ASHESI UNIVERSITY

BUILDING A LOW-COST BIOMEDICAL DEVICE TO IMPROVE ACCURACY IN PNEUMONIA DIAGNOSIS IN UNDER FIVE CHILDREN

APPLIED PROJECT

B.Sc. Electrical and Electronics Engineering

Esau Mhandu

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CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical and Electronic Engineering.

Esau Mhandu

ID Number: 51832019

2019

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:……Esau Mhandu…… ……

Candidate's Name: ……Esau Mhandu…….

Date: ……23-04-2019……

I hereby declare that the preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Signature:……

Supervisor's Name: ……

Date: ……

Dedication

This project is dedicated to my youngest brother, Bright Mhandu, whose presence in my life has been a source of motivation.

Acknowledgements

Appreciation goes to my supervisor, Dr. Danyuo Yiporo whose encouragement and academic advice has helped me to undertake this project.

I am also very grateful to the MasterCard Foundation for the scholarship given to me to study at Ashesi University. Appreciation is also extended to the Ashesi University for financial support.

Finally, I wish to express my gratitude to the staff and faculties at Ashesi University for their constant support throughout my stay at the University.

Abstract

Pneumonia has been the leading cause of death among children under the age of five in sub-Saharan Africa, killing more children than the number of children dying from HIV/AIDS. The current methods of diagnosing pneumonia are limited by poor sensitivity and accuracy and they are also expensive. In this project, a low-cost biomedical device was designed and developed to improve the accuracy in diagnosing pneumonia hence assisting in correct prescription of drugs to children. Sounds waves were transmitted from a surface exciter which was connected to an Arduino-powered circuit. The sounds waves were allowed to pass through one side of a lung phantom made of sponge and were detected on the other side using an electronic stethoscope. 4 dry sponges and four wet sponges were used to represent a healthy lung and a pneumonia consolidated lung respectively. The sound signals detected by the electronic stethoscope were analyzed using the Digital Signal Processing toolboxes in Audacity and MATLAB software. The difference in the resonant frequencies when the sound waves traveled through the dry and wet sponges was used to diagnose pneumonia. The device uses a non-invasive method which does not cause any health defects, unlike the chest x-ray method which can cause cancer due to its use of electromagnetic radiation to diagnose pneumonia. The results were then discussed for the design and application in pneumonia diagnosis in infants

Table of Contents

List of Figures

List of Tables

Chapter One

1.0 Introduction and Background Studies

1.1 Introduction

Pneumonia is a respiratory infection that causes inflammation of alveoli in the lungs [1]. Alveoli are air sacs known to be responsible for gaseous exchange (oxygen and carbon dioxide) between the lungs and the bloodstream [1,2]. An inflamed alveolus could be filled with fluid or puss which makes it difficult for a patient with pneumonia to breathe due to lack of oxygen [3,4]. When there is a lack of oxygen in the alveoli, it could cause other body organs to malfunction. Typical examples are the malfunctioning of the heart and the liver which eventually leads to death [5,6].

Pneumonia has been a leading worldwide cause of deaths among children. Every year, it kills approximately 1.4 million children under the age of five years, accounting for 18% of all deaths worldwide [7-9]. In 2015, pneumonia accounted for the death of 920 136 children worldwide [10]. Pneumonia is prevalent in South Asia and sub-Saharan Africa [11]. Pneumonia became the single biggest killer disease in Malawi, killing ~1,000 babies and young children [12].

The agents responsible for spreading pneumonia include viruses, bacteria and fungi [3, 13]. Symptoms of pneumonia include coughs (producing greenish and yellowish mucus and sometimes blood), fever, difficulties in breathing, sharp chest pains and crackles when coughing [3, 14, 15].

1.2 Current Clinical Diagnosis Methods

Diagnostic pneumonia devices for proper detection of pneumonia are characterized by high sensitivity and specificity. Sensitivity signifies the ability of the device to detect

pneumonia in a patient with high precision while specificity implies the ability of the device or system to falsely identify pneumonia. Current clinical methods commonly used to diagnose pneumonia involve physical examination and chest x-ray [15].

1.2.1 Physical Examination

During physical examinations, doctors observe a patient based on symptoms to detect the possibility of the patient having pneumonia. However, the sensitivity of this method is low at 58% and the specificity is 67%. This is because symptoms like difficulties in breathing are also found in other diseases like asthma [16]. Pneumonia and asthma are commonly misdiagnosed diseases since both have symptoms of difficulties in breathing. Poor diagnosis leads to excessive antibiotic prescription and wastage of drugs [17].

1.2.2 Chest x-ray

Chest x-ray is the most reliable method currently used in Africa which allows for the determination of fluid accumulation in the lungs. Its sensitivity is 74% and specificity is 84%. However, it is expensive to carry out this method and it is also unavailable in developing countries with poor infrastructure. X-ray works through the release of radiation into the body of a patient. However, it is not recommended for a person to undergo an x-ray examination more than once a year since it can increase the chances of getting cancer [18, 19]. This reduces the chances of a person to be successfully diagnosed.

Because of the cost implications in this method, patients tend to go for the physical examination. However, this method lacks specificity and early detection. In general, both methods (chest x-ray and physical examination) are limited by interobserver errors and are not available to the larger communities in Africa.

Moreover, there has not been many efforts towards the use of digitized tools for accurate diagnosis of pneumonia. Part of this will be addressed in this project towards providing effective detection and diagnosis of pneumonia.

1.3 Motivation and Justification of the Current Studies

Pneumonia has been the leading cause of death for children under the age of five [20, 21]. It is approximated that the mortality rate due to pneumonia is 1 million children per year, greater than the combined mortality rate due to HIV/AIDS, diarrhea and malaria [21]. This may be due to the fact that children have a weak immune system to fight against the disease. Also, clinicians rely mainly on physical examinations to diagnose pneumonia among children due to the dangers associated with x-ray radiation. Due to poorly developed infrastructure, there hasn't been a successful non-invasive and digitalized way of diagnosing pneumonia in Africa. Mortality rates due to pneumonia are also linked to poverty factors such lack of safe drinking water, poor sanitation, malnutrition and poor access to health care [22]. Globally, pneumonia accounted for approximately 16% of the 5.6 million deaths of children under the age of 5, killing around 880000 children in 2016 [22]. Mortality rate increases due to failure to detect pneumonia at an early stage or poor diagnosis of pneumonia. This paper seeks to address the problem of cost, low specificity and sensitivity of the current diagnosis methods. Hence, this project is technologically driven to improve devices for pneumonia diagnosis that can reduce the mortality rate of children and improve outcomes in pneumonia treatment.

1.4 Project Goal and Specific Objectives

The current methods for detecting pneumonia are limited by their unavailability and expensiveness. The goal of this project is to design a low-cost, non-invasive diagnosis system that can increase detection sensitivity, accuracy and specificity during pneumonia detection.

The project is stipulated to be carried out by achieving the following milestones.

- To build a sound wave generating and receiving system using electronic components
- To detect and differentiate a pneumonia-consolidated lung from a healthy lung

1.5 Expected Outcomes

Sponge filled water will represent a patient's lung with pneumonia and a dry sponge will represent a patient's lung without pneumonia. Sound transmitter and receiver circuits will be built. Sound waves will be transmitted through the sponge, and their movement is analyzed using Matlab Software's features like Digital Signal Processing. Wave decomposition, time and frequency domains will be used to analyze the behavior of the sound waves. Results from a sponge with water will be compared with those from a dry sponge.

