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Study and review the design and construction of digital stethoscope

Abstract

Certain key points must be taken into account when designing a digital stethoscope. First, when converting an acoustic stethoscope to an electronic stethoscope, it must be noted that operating rooms, in general, are places where all types of medical equipment exist, and they are typically the main sources of noise production.
Several important points should be considered in the design of digital medical stethoscopes. The first point is that the design of these stethoscope should be such that the ambient noise has a minimal effect on their output. Anesthesiologists also use stethoscopes in the operating room. The solution to this problem is to adjust the length of the stethoscope. Also, in acoustic phones, only the doctor is able to hear the sounds of the phone, but sometimes doctors need the sound of the phone to be broadcast from several headphones or speakers to all the people in the room. The overall goal of designing digital medical procedures is to add the aforementioned features to acoustic Stethoscope. In the design of the prototype, the amplification of the subtle sounds of the body should be put on the agenda, then the removal of ambient noises and the prevention of noise amplification and the use of special filters should be taken into consideration.

Keywords: *Digital stethoscope, subtle body sounds, ambient noise, heart sounds.*

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1. Introduction

Various methods such as echocardiography, ECG signal preparation and cardiac sound are employed to analyze heart function and diagnose heart disease. Imaging and ECG signaling methods are expensive or performed by specialist doctors who confirm diagnoses obtained through other methods. The problem with heart sound listening is that this sound is not strong enough, and adequate practice, experience and access to different information are required in this regard. Also, to hear a certain sound in the heart, one must pay attention to a certain phase of the heart. Using diagrams, processing the heart sound signal and drawing the processed sound signal provides us with more information. Time and frequency information can be accessed if the frequency analysis is performed through wavelet transformation. Frequent cardiovascular checkup is important in examining cardiovascular diseases and the treatment of chronic illnesses, as heart-related ailments become much more complicated when other conditions such as coronary heart disease and high blood pressure exist. If a heart condition is not treated immediately in the long term, it can lead to sudden heart disease. In fact, if treatment is delayed and time is lost for optimal treatment, this can even lead to unpredictable and deadly consequences.

Just as hearing the heartbeat is one of the most basic ways to assess heart function, a stethoscope can be applied to listen to respiration and heartbeat sounds and to diagnose most heart disorders and other diseases.

Anesthesiologists must listen to the patient's heart and respiration sounds during anesthesia care. Although handheld stethoscopes are commonly used, they can only be employed by one individual and are not easy to use. An electronic stethoscope is designed using a speaker and microphone system and serves much larger practical purposes. The most suitable power supply must be found to improve the existing device .Ideally, changes should be made to allow a dual microphone system with wireless capabilities and the main receiver with a speaker and headphone jack for private listening. Although the stethoscope is a very simple device, it is one of the most important diagnostic tools in the medical field.

Stethoscopes have been replaced and often recovered for over two centuries, but they have never deviated from their original design. In 1843, a physician from New York named George P. Cammann modified the stethoscope, made the tube flexible, and designed two ducts to be placed into the ears. [1] In 1855, Dr. Kaman devised a stethoscope made from the following material: the chest part was made of ebony wood, the tubes were of wire covered with silk cloth soaked in tree gum, and the ear parts were made of ivory. No major changes were made to stethoscopes until the 1960s, and in the same year, Harvard professor Dr. Littmann developed a stethoscope that owned suitable acoustic properties. Dr. Littman is a cardiologist of global fame in electrocardiography [2]

In 1961, he explained a stethoscope's features in AMA magazine: "it is better for the chest part to have two parts, one called the bell to listen to the bass sounds and one with the plastic diaphragm to filter the sound. The tube should be hard with a single duct and be as short as possible. Also, the stethoscope should be light and easy to work with.

Litman stethoscope is currently the most popular brand in the stethoscope market and is equally popular and best-selling. Modern technological advances have now brought new developments and features to stethoscopes [3]. Following the changes in digital stethoscopes, acoustic stethoscopes have now been upgraded. In fact, they have become smaller, more beautiful and more functional. In the new design, not only can users listen to the sound of patients' internal organs in groups, but it is also possible to receive these sounds through radio waves from far distances. In educational institutions and universities, it is made possible to hear the voices once considered educational by the clinical faculty, collectively and individually.

With the new model, a radio receiver of any size can transmit educational sounds live [4]. Receptions of this system will be able to transfer via wireless waves. These facilities will be highly helpful in transporting critically ill patients by ambulances to the guidance headquarters, transfer team and treatment centers. By adding a simple wireless circuit to the training stethoscope, the heartbeat of critically ill patients can be controlled remotely using radio waves. Accordingly, this study aims to design and develop a digital stethoscope.

