign of the medical professionals today. Conventional stethoscope mainly includes a chest piece which is connected by a split "Y" hollow flexible tube to the earpieces (Figure 1). The flexible PVC ear tubes basically isolate the auscultation sound and transfer it to the physician's ears with a minimum quality loss (www.linkedin.com, n.d.). Chest piece which is known as the head of the stethoscope consists of a diaphragm - to transmit higher frequency components and bell-for lower frequency sounds transmission (Landge, Kidambi, Singhal and Basha, 2018). But it further got many difficulties since most of the internal body sounds including cardiac sounds contain low frequency components between 10-200 Hz (Swarup and Makaryus, 2018). Moreover, the sound quality of the conventional stethoscope is very low specially when there is a thick chest wall. And due to variations of hearing sensitivity and disturbances in the measuring environment, sometimes physicians may not be able to recognize low frequency features of cardiac and pulmonary sounds. Artifacts and background noises, leakages in tubing can also disturb in feature recognition of cardiac sounds. Since there is no technique for noise reduction and further analysis in conventional stethoscope, it can lead doctors for wrong diseases diagnosis due to low accuracy.

Electronic stethoscope has been developed with many more advancements to overcome most of those difficulties and limitations of conventional stethoscope and it can be used for auscultation process for disease diagnosis with high accuracy. Electronic stethoscopes can be used in most of the clinical scenarios including listening to internal cardiac and pulmonary sounds, to detect abnorma changes in breathing sounds, to detect air or fluid around lungs etc. Further, it increases the accuracy of heart mummer recognition and cardiac disease diagnosis as well. The key component of the electronic stethoscope over conventional stethoscope is it converts the acoustic sounds into electrical signal and an advanced analysis can be done. Electronic stethoscope combined with sound amplification, filters and other noise reduction techniques improves the sound quality making auscultation process more accurate. A wireless data transmission can be done by using Bluetooth connection module in the recorder. Thus, the recorded data can be transmitted to wireless mobile terminal such as mobile phone or any kind of a computer for further analysis. This can be used to for remote patient monitoring and can obtain a real time graphical analysis of cardiac sounds captured at chest piece. Moreover, enhancements can be added for digitally record the captured data and play back options with different speeds. Hence, due to its high efficiency and accuracy, electronic stethoscope can be developed as a main medical device to detect cardiac sounds.

There are different variety of electronic stethoscopes commercially available with different technical advancements and specifications. Many researches have been done to improve the further efficiency and accuracy adding more features to electronic stethoscope (Figure2). Thus, the review paper mainly focuses on how electronic stethoscopes are developed as a sophisticated medical device for the auscultation process in disease diagnosis with a higher efficiency.

Figure 6 . Components of Conventional stethoscope
Source: (www.linkedin.com, n.d.)

II. METHODOLOGY

Literature review plays an integral role in academic field which study and analyse the knowledge on different areas. It is also a better source of a general summary of an interested topic. The Research topic was initialized, and further reading was done to obtain broader knowledge on area of study. First, by searching key words in different data bases like Google scholar, ResearchGate etc., journals, review papers and research articles published recently related to topic were collected. Abstract of sources were checked in order to omit duplicates and to obtain only the relevant articles. Due to limitations of the conventional stethoscope, many studies have been conducted to overcome those difficulties providing innovative solutions through modern technology, resulting advanced cost effective electronic stethoscopes with higher accuracy. Hence, the sources were studied in depth to provide an efficient literature review on advancements of an electronic stethoscope.

III. LITERATURE REVIEW

A. Key Modules in Electronic Stethoscope

Electronic stethoscope mainly consists of three modules: data acquisition; pre-processing; signal processing.

1) Data Acquisition: Since internal body sounds contain low frequency component, amplification of the auscultated sound below the threshold is required. In the first module, it includes sensor or a microphone on chest piece to capture the acoustic sounds and amplifiers to amplify acoustic sound into audible level along with transducers to identify cardiac sounds. Since the sound signal can contain noise and artifacts, external filters are added to exclude unwanted frequency components beyond the required range. By adding a loudspeaker, it overcomes the difficulties if there are issues with variations of sensitivity of hearing enabling doctors to listen to internal body sounds clearly in real time, but further analysis and graphical visualization is absent.