Chapter Two

2.0 Literature Review

2.1 Introduction

Pneumonia is the leading cause of increased mortality rate among children under the age of five due to factors related to poverty which include poor sanitation, undernutrition, indoor air pollution and poor access to health care facilities [23]. In 2015, 68% of the world's population had access to adequate sanitation facilities [24]. There are insufficient physicians per patients as reported by the World Health Organization (WHO) for member states with a health worker density less than 1 physician per 1000 population [24]. It has been reported that, 50% of deaths occurred in Africa due to pneumonia, with most deaths being concentrated in the sub-Saharan countries like Uganda. In Uganda, pneumonia caused ~6 million deaths per year among children under the age of five, with 1 in 5 caretakers having to diagnose pneumonia correctly [25]. The inability to diagnose the symptoms of pneumonia caused an increase in mortality rates in Uganda [26]. In Uganda, pneumonia is misdiagnosed as malaria hence children are sometimes offered antimalarial drugs [27]. This poor treatment results in more death of children.

2.2 Conventional methods and limitations

Chest radiography and physical examinations are the common methods used currently to diagnose pneumonia in our hospitals. Chest radiography, which is taken to be the gold standard method for diagnosing pneumonia, is reported to have sensitivity and specificity of 74% and 84% respectively [28, 29]. This method is limited by interobserver agreement error which was found to be ~85% and above [28,30]. This difference can mean a false diagnosis of pneumonia. Due to the high cost and inaccessibility of chest

radiography, people usually opt for the physical examination. However, the physical examination has lower sensitivity and specificity values of 58-75% and 47-69% respectively [28, 31, 32]. This is due to errors in interpreting results. The interobserver agreement error between two pulmonologists was in the range of 60-72% [28, 31].

Several studies which include automated and non-automated methods have been explored to diagnose pneumonia based on pleural fluid and lung sounds [33,34]. Electronically automated methods prove to be more reliable since digital information is free from interobserver errors and allow for reproductively in results. Hence, they are more accurate.

2.21 Auscultatory Chest Percussion

The use of physical methods in the detection of pneumonia includes the chest auscultatory percussion where a sound stimulus is introduced to the chest of a patient through tapping the chest with a finger and detecting the audio change at the back of the chest using a stethoscope [35-37]. This method is based on sound transmission and distortion when sound waves travel in different mediums and can be used to detect if a lung is filled with fluid, that is, air or liquid [38]. For example, dull sounds imply a fluid consolidated lung and bright sounds are suggestive of air-filled lungs [39]. The accuracy of the percussion method is dependent on the expertise of the doctor hence it is unreliable.

Previous study developed a computational model of sound transmission in the chest for surface acoustic excitation. It explored lung acoustics using an electromagnetic shaker which was introduced on the sternum to provide an automated sound input and using a laser Doppler vibrometer to measure the vibrations at the back [28, 40]. The system was used in the detection of pneumothorax which is a condition in which the lung tissues collapse due to the accumulation of air in the spaces between lungs (pleural space) [40, 41]. This model

is proven to be effective but had low portability since the input device was heavy (> 2 kg). For admitted patients in hospitals, invasive methods like inserting a speaker, via the endotracheal tube, in the chest of a patient through the throat can be used [42]. However, this method is not appropriate for use in other population.

The use of automated input sound waves is still under study in pneumonia diagnosis although many studies have shown promising results. A previous study which explored the diagnosis of pneumonia by using 40 sensors to record breath sounds reported 90% sensitivity and 80% specificity values which were compared to the chest radiography [43]. However, the accuracy of the results was dependent on the severity of pneumonia and the use of 40 sensors limited the portability and increased the cost of the device.

2.2 Properties of Lungs

The wave resonance, absorption and sound transmission through the chest are analyzed in the detection of pneumonia [44]. Men and women have different chest resonant frequencies, 125Hz for men, 150-175 Hz for women and 200-400Hz for children [44]. As sound travels through the chest cavity, the chest acts as a low pass filter that absorbs frequencies above 1000Hz [44-46]. The behavior of sound waves is altered by the different mediums in the chest cavity. That is, the chest wall, pleural space (which collects inflammatory fluid in the presence of a disease like pneumonia) and the lung tissues (composed of gas and tissue) can alter sound waves [47]. Hence, analyzing the movement of sound waves through the lung can help in the detection of pneumonia (lung with pleural fluid).

2.3 Challenges in Pneumonia Diagnosis

The main challenges in the pneumonia diagnosis in developing countries are inadequate or inappropriately trained staff, unavailability of chest x-ray equipment, a

clinical overlap of malaria and pneumonia and dysfunctional health system [48]. In 2014, United Nationals International Children Emergency Fund (UNICEF) developed a target product profile (TPP) to support and guide the development of a device that can accurately and effectively diagnose pneumonia in

2.6 Scope of Work

Chapter one focused on the introduction of the project which included the background of pneumonia, objectives of the project and expected goals. Chapter two places emphasis on the knowledge from literature review - the statistical data of pneumonia, diagnosis techniques and their limitations, control strategies and challenges with pneumonia diagnosis in developing countries. Chapter three will contain the list of materials for the project as well as the experimental description of the procedures to be taken while undertaking the project. Chapter three will also introduce the design of the device and the selection of actuator and sensor for the device as well as the justification of the design. The design criteria for which the device will be based upon will also be explained in Chapter three.

Chapter Three

3.0 Materials and Methods

3.1 Materials and Equipment

The software Audacity and MATLAB were free downloaded and paid for by Ashesi University respectively. The surface exciter (HYD-20) and the grouting sponge (QEP 70005Q-6D) were purchased from Amazon. The Arduino microcontroller, capacitors, resistors and amplifiers were provided by Ashesi University.

3.2 Principle of Operation of Device

The device has two components – the actuator and the sensor. The actuator is responsible for the generation and transmission of sound waves. The sensor is responsible for recording sound waves and converts the sound waves into electrical signals. The actuator transmits sound waves through the chest and the sound waves are recorded by the stethoscope at the back of the patient. The data is recorded and analyzed using Matlab.

3.3 Actuator

An actuator was chosen based on its size (which affects the portability and comfort of the device), the frequency range of sound waves it can produce and intensity of the sound waves at low frequency (which affects the reliability of device). The common actuators (piezoelectric transducers, speakers, surface exciters and push/pull solenoids) were considered. Power requirements and range of frequencies used were used by applying the work efficiency on the stomach (provides a resonant response) and knee (provides a dull response) [28]. The following Pugh chart in Table 3.1 was developed for the actuator selection. A scale of 1 to 5 was used where ‘1’ represents a low response and ‘5’ represents

a high response. The weights of the criteria were extracted from the design standards set by UNICEF [39].

Table 1: Pugh Chart for Actuator

Criteria	Weight	Push/Pull Solenoid	Piezoelectric Transducer	Speaker	Surface Exciter
Intensity	5	5	1	2	4
Cost	3	3	4	3	3
Portability	3	1	5	4	4
Battery Life	2	2	4	4	4
Total Score		41	40	39	49

[1]low actuator performance and [5]high actuator performance.

The actuator with the highest weighted score was the surface exciter. This is because it can produce frequencies from 50 Hz and is portable to be incorporated into a small device [48].

3.4 Sensor (Stethoscope)

An electronic stethoscope will be built, which consists of an electret microphone, a preamplifier, low pass filter and power amplifier. The signal is produced as sound and analyzed using Matlab.

The operation of the device to be developed is shown in the diagram below in Figure 3.1.