2. Method

All the designs of this study were done in MATLAB software, which is described in the continuation of how to do the designs.

3-result

3-1-Designing Digital Stethoscope

Certain key points must be taken into account when designing a digital stethoscope. First, when converting an acoustic stethoscope to an electronic stethoscope, it must be noted that operating rooms, in general, are places where all types of medical equipment exist, and they are typically the main sources of noise production. Therefore, they can disturb any electronic output received in the room. These stethoscopes should, thus, be designed so that ambient noise has minimal impact on their output, and the user is assured that the received sounds are only the patient's heart and respiration sounds. Similarly, a digital stethoscope must be able to amplify and clarify the body sounds of patients. Second, the digital stethoscope's length matters. In the operating room, anesthesiologists also use stethoscopes and constantly move around the patient's bed and anesthesia machine, increasing or decreasing the dose of the patient's drug. As a result, the short length of the stethoscope prevents them from accessing the patient's heart sound while adjusting the drug dose. The solution to this problem is the adjustability of the length of the stethoscope. Third, the sounds received by the therapist are significant. In acoustic stethoscopes, only one doctor can hear the sounds of the stethoscope, but sometimes doctors need the sound of the stethoscope to be played through several headphones or speakers for everyone in the room. In addition to the above points, the designed stethoscope must possess all the features of an acoustic stethoscope and at the same time be light, portable and inexpensive. Such a stethoscope should never injure the patient on the surgical bed or interfere with their body implants as they are connected to various voltage devices. The overall goal of designing a digital stethoscope is to add these features to the acoustic stethoscope. Therefore, in designing the prototype, the amplification of subtle body sounds, elimination of ambient noises, prevention of noise amplification, and special filters should be prioritized. It must also be noted that the amplification and filtering processes should not affect heart and respiration sounds, as slight differences in the patient's body sound can make a huge difference in medical diagnosis.

To identify the active parts of the frequency spectrum, a research team collected different samples of heart and respiration sounds. To this end, the team designed a particular stethoscope. In this stethoscope, part of the plastic tube that led to the ears was cut and connected to a condenser microphone. Microphone fittings and the plastic tube were coated with form and tube glue. Heart sounds were collected from different chest parts with different amplification gains. Also, respiration sounds were accumulated from various parts of the patient's back above the sternum and below the right shoulder blade. Different gains (25%, 50%, 75% and 100%) were tested to see how much amplification was appropriate and how much amplification was harmful to body sounds. The team used MATLAB software and fast Fourier transform to process the signal and find the heart frequency spectrum. Next, they formed a frequency-amplitude spectrum diagram and found that the heartbeat sound was at 300Hz or less. (**Figure 1)**

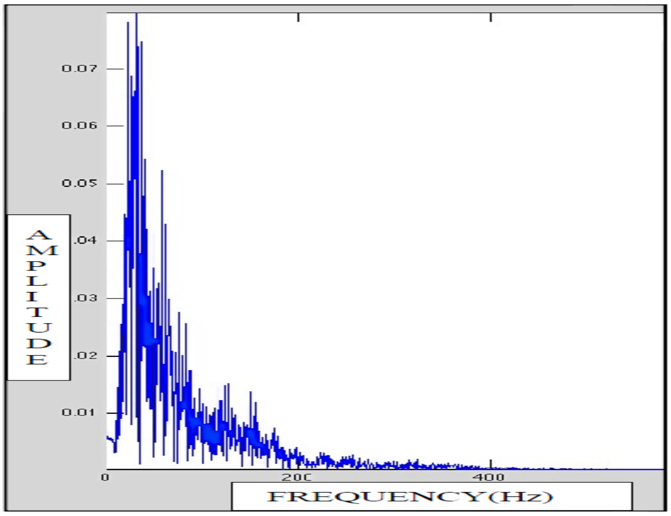

Figure 1: Frequency-amplitude spectrum diagram

Heart sound was heard clearly by inserting the gain of 100%, but a low-pass filter had to be used to remove annoying noises. Therefore, the research team designed a low-pass filter with an active, low-pass third-order Butterworth filter and routed frequencies as low as 400Hz.(**Figure 2)**