Hence, a microcontroller or an analog to digital converter is included to convert amplified and filtered acoustic sound signal into a digital signal. It is essential to determine the correct bit resolution and sampling frequency for a better signal analysis. For a higher accuracy to be obtained, an analog to digital converter with a high bit resolution and high sampling frequency should be obtained. Moreover, the air gap between the diaphragm and microphone open up the possibility to generate unwanted ambient noise between two diaphragm surfaces which in turn can results a false electrical signal. To overcome such difficulties, a piezoelectric transducer can be added which removes ambient noise of the signal. In a piezoelectric transducer, piezoelectric crystals are combined to diaphragm of the chest piece which generates the electrical signal due to its deformation. Hence, electrical charges releases when a pressure is applied due to cardiac sounds including heartbeat or any other pulmonary sounds. Therefore, the ambient noise present in captured sound at chest piece is filtered out before the amplification, enabling an optimal listening of the actual auscultation sound for medical professionals. 3M® Littmann electronic stethoscopes include piezoelectric sensor which further amplify the sound signal up to 24 times (Landge, Kidambi, Singhal and Basha, 2018). Micro-electromechanical system (MEMS) piezoresistive electronic sensors also generate electrical signals with higher sensitivity and accuracy (Zhang et al, 2016). Electronic stethoscopes with those sensors show significant role is cardiac disease diagnosis with a higher performance.

Another alternative for the purpose of transducer is a capacitive MEMS. Despite other methods of transducers, this system detects the change in the capacitance, which is created due to acoustic pressure occurred by cardiac sounds. Hence, the resultant electrical signal generated at this system is directly proportional to the acoustic pressure (Bassiachvili et al, 2008). Thus, in capacitive MEMS, the capacitance change is converted into an electrical signal. Compared to other types of sensors, MEMS sensor is smaller in size and contains a higher temperature stability. Thinklabs® One Digital stethoscope is a one good commercially available example for an electronic stethoscope where capacitive MEMS is included *(Swarup and Makaryus, 2018)*. Thus, the electronic stethoscopes containing capacitive MEMS include an adaptive noise canceller and can amplify the acoustic sound up to 100 times resulting a better amplification (Leng, San Tan, Chai and Wang, 2015). In addition to that, Thinklabs® One Digital stethoscopes contains advanced techniques for specific cardiac sound extraction and for further analysis of cardiac and pulmonary frequencies.

2) Pre-Processing : Pre-processing module includes denoising techniques and signal normalization techniques along with segmentation to enhance the electrical signal with more accuracy. This module is used to filter out artifacts and other noises using digital filters which have not been filtered by external filters used in data acquisition module. This in turn removes undesired features and sounds in the cardiac sounds detected in data acquisition module and increases the accuracy of the obtained acoustic signal. Different bandpass filters, High pass and low pass filters have been used for linear filtering depending on different situations according to the requirement. It helps in extracting the desired signal within the interested frequency band eliminating noise. Thus, the techniques used in pre-processing module in turn increases the signal-noise ratio (SNR) of the final output signal. The obtained signal is then normalized to a certain range and segmented into cycles localizing the sound peaks which make possible to detect specific components of cardiac sounds clearly and to conduct further feature extraction techniques. Specially, since stethoscope is an integral medical device in cardiac disease diagnosis, advanced techniques for segmentation and feature extraction procedures make it possible for doctors to perform auscultation and diagnosis with ease. Hidden Markov Model (HMM) is a statistical Markov model which is widely used for segmentation where both the specificity and Sensitivity are above 95% (Ghosh, Nagarajan and Tripathy, 2020). Short Time Fourier Transform, Continuous Wavelet Transform (CWT), Discrete Wavelet Transform etc are some more advanced techniques that can be used in pre-processing module (Ghosh, Nagarajan and Tripathy, 2020).

Figure 2. Commercially available Electronic stethoscopes Source : (Pinto et al., 2017)

3) Signal Processing: The last module of the electronic stethoscope is used for signal processing. In this module, feature extraction and a higher order classification of the cardiac sounds can be obtained using advanced mathematical techniques. Hence it enables to extract required features converting raw data into a parametric representation of interested sections for better cardiac sound classification. Feature classification provides a better interface for medical professionals to conduct an accurate diagnostic decision making. Based on the performance of different heart sound classifiers, Support Vector Machine (SVM) with kernel function and Artificial Neural Networks (ANN) can be considered as good heart sound classifiers due to the high sensitivity and accuracy of above 98% (Ghosh, Nagarajan and Tripathy, 2020). Support Vector Machine (SVM) is a linear data-based model which can be used to detect smaller murmurs where a higher accuracy can be obtained with a reduced amount of computing power (Ghosh, Nagarajan and Tripathy, 2020). To detect heart sound abnormalities in real-time, Artificial Neural Networks (ANN) shows significant sensitivity and accuracy but when comparing with SVM, ANN requires higher computational power and time (Ghosh, Nagarajan and Tripathy, 2020). Since almost all the physiological signals are non-stationary signals, feature extraction procedure is quite challenging, and it requires analysis in both time and frequency domains to conduct a better analysis.Short-Time Fourier transform (STFT), Discrete Wavelet Transform (DWT), Discrete Cosine Transform (DCT), Linear Frequency Band Cepstral (LFBC), the Mel-Frequency Cepstrum Coefficients (MFCC) and linear predictive coding (LPC) provides advanced and accurate feature extraction procedures used for cardiac sound analysis (Ghosh, Nagarajan and Tripathy, 2020). These advanced mathematical techniques make it possible to conduct an effective analysis of non-stationary biological signals captured at diaphragm becoming aid for doctors to conduct advanced auscultation procedure. Thinklabs® One Digital stethoscope is one such good example available in the industry which contains specific cardiac sound extraction techniques and advanced mathematical algorithms for pulmonary disease detection.