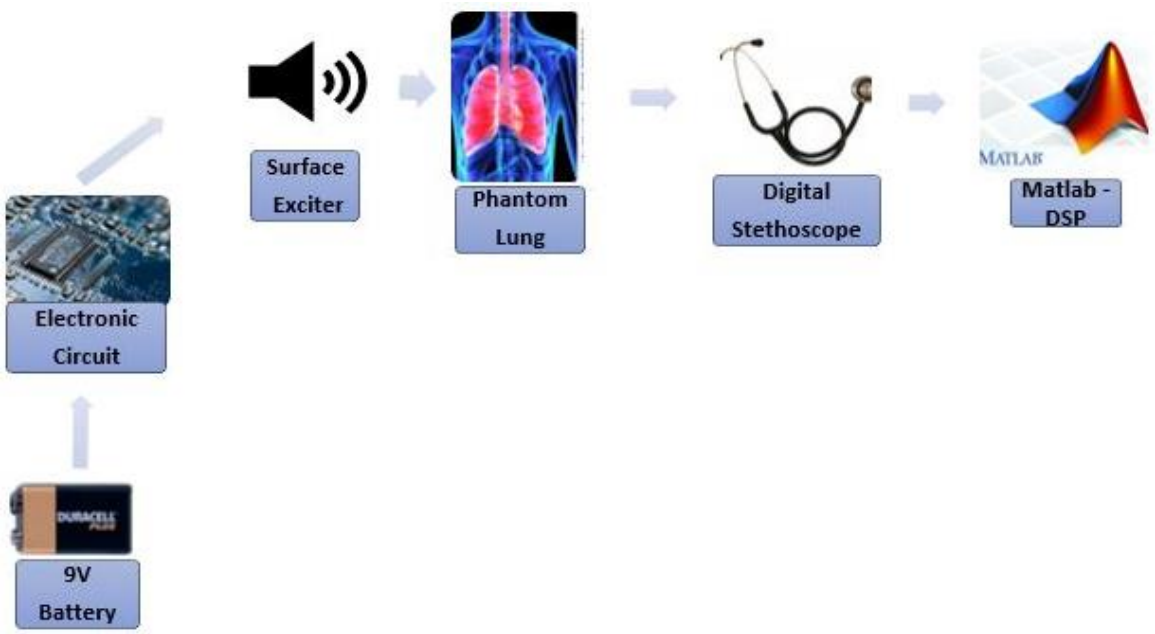

Figure 3. 1: Block Diagram of Device

From Figure 3.1, a battery is used to power the electronic circuit. The surface exciter produces and transmits sound waves through the sponge (representing a human lung). The sound waves are detected by the stethoscope at the best of the patient. The waves are analyzed using Matlab and the results undergo digital signal processing. Transfer function will be made from the graphs and the resonance frequencies obtained to determine if the lung is pneumonia consolidated or not.

3.5 Experimental Procedures

3.5.1 Lung Phantom

The aim is to develop a lung phantom, which is a model representation and replication of a normal human lung. This allows for the testing of sound transmission to be done more accurately [34].

To develop the lung phantom, a grouting sponge was used. A healthy lung was demonstrated by a dry sponge while a pneumonia consolidated lung was demonstrated by a

wet sponge (dry sponge soaked in water). The surface exciter is put on one end on of the sponge to transmit sound waves while the stethoscope head is put on the other end to detect the signals. The setup is as shown in Figure 3.2

Figure 3. 2: Setup of the Lung Phantom

3.5.2 Surface Exciter Demonstrated

A surface exciter was chosen based on the criteria shown in the Pugh chart developed in Table 1. The actuator generates and transmits sound waves from 50 to 100 Hz into the chest which is simulated by the lung phantom. On a human being, the surface exciter is placed on the manubrium and the stethoscope placed on corresponding quadrants of the lung at the back of a patient. In this experiment, the surface exciter is placed on the surface of the

sponge while the stethoscope microphone place on the other side of the bucket. The surface exciter will transmit sounds for 30 seconds.

The surface exciter was connected to an Arduino microcontroller which allows for the generation of a tone signal of frequencies (0-100 Hz). The connection of the actuator circuit is as shown below in Figure 3.3.

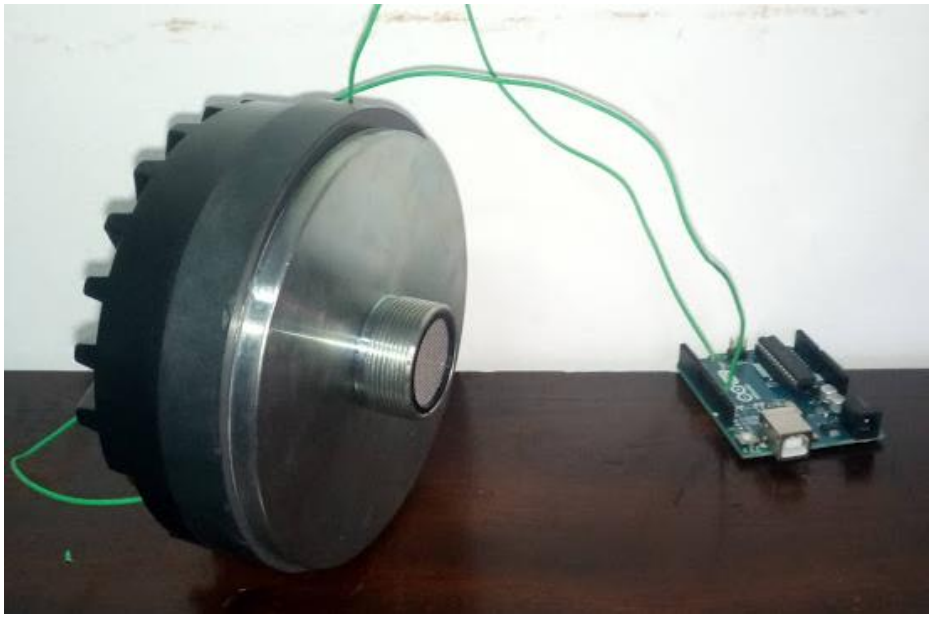

Figure 3. 3: Actuator Connected to Arduino

3.5.3 Stethoscope Design

Proteus software was used to develop and build the circuit of a digital electronic stethoscope. The circuit is as shown below in Figure 3.4.

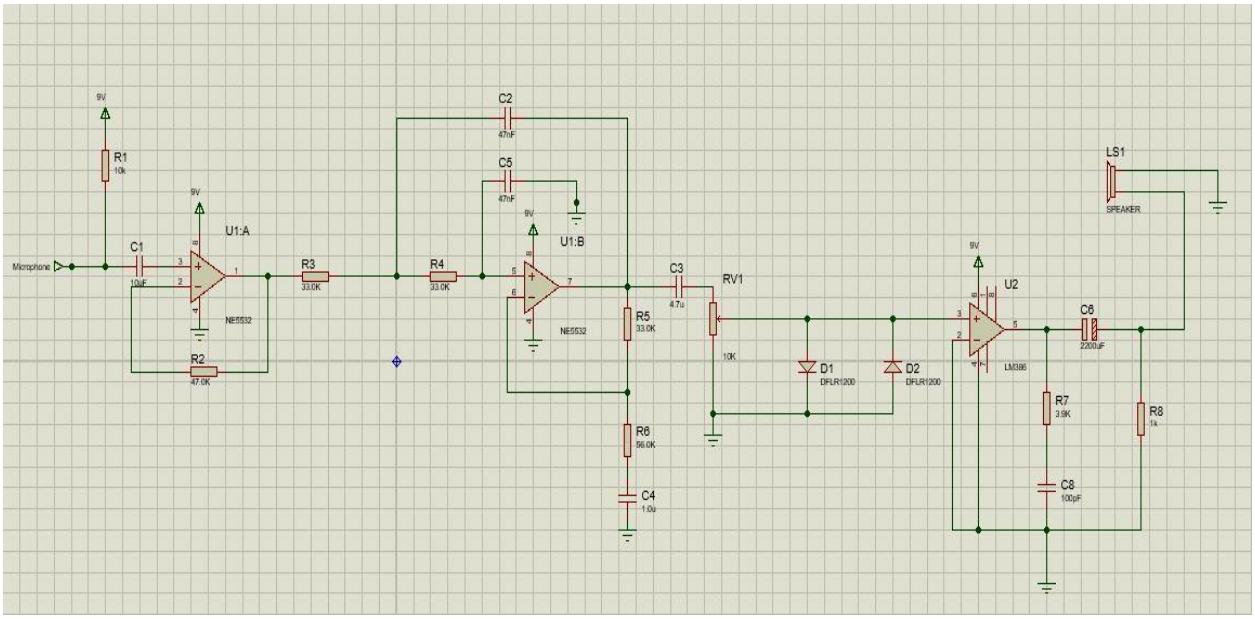

Figure 3. 4: Electronic Stethoscope for Lung Sound Detection.