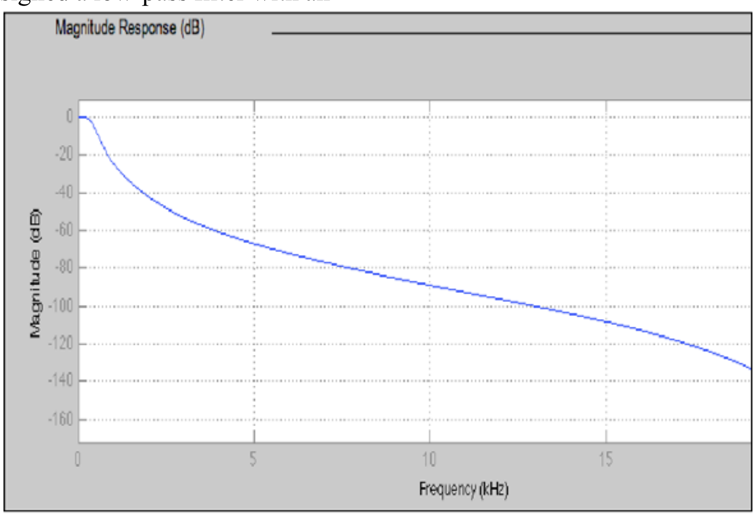

Figure 2: low-pass filter results

In designing the circuits of this stethoscope, all the basic features of an acoustic stethoscope had to be preserved, and only the produced acoustic sound should have been converted into digital sounds. To this end, the design had to include three main parts: primary audio receivers, acoustic to the digital sound converter, and audio signals amplifier and filter. Figure 3 shows the circuit design of the digital stethoscope.

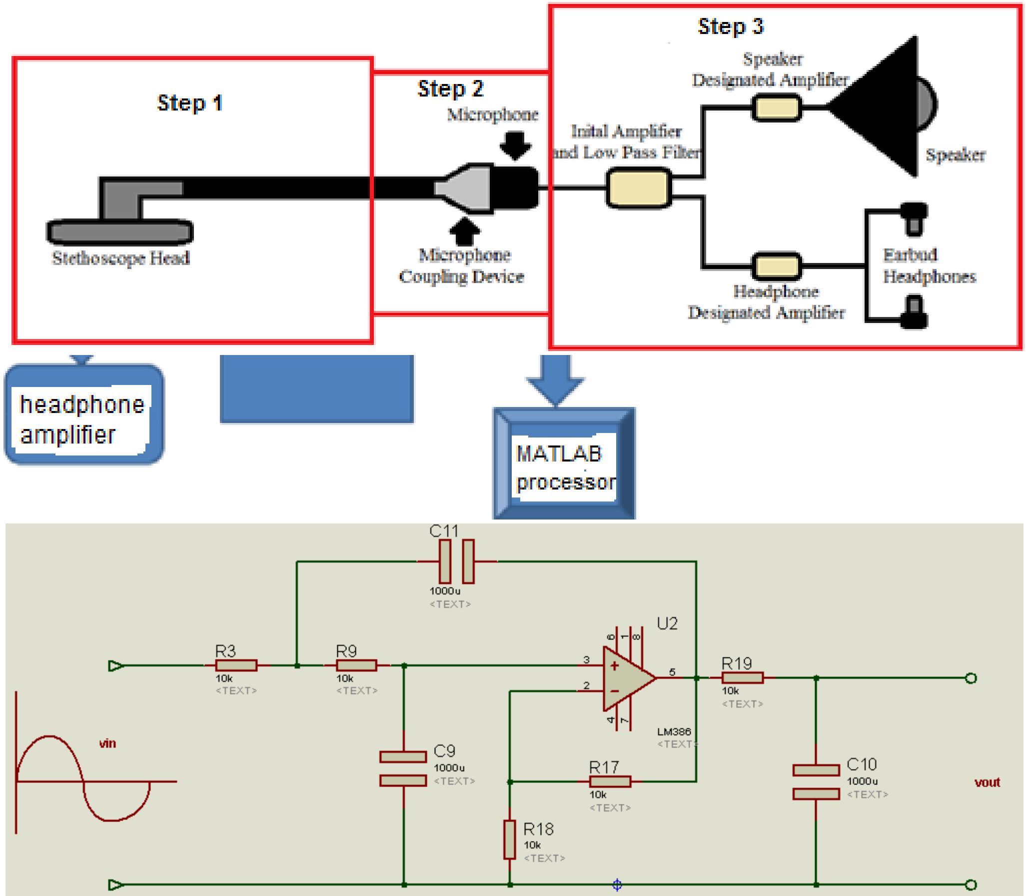

Figure 3: Design of stethoscope circuits

3-2- Stethoscope Microphone System

Three different microphones were analyzed and compared to have the best microphone for use in the final design. The microphones intended for use included a condenser microphone, a fiber optic microphone and a microelectronic. Table 1 shows the types of microphones.