Figure 3. Smartphone Sthethoscope apps :
a. SensiCardiac,b.SthethoCloud

Source : (Leng, San Tan, Chai and Wang, 2015)

4) Modifications Can be Added in Designing

The electrical signal created by conversion of the audio signal can be recorded by adding a recorder along with a wireless data transmission module based on Bluetooth connection. In addition, small digital display can be added in the electronic stethoscope for data visualization. But, since it is not practical to include a large display, a clear analysed graphical content and more information may not be available on the display.

Due to variations in advanced technologies and techniques used, a wide variety of high quality electronic stethoscopes are available today. L`ittmann 3M model, the Thinklabs One Digital, Welch Allyn Elite electronic stethoscope, Cardionics E-scope II, EcoScope, and ViScope etc are few of the electronic stethoscopes that are commercially available today (Pinto et al., 2017). Among them, L`ittmann 3M model, the Thinklabs One Digital are widely used electronic stethoscopes which contains bell mode and diaphragm mode with higher order amplification and ambient noise reduction techniques. Welch-Allyn® Elite is another advanced Electronic Stethoscope which contains a bell mode with a varying frequency range. When a cardiac sound is to be detected, 20 - 420 Hz frequency range is used and 350 - 1900 Hz range in diaphragm mode is used to detect pulmonary diseases and abnormalities *(Swarup and Makaryus, 2018)*. Cardionics E-scope II is another type which uses a microphone and amplify the sound signal up to 30 times, but feature extraction techniques are absent. Bluetooth based wireless data transmission modules are widely used in most of the commercially available electronic stethoscopes. Some advanced digital stethoscopes have the ability to connect with remote signal processing units in devices by transmitting the signal wirelessly. A smartphone, handheld PC or any type of a computer can be connected as the wireless mobile terminal to capture the data via Bluetooth through wireless data transmission modules for real-time graphical visualization of the signal.

For the analysis of sound data obtained from electronic stethoscope, some advanced software have been developed which make diagnosis process easier and accurate for doctors. Smartphone stethoscope apps have been developed for real time graphical visualization of auscultation sounds by connecting with electronic stethoscopes. SensiCardiac, StethoCloud, Thinklabs, Thinklabs and Mobile Stethoscope are some mobile phone apps that are already used in the field (Leng, San Tan, Chai and Wang, 2015) (Figure 3). According to surveys and researches, SensiCardiac app is considered as the best and accurate software to detect heart murmurs (Leng, San Tan, Chai and Wang, 2015). It contains advance cardiac sound classification and feature extraction techniques, hence it has a higher sensitivity to detect both pathological murmurs and normal ones accurately. The Littmann Steth assist software included in Littmann M3200 model also analyses and converts the data and display a phonocardiogram or spectral graph as the output *(Landge, Kidambi, Singhal and Basha, 2018)* (Figure 4). Thinklabs app also gives the ability to record the signal and real time visualisation of PCG signal and contains screen signal editing techniques as well. The software can be modified by adding various denoising techniques to remove artifacts, play back options with different speeds and to store and record data. Moreover, there are ongoing researches to develop software by adding more complex mathematical algorithms and machine learning approaches for cardiac feature recognition.

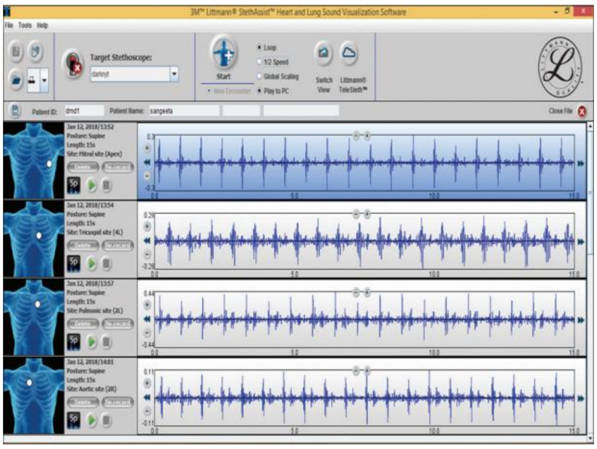

Figure 4.Graphical representation of phonocardiogram using Littman Steth assist software