The circuit was also constructed on the breadboard as shown in Figure 3.5 below.

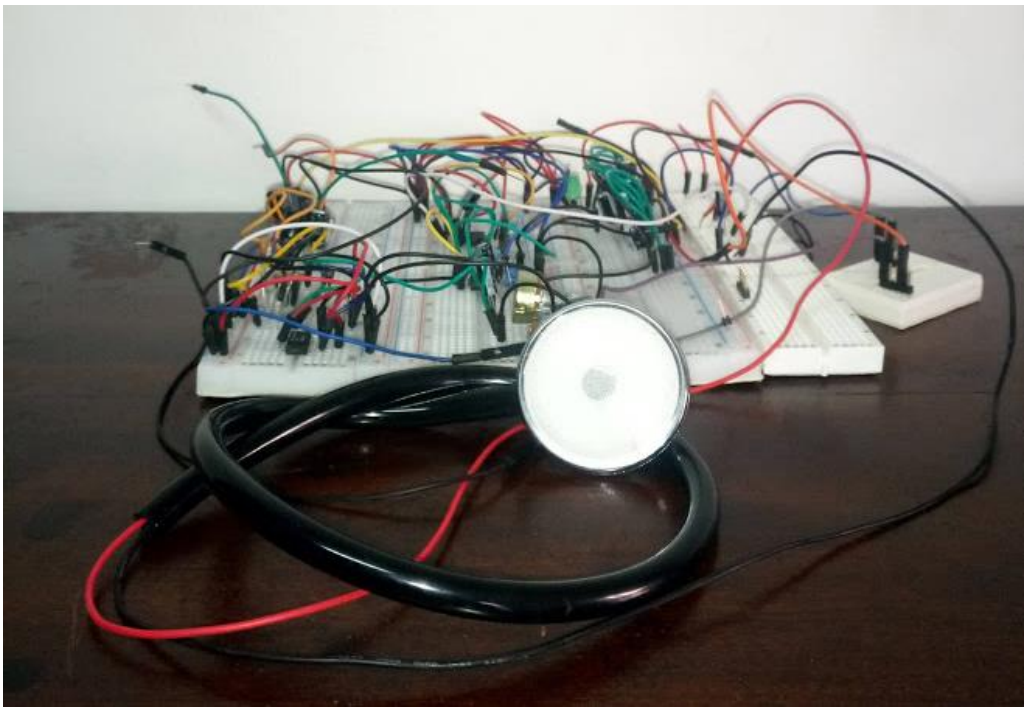

Figure 3. 5: Stethoscope Breadboard Connection

A 9V power supply was used to power the circuit. Amplifier UA:1 (NE5532) is a dual, low-noise amplifier. It represents the signal acquisition circuit which consists of the

electret microphone connected to a pull-up resistor, R1. The electret microphone is a transducer which converts sound signals to electrical signals that can be amplified and filtered. Capacitor C1 removes the dc offset hence, allowing only ac output. The circuit makes use of the negative feedback system to generate and amplify ac output of the microphone and bring it to a suitable level. The electret microphone is attached to a chest piece (taken from a manufactured stethoscope) to insulate the microphone from background noise when the stethoscope head is placed on the skin surface.

The amplified signal has noise components, hence, the need to filter and remove the noise. Amplifier UA:2 represents a low noise Sallen-Key Butterworth low-pass filter. The cutoff frequency of this filter is calculated using the following equation.

$$F_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(33 * 10^3)(47 * 10^{-9})} = 102.6\ Hz$$

The Sallen-Key filter allows only signals which frequency below the 102.3 Hz and cuts off the signals with frequency above the cutoff frequency.

The transfer function for the Sallen-Key lowpass filter was determined using the following equation

$$G(s) = \frac{K}{R_3R_4C_2C_5s^2 + s(R_3C_2 + R_4C_5 + R_3C_2(1-K) + 1}$$

Where K= 1.

$$G(s) = \frac{416666}{s^2 + 1292s + 416666}$$

After filtering, the capacitor, C3, blocks the dc from passing through, hence only allowing the ac to come out. This ac signal is amplified by the audio amplifier, LM386. The capacitor, C6, filter the dc signal and the ac output signal is sent to the speaker using an aux cable. The sound can be heard on the speaker. The microphone is also separated away from the speaker to prevent the development of acoustical feedback which distorts the results

The full breadboard connection of the device is as shown below in Figure 3.6

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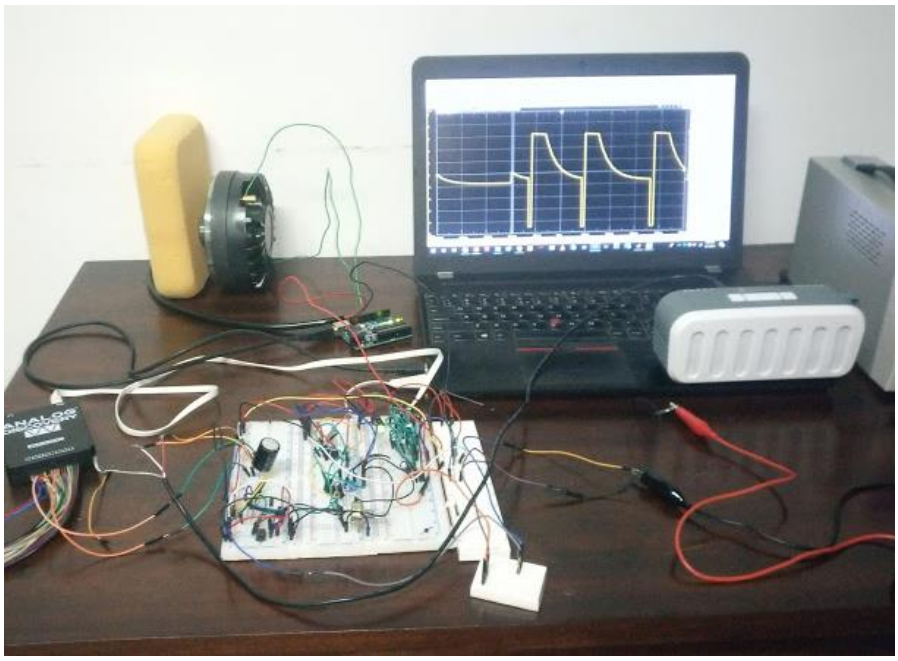


Figure 3. 6: Device Full Breadboard Connection

Audacity and MATLAB software were used to perform Digital Signal Processing of the sound waves as they pass through the wet and dry sponge. The power spectrums of the sound waves as they pass through each sponge are plotted and the resonant frequencies determined. The differences in the resonance frequencies were used to categorize a pneumonia-infected lung and a healthy lung.

Chapter Four

4.0 Results

4.1 Dry Sponge

The raw signal profile for the sound as it passes through the dry sponge is shown in Figure 4.1. The x-axis represents the time in seconds and the y-axis represents the amplitude.