Table 1: Types of microphones

Weight	Design	MEMS	Fiber Optic	Condenser
0.3	Size	10	9	7
0.3	Sensitivity	9	10	10
0.15	Cost	8	3	7
0.1	Power	9	7	6
0.1	Feasibility	8	5	7
0.05	Interference from Medical Devices	7	10	7
	Total	8.95	7.85	7.8

The first option is a condenser microphone powered by a capacitor that converts sound energy into electrical energy. The front surface of the diaphragm is made of lightweight material and vibrates when hit by sound waves. This causes the distance between the diaphragm and the rear surface to change, leading to a change in capacitance, as provided by this equation. A single voltage must be supplied across two capacitor levels to change the capacitance. This voltage is usually supplied by an external power supply, such as a small battery in the microphone. The external power supply also allows the condenser microphone to have more output when compared to self-powered microphones such as dynamic microphones. Due to their sensitivity to sound and acceptable frequency suction, a condenser microphone is popular in laboratories and recording studios. (**Figure 4)**

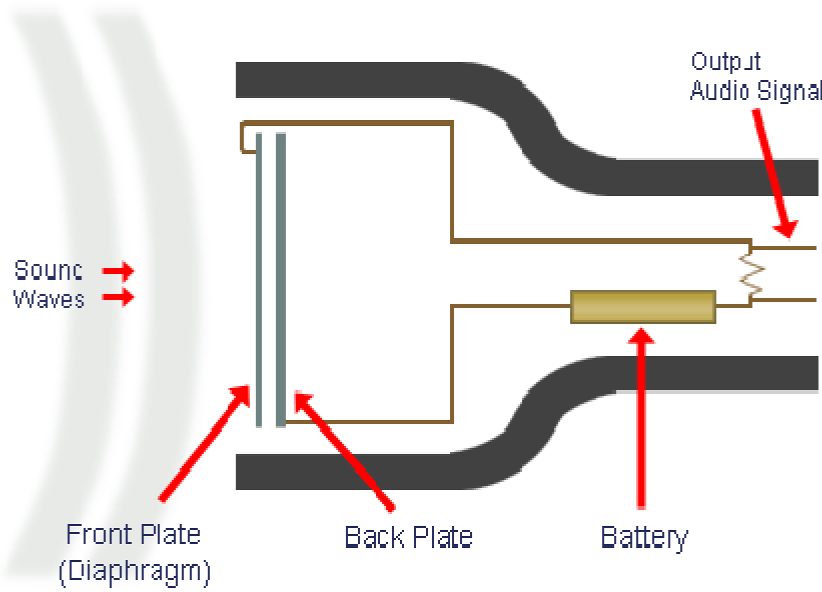

Figure 4: Condenser microphones

The second option is a fiber optic microphone. Fiber optic microphones operate by measuring changes in light intensity instead of changes in capacitive and magnetic fields like old microphones.

3-3- Amplifier System

Two main classes of amplifiers were included in the designed stethoscope for signal amplification. AB and D both act in the same way, taking power from one source and using it to increase the signal amplitude while maintaining the input signal's shape. The main advantage of a class D amplifier is power efficiency. Normally, metal-oxide-semiconductor field-effect transistors are used and operate with very low resistance, resulting in minimal power losses. They can achieve peak efficiencies of more than 90%. However, using a D amplifier that converts the analog input signal to digital deviation is called a gradual error. Compensation for this error can be difficult, especially if it is set up incorrectly. (**Figure 5**)

$$V_{out} = \frac{R_2}{R_1 + R_2}(V_{in})$$

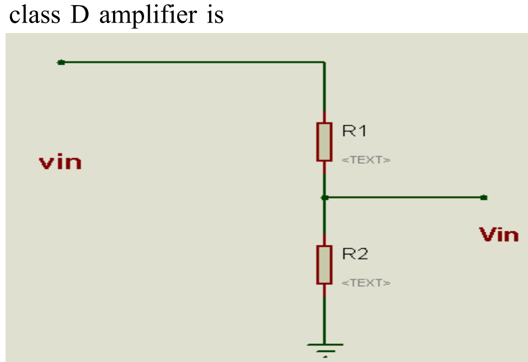

Figure 5: Two major classes of amplifiers in signal amplification

For this reason, the AB class was used in the design for improvement. The peak efficiency was less than 78.5% and required a thermal sink. Since the design required a relatively large speaker, the location of the receiver box had to be large enough to accommodate several heat sinks. Using AB class amplifiers also allowed the circuit to maintain the analog and simplify the partial design, thus allowing for easier modifications after testing. Figure 6 shows the location of the receiver box.