Source : (Landge, Kidambi, Singhal and Basha, 2018)

5) Impact on Medical Sector

When using traditional stethoscope for covid-19 patients in wards, doctors have to face many difficulties. But to prevent intensive care conditions of covid-19 patients, it is essential to perform auscultation procedure for accurate disease diagnosis. These types of electronic stethoscopes can be very beneficial compared to Conventional stethoscope because doctors have the opportunity to analyse cardiac and respiratory sounds of the patient through real-time wireless mobile terminals easily *(Jain et al., 2021)*. Hence, medical professionals can listen to auscultation sound of covid-19 patients using a headset or quality earphones and can obtain a visualization of cardiac sounds using smartphone. Moreover, since the advanced electronic stethoscope are capable of transmitting captured data wirelessly, it can be further developed for the use of remote patient monitoring in telemedicine allowing specialized physicians to exam patients and analysis cardiac and pulmonary sounds in real time *(Landge, Kidambi, Singhal and Basha, 2018).* Thus, this can in turn become a highlighted even in the field of telemedicine as well.

Moreover, when giving cancer treatments like Iodine131, patients are isolated due to penetrating radiation. Thus, auscultation procedure cannot be conduct by conventional stethoscope though it is required to monitor cancer patients frequently. To overcome this, digital stethoscopes can be used. By giving instructions about the placement of diaphragm for the patients, doctors can listen and analyse internal body sounds in multiple times with advanced play back and speed changing options.

When there are limited resources are available for disease diagnosis procedure, and an ECG machines cannot be accessed in emergency situations, electronic stethoscope makes possible for doctor to detect cardiac murmurs and supports to recognize cardiopulmonary pathological features for accurate disease diagnosis compared to conventional stethoscope.

Since conventional stethoscope is a single purpose device, it is difficult to use when teaching junior medical students. To overcome those practical issues electronic stethoscopes are used because the added loudspeaker enables multiple listeners to hear internal body sounds multiple times and the graphical representations of the signal can be used by senior doctors to teach about even the very low frequency components of cardiac sounds (Legget et al., 2018).

IV. DISCUSSION

The paper reviews about the limitations of the conventional stethoscope and how electronic stethoscope has overcome the drawbacks by using advanced modern technology. It shows that the electronic stethoscope has become an accurate, effective medical device that can be used to conduct auscultation procedure for disease diagnosis. Thus, conventional stethoscope is already outdated to conduct auscultation process due to the high efficiency and accuracy of the electronic stethoscope (Landge, Kidambi, Singhal and Basha, 2018). But, still, most of the doctors are lack of modern and sophisticated medical devices like electronic stethoscopes which make easier for doctors to conduct an accurate clinical decision making. Hence, it may cause auscultation procedure to be more complex, resulting wrong disease diagnosis due to low accuracy. Since real-time visualization, graphical analysis and feature extraction can be done using electronic stethoscopes incorporated with wireless data transmission techniques like Bluetooth technology, it makes easier for doctors to conduct remote patient monitoring marking a revolutionized point in telemedicine. It further makes it possible to detect even very low frequency components which cannot be detect by conventional stethoscope. Moreover, electronic stethoscope enables advanced noise reduction techniques over conventional stethoscope and most of the researches approaches to enhance the feature extractions and noise reduction techniques in pre-processing and signal processing modules providing modern solutions and advancements in clinical disease diagnosis procedure through auscultation.

V. CONCLUSION

The review paper addresses the key advancements and features that can be included in electronic stethoscope to increase the efficiency of auscultation procedure for accurate disease diagnosis. The paper discusses about the designing process and the main modules of the electronic stethoscope. Already existing electronic stethoscopes are not deeply analysed and compared among others due to shortage of literature based on comparison of electronic stethoscopes. Further improvements on amplification, denoising, feature extraction and real-time visualization techniques depicts that the modern technology has made the auscultation process with revolutionary advancements compared to traditional conventional stethoscope. In conclusion, the literature review paper reveals how innovative advancements in modern technology that can be included in stethoscopes to improve the accuracy of auscultation and in turn to enhance the overall quality of the healthcare sector.

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AUTHOR BIOGRAPHY

Sithumini Perera is currently a BSc (Hons) Biomedical Engineering undergraduate in the Department of Electrical, Electronic and Telecommunication Engineering of the Faculty of Engineering at General Sir John Kotelawala Defence University.