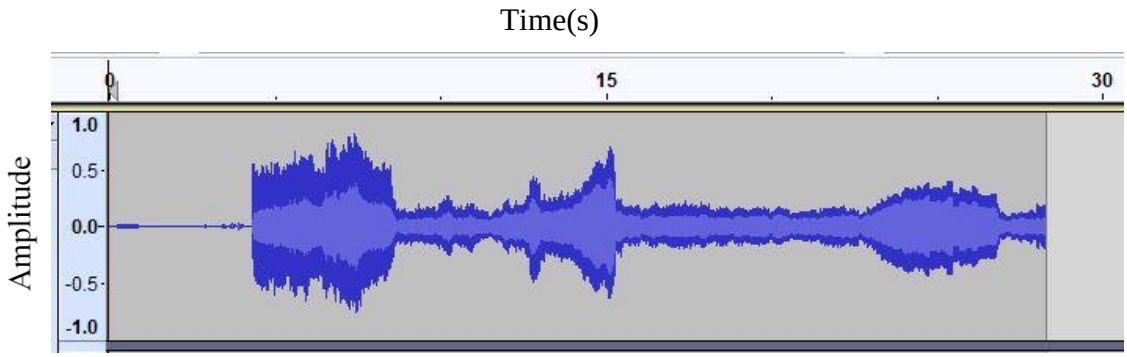


Figure 4. 1: Raw Signal Profile

In Figure 4.1, from 0 to about 3 seconds, the signal profile represents the noise from the surroundings. To clear the signal of this noise, the noise profile was applied to the whole signal and removed. At the very high pitches, the signal has a high amplitude at a low pitch, the signal has a low amplitude. Hence, the signal profile shows the variation of the pitch as the frequency of the sound is increased.

4.11 Signal Noise Removing

The resulting signal after removing the common noise is shown in Figure 4.2

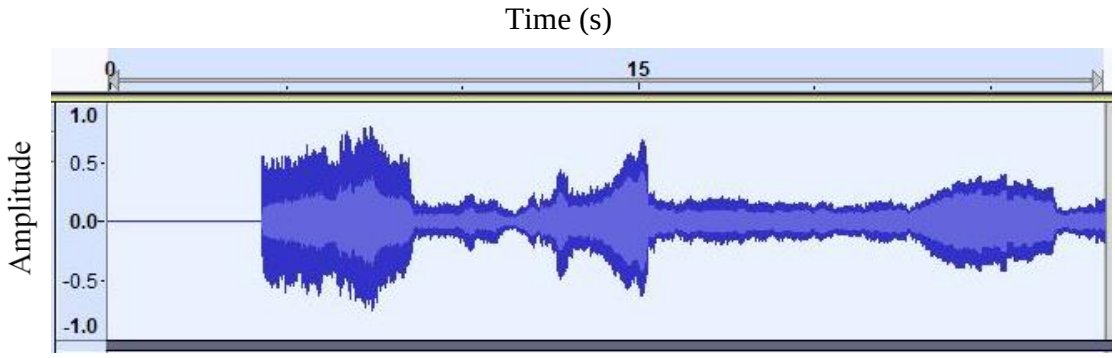


Figure 4. 2: Signal with Noise Profile Removed

The noise profile has been removed as can be shown in Fig 4.2 where there is now a straight line.

4.12 Signal Normalization

Normalization was done to bring peaks to a target level by applying a constant amount of gain to the signal. The signal was normalized using a gain of -2.0 dB. Normalization also results in the change in volume either increasing or decreasing.

The resulting signal after normalization is shown in Figure 4.3.

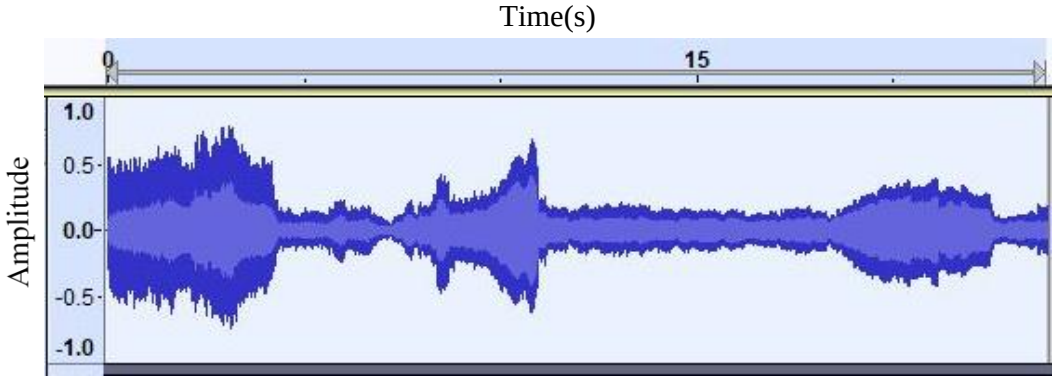


Figure 4. 3: Signal After Normalization

4.13 Signal Equalization and Compression

Equalization of the signal was done to boost the frequencies of the signal to bring out a more natural sound. Dynamic Range Compression of the signal was performed in order to produce a smoother curve through reduction of loud sounds and increment of soft sounds. The result is shown in Figure 4.4.

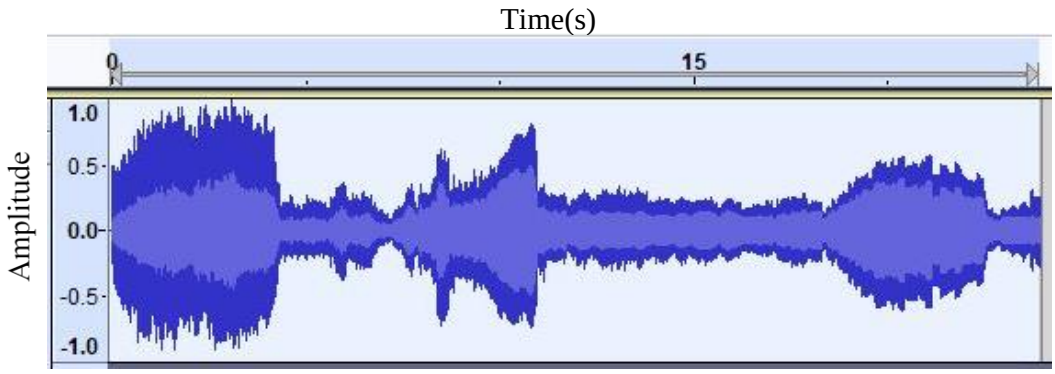


Figure 4. 4: Signal After Equalization and Compression

The amplitude of the signal in Figure 4.4 increased due to equalization and compression effects. The signal became more audible.

4.14 Signal Renormalization

The signal was renormalized to bring the peaks to a suitable level as shown in Figure 4.5 below.

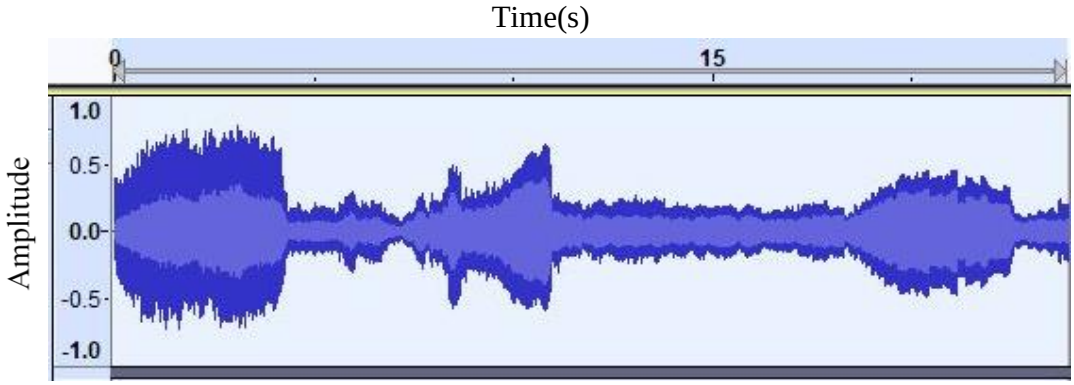


Figure 4. 5: Signal after Normalization

4.15 Signal Spectrogram

The spectrogram is a qualitative analysis graph which shows the variation of frequency with time. The spectrogram for the signal as it passes through the dry sponge is as shown in Figure 4.6 below. The horizontal axis represents time in seconds while the vertical axis represents frequency of the sound waves in Hertz.