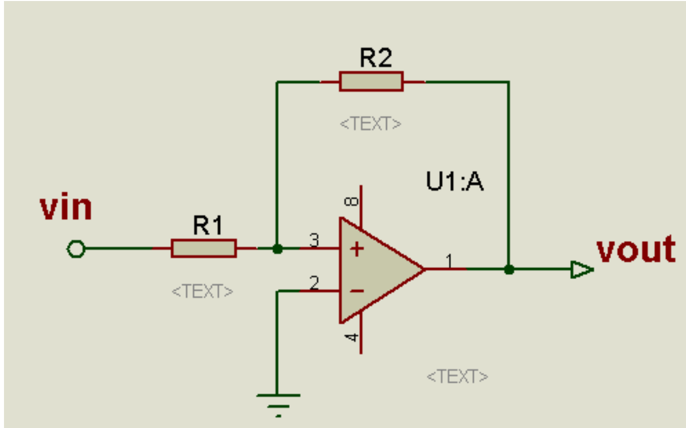

Figure 6: Location of the receiving box

3-4- Digital Stethoscope Speaker

Choosing a speaker is highly significant in the final design because while the rest of the design may be fully functional, the final product will fail to be functional if the employed speaker does not have the required frequency range. The team, therefore, decided to use a final payleHome speaker, a 4PCB4BK 200-watt small cubic inch, in the final design. This speaker increases the frequency response curve from 20 Hz to 18 Hz, which includes the frequency range required by design. The box size was relatively small, 4.8 inches, with 4.8 inches in width and 2.5 inches in depth, and the speaker had an 8 ohms impedance. This speaker connects to the output circuit and provides access to heart and lung sounds from the circuit.

3-5- Digital Stethoscope's Consumption Current

The two microphones were powered by two quadruple functional amplifiers that amplified the filter and signal, and of the two operational amplifiers and signals, a single mixer was routed. As a result, the sound was more filtered, the volume was tripled, and the bass balance between the two signals could be changed. It then sent an output switch to an amplifier circuit in a speaker or headphone from which sound could be heard. The system was powered by 12 volts. Electronic stethoscopes have a similar function, except that in these stethoscopes, the received sound is converted into electrical signals and transmitted by wire to the listener's ear. Digital stethoscopes can amplify, filter aperture sounds and in some cases, record data. The device's hardware consists of the following components: power supply, sensor, preamplifier, low-pass filter and power amplifier. Audio outputs and device software also include a phonocardiogram monitor.

3-6- Stethoscope's Power Supply

The sensor part of the device needed a power supply. Many digital stethoscopes use one or two 1.5-volt batteries. This design requires a switching regulator to increase the voltage by 3 or 5 volts per circuit used when necessary. The device also used rechargeable batteries. A new phonocardiographic recording system has been developed by Okarnin et al., powered by a 5-volt battery in its container.

3-7- Stethoscopes Monitor

Some digital stethoscopes have a simple, small display monitor that fits into the space on the stethoscope. The stethoscope model made by Yang et al. has a 3.5-inch LCD that connects to a PC via a serial port and simultaneously displays the waveform of heart signals. The model, developed by Tao et al. collects the data and displays it by sending it to a computer. Yi Luo et al. have designed an electronic stethoscope that is video, portable and has Bluetooth, and functions with the help of Lab view software version 8.20. Due to the high speed of this software, Microsoft VB software is used in the model made by Chen et al. Heartbeat sensors are connected to the computer through the serial connection.

4- discussion and Conclusion

In a digital stethoscope, one can use the computer to see the heartbeat waveform, heartbeat rate and zoom, store and process the signals sent by the stethoscope. Technological advances are leading to cheaper and more accurate pieces and parts, which are increasingly accessible for manufacturers, increasing the accuracy of the information obtained from medical equipment and ease of treatment. Due to their unique features like being wireless and able to receive and transmit electronic data, reduce noise and capture video output, the electronic stethoscopes will overtake acoustic types in terms of advantages, which is happening through increasing technological advances.

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Ethical statements: None

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