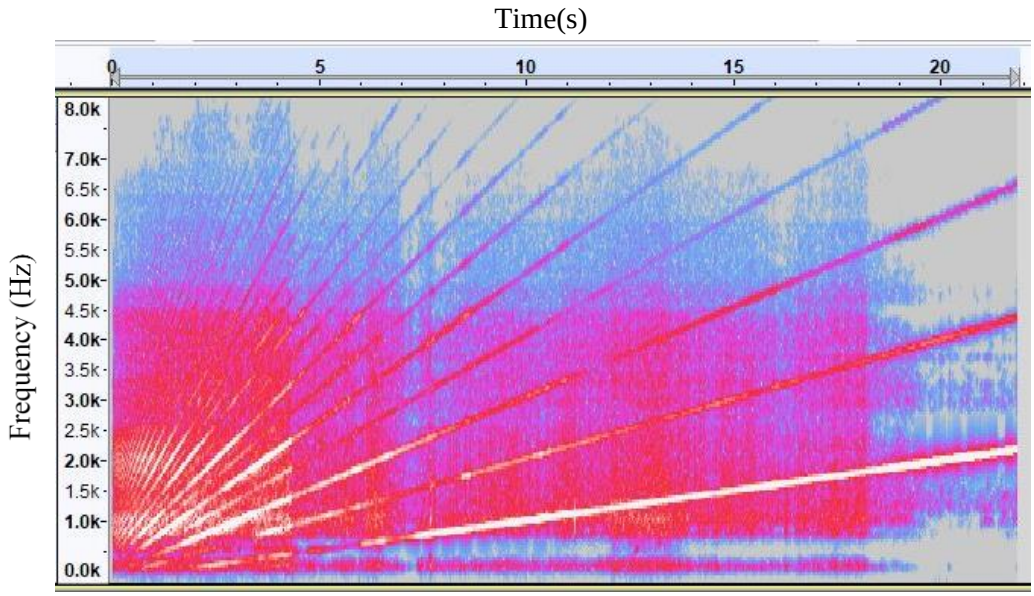


Figure 4. 6: Spectrum of Sound Waves out of the Dry Sponge

The different colors show the spread of frequency of the signal as it passes through the sponge. More frequencies of the signal are concentrated in the region less than 5 seconds.

This is the same region in which high magnitudes of the signal are available as shown in Figure 4.5.

To get a quantitative analysis of the sound waves as they pass through the dry sponge, a spectrum of the signal was plotted as shown in Figure 4.7 below.

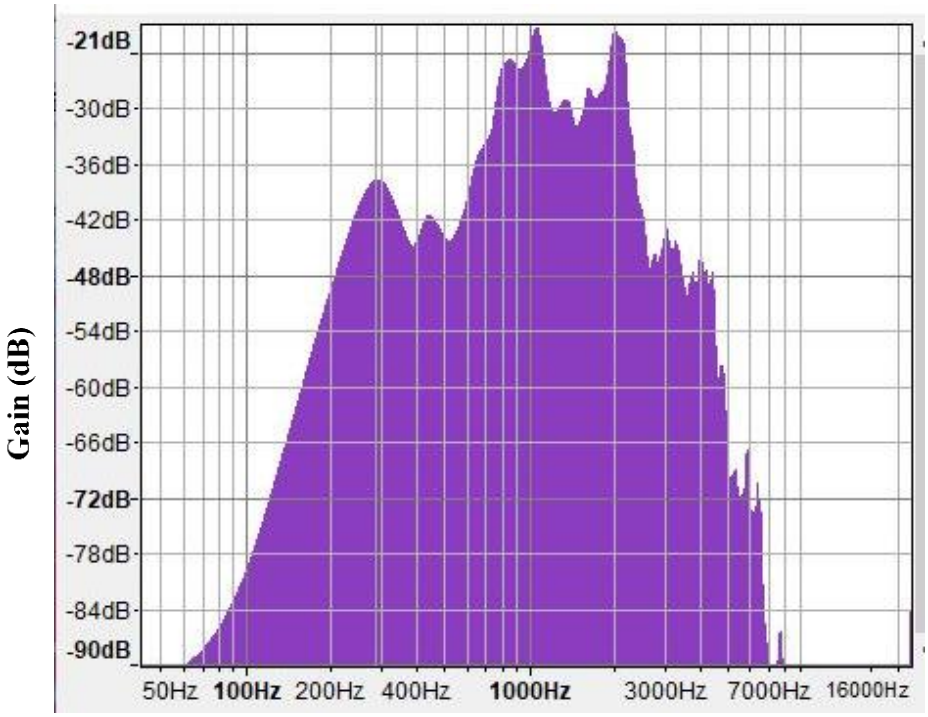


Figure 4. 7: Signal Spectrum for the Dry Sponge.

The resonant frequency was recorded at 1050 Hz at sound waves of -14 Db. The dry sponge acted as a low pass filter with a cutoff frequency of about 2000 Hz, allowing fewer signals with frequency above the cutoff frequency to pass through.

4.2 Wet Sponge

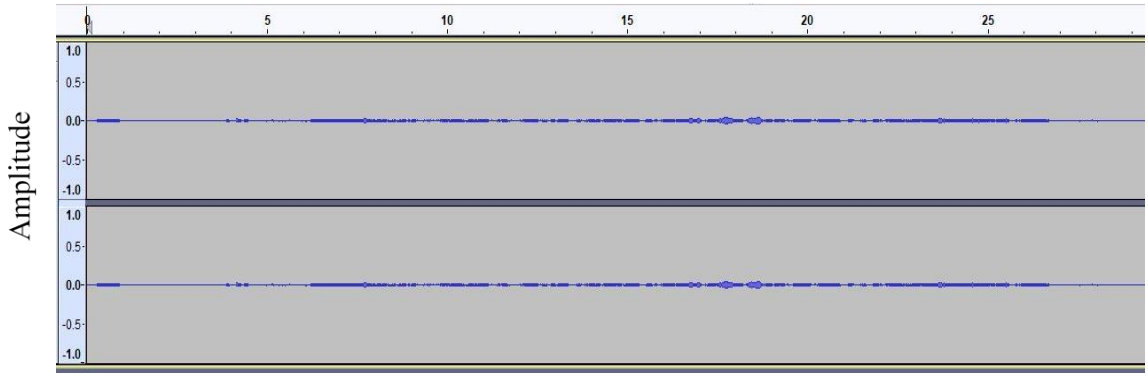
4.21 Filtration and Amplification

The processes for filtering and amplifying the signal as it passes through the wet sponge – noise removal, normalization, equalization and compression were also performed.

The following graphs shows (Figure 4.8a -c) and (Figure 4.9a-b) show the resulting graphs after each process. The horizontal axis represents time in seconds while the vertical axis represents the amplitude of the signal.

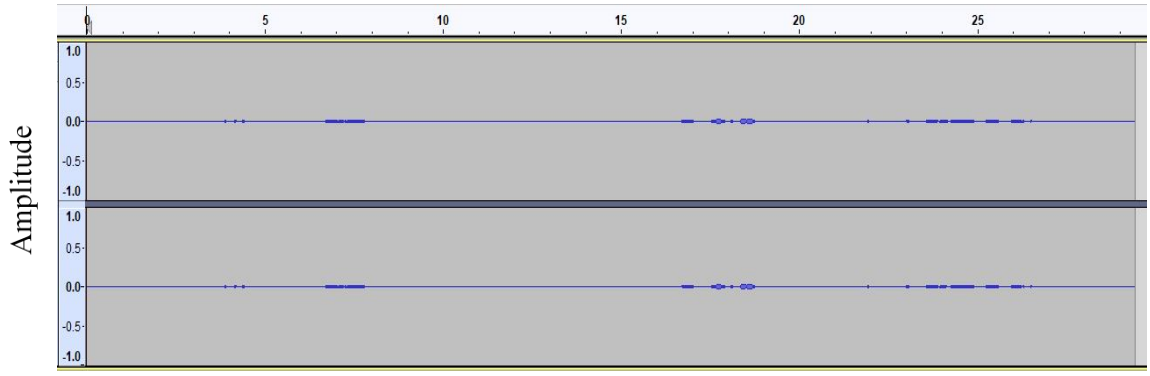
(a)

Time(s)



(b)

Time (s)



(c)

Time(s)

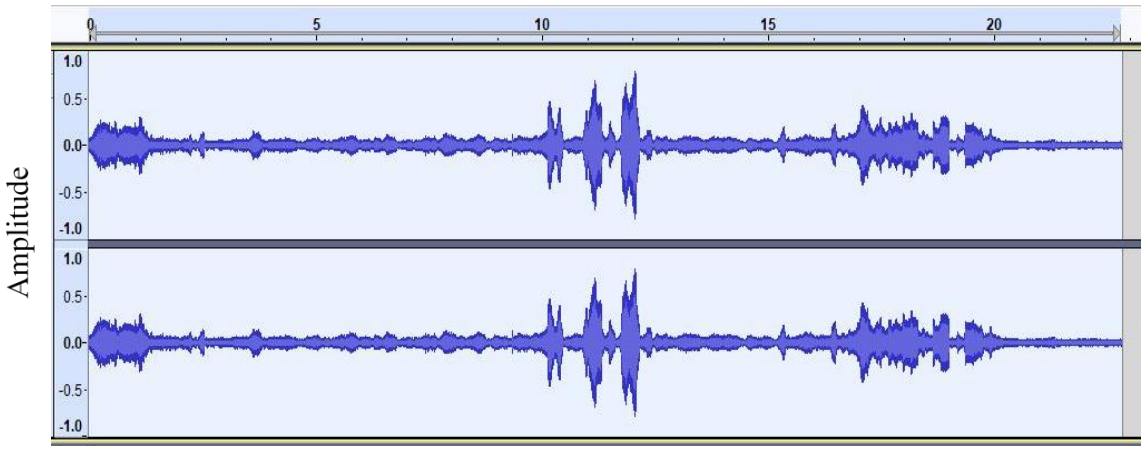
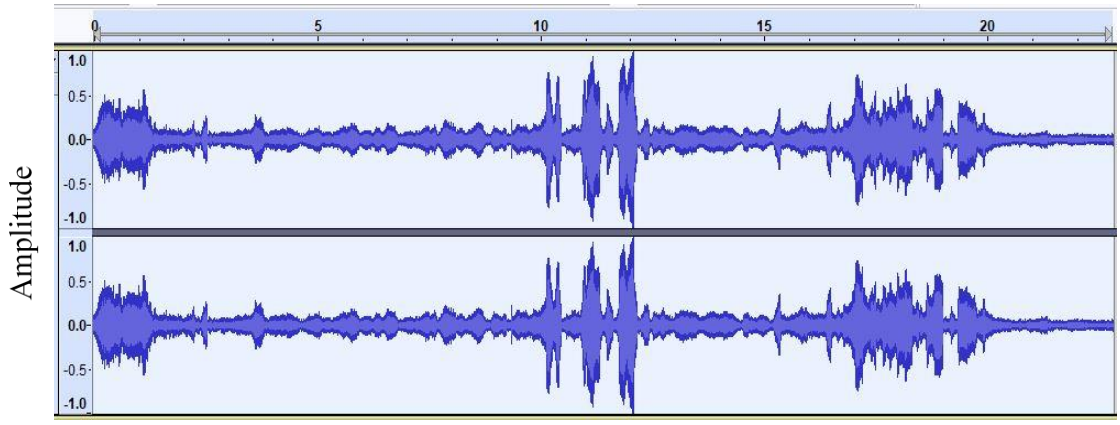


Figure 4. 8: **(a)** Raw Signal out of the Wet Sponge, (b) Signal after Noise Removal, and (c) Signal after Normalization.

(a)

Time(s)



(b)

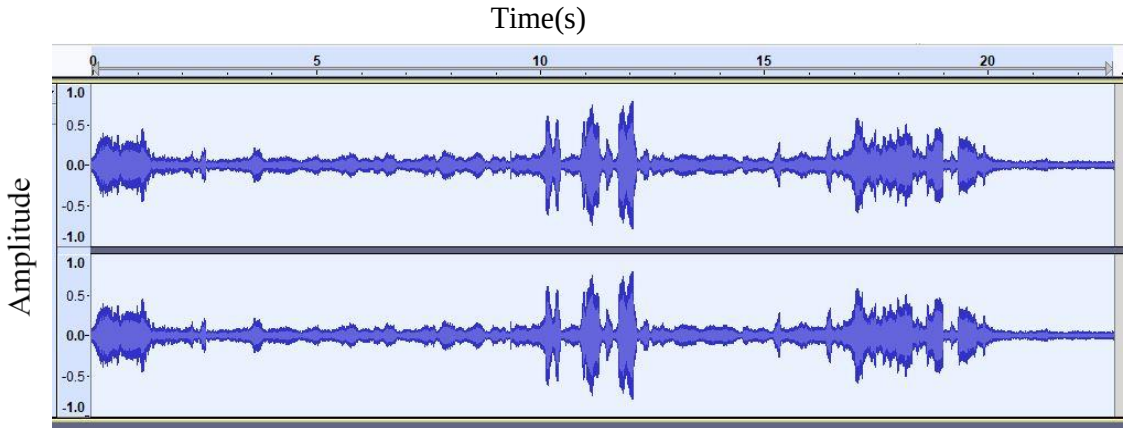


Figure 4. 9: (a) Signal after Equalization and Compression, and (b) Signal after Renormalization.

4.22 Signal Spectrogram

`The signal spectrogram as the sound passes through the wet sponge is as shown in Figure 4.10.

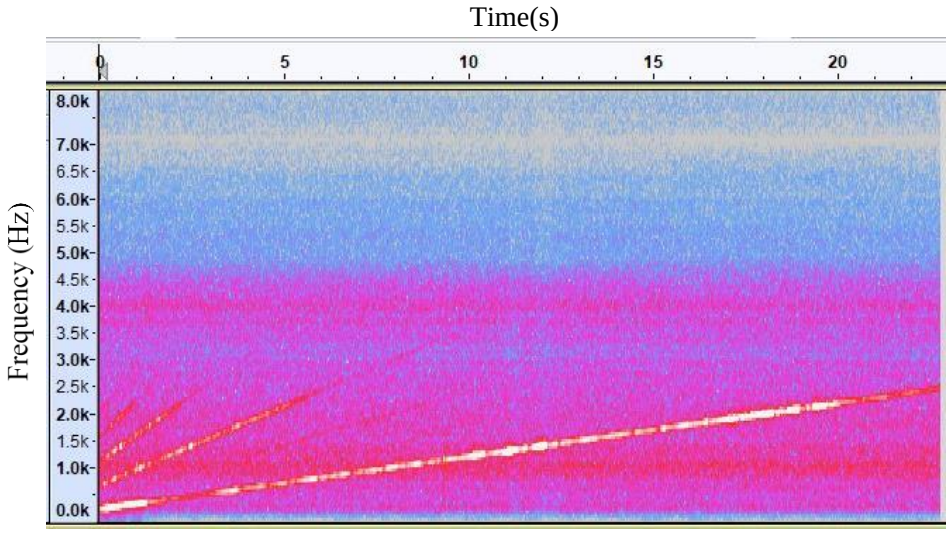


Figure 4. 10: Spectrum of Sound Waves out of the Wet Sponge

From Figure 4.10, the frequencies of the signal passing through the wet sponge are fairly distributed over time. The amplitudes are very low which implies that the wet sponge absorbs most of the signals.

A spectrum of the signal was also plotted to show the variation of frequencies of the signal through the wet sponge with its power as shown in Figure 4.11.

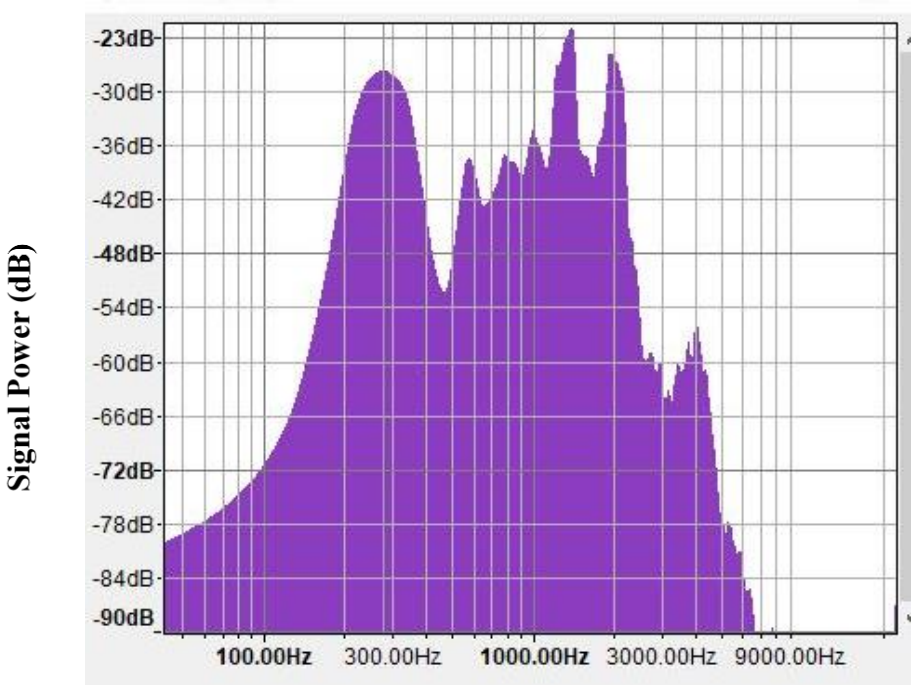


Figure 4. 11: Signal Spectrum for the Wet Sponge

For the dry sponge, the signal had a peak power -20 dB at the resonance frequency of 300 Hz. After this frequency, the signal power seemed to decrease until about 1350 Hz where there is a peak of -16 dB.

4.3 Power Spectrum of Wet and Dry Sponge

Because the signal of interest is the range of 50 Hz to 1000 Hz, the two power spectrums were plotted with OriginPro-8 and the result is shown below in Figure 4.12.

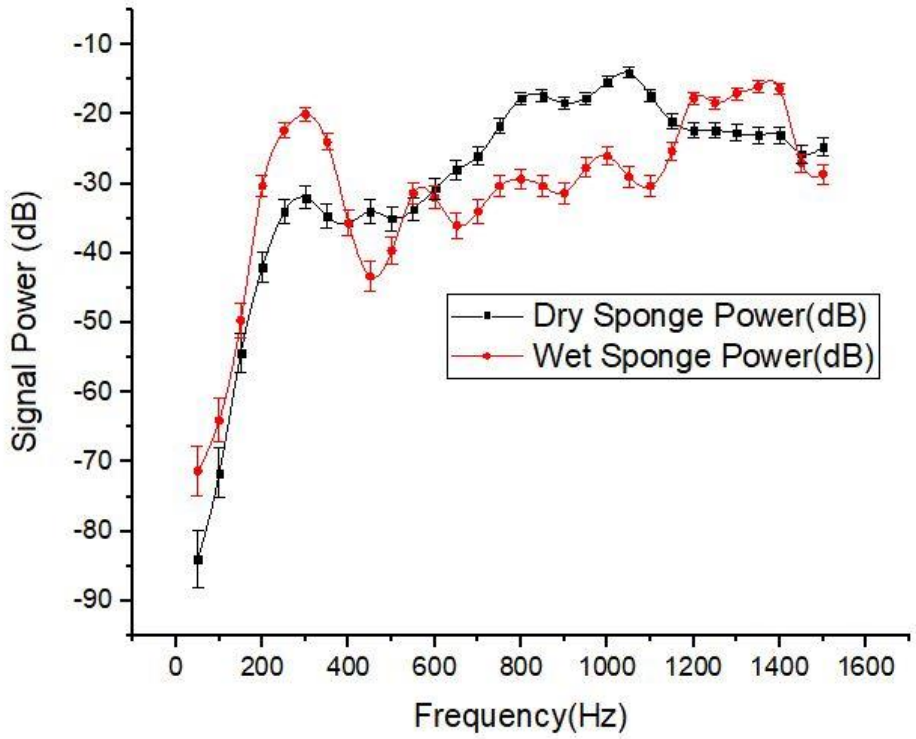


Figure 4. 12: Plot for Both Dry and Wet Sponge

The resonant frequency for the wet sponge is lower than that for the dry sponge. This implies that at the resonant frequency of the wet sponge (300 Hz), the wet sponge acts as a high pass filter (allowing fewer signals above 300 Hz to pass through) while the dry sponge acts as a high pass filter (allowing more signal above the 300 Hz to pass through the sponge). This difference in the behavior of the signal power can be used in the diagnosis of pneumonia. Sound waves traveling through a pneumonia-consolidated lung (having fluid) have a resonant frequency of less than 500 Hz while sound waves traveling through a pneumonia free lung (healthy lung with hair) have a resonant frequency around 1000 Hz.

Chapter Five

5.0 Limitations, Conclusion and Recommendations

5.1 Limitations

Although the most important parts of the device including the stethoscope were working, there were some limitations in obtaining data to make a conclusive argument. The electret microphone used was sensitive enough to give variations of voltage against time. The required surface exciter was not supplied due to its shortage on the market. However, an ordinary speaker was used to improvise. The speaker could not transmit strong sound waves that can be converted to voltage by the microphone into clear electric voltage. A surface exciter works by causing vibrations and reflection of sound waves such that when it is put on a surface, it turns that surface into a speaker. An ordinary speaker, however, when it is covered with the sponge, the sound is reduced from passing through the sponge. Thus, the actuator could not perform as required.

5.3 Conclusions

This project shows a distinct difference in the resonant frequencies when sound waves pass through wet and dry sponges. This proves that sound behaves differently when it passes through a biological fluid and it would when it passes through the air. With a pneumonia consolidated lung being filled with fluid, the device can be used to detect the fluid in children under the age of five by checking the power of the signal as it travels through the chest of a child.

5.2 Future Plans

Future works for the project include using an already manufactured stethoscope which is more sensitive to detect sound signals. The next phase is to ensure the device is

scrutinized by a review board so that testing can be done on people. To test the device on people, patients who have been diagnosed with pneumonia will be tested using the device. The data obtained will be analyzed and used to calculate the sensitivity, specificity and accuracy of the device. These results will be used to compare the functionality and accuracy of the device with the already used methods of diagnosis of pneumonia on the market.

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