Design a Stethoscope Digital to Keep the Medical Practitioner at an Adequate Distance While Examining the Patient

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Abstract. A stethoscope is an instrument in medicine used to listen to the sounds produced in the body or auscultation, primarily to listen to the sound from the lungs and heartbeat. Medical practitioners usually use the sound from a stethoscope as an indicator to diagnose an illness. Regular stethoscope with earpiece is less effective to use since the novel coronavirus quickly spreading from saliva droplets. Medical practitioners have difficulty attaching the conventional stethoscope to the ear because they have to use personal protective equipment, including head covering, to deal with coronavirus patients and patients with other medical complaints. This research designs a digital stethoscope that can be used even the head of medical practitioners covered by safety clothes. This stethoscope has a sound sensor, OLED, a microprocessor, and a speaker. The sound of lungs and heartbeat from 30 volunteers was recorded to investigate the frequency of noise, lung, and heartbeat. A bandpass filter was designed to get the signal with an upper cut-off frequency of 50 Hz to 80 Hz and a lower cut-off frequency of 5 Hz. The result shows that this stethoscope can detect the number of heartbeats and give a clear lung sound. This device can help medical practitioners examine patients while keeping their distance from patients.

1. Introduction
A stethoscope is a prime medical instrument usually used by the medical practitioner to diagnose and treat the patients[1]. Currently, there are two types of stethoscopes; those are acoustic stethoscopes and electronic stethoscopes. The technique of using a stethoscope to distinguish between normal and abnormal sounds is called auscultation[2]. Auscultation can provide accurate and diagnostic information regarding the heart, lung, and tracheal[3]. This diagnostic is usually precisely done in the cardiovascular, respiratory, and gastrointestinal systems. However, because of the Coronavirus pandemic, the regular stethoscope that uses earpiece is less significant, considering that the medical practitioners have to wear clothes that cover all of their bodies, including the head[4,5]. It is officially named Personal Protective Equipment (PPE). For this reason, a stethoscope is needed that can be connected using speakers and a headset so that medical personnel can treat patients while still wearing complete Personal Protective Equipment.
There are several journals and research related to stethoscopes, both acoustic stethoscopes and digital stethoscopes[6–8]. All of this research used some kind of signal filters to optimizing the performance of the stethoscope. The use of the band pass filter to filter the sound from the mic condenser is more frequently implemented. Some of them use medical analysis, such as systolic and diastolic murmur[4]. Data processing using the Internet of Things has been carried out related to this topic[8,9]. The purpose of this final project is to design a digital stethoscope with a sound output system that can be connected to speakers and headsets so that medical practitioners have no difficulty examining patients using a stethoscope even with a complete PPE. This research designs a digital stethoscope that can be used even the head of medical practitioners covered by safety clothes.

2. Materials and methods
The digital stethoscope captured sound from the lungs and heartbeats as the input. The output is the heart or lung sound that can be heard from the speaker and headset. Besides that, the rate of the heartbeat has been shown in OLED (organic light-emitting diode) as the display.

2.1. Data Collection
Data collection is carried out to determine the cut-off frequency of filter in order to get clear sound from the digital stethoscope. The data were collected by recording the sound of heartbeats and lungs (breath) of 30 respondents. Lungs and heartbeats sounds were recorded using three stethoscopes with different brands. The output from the stethoscope goes directly to the laptop using a modified audio jack cable. The chestpiece of stethoscope is attached to several points on respondent’s body or what is called auscultation. Heart and lung auscultations are in the area shown in figure 1.

![Figure 1](image)

Figure 1. (a) Heart auscultation’s points, and (b) Lung auscultation’s points

Figure 1a shows four locations of heart auscultations. The heart auscultation positions from 1 to 4, respectively, are aortic valve, pulmonary valve, tricuspid valve, and mitral valve. Lung auscultation is carried out by taking data from four breath sounds (figure 1b). Those lung auscultation positions from 1 to 4 are tracheal breath sounds, bronchial breath sounds, bronchovesicular breath sounds and vesicular breath sounds.

2.2. Fast Fourier Transform
The obtained data was in time domain signal form. The timedomain signal was converted into the frequency domain signal by using Fast Fourier Transform (FFT)[10]as formulated in equation (1). It is necessary to distinguish the noise, lungs and heartbeats sound frequency.
Where

\[ X[k] = \sum_{n=0}^{N-1} x[n] e^{-j\frac{2\pi nk}{N}} \]  

MATLAB provides the FFT function to assist mathematical computations with a specific syntax. The FFT result in MATLAB will obtain the frequency domain signal and a graph of the frequency distribution from the sound that has been recorded. This result is analyzed to differentiate the frequency of the heart, breath, and noise. The analysis results obtain both upper cut-off frequency and lower cut-off frequency to design the bandpass Filter.

2.3. Stethoscope Digital System

The hardware of the digital stethoscope required consists of a stethoscope chest piece, rubber tube, mic condenser, a preamp circuit, a bandpass filter circuit, a microprocessor, a speaker, and a display output. The digital stethoscope receives sound as input captured from the bell and diaphragm where the stethoscope chest piece is located. The system's output is sound and the display of the number of heart rate in a minute. The digital stethoscope hardware design is shown in figure 2.

![Figure 2. Hardware design.](image)

The stethoscope or tubing will be connected to the condenser mic then proceed to a small box. This box contains the amplifier circuit, filters circuit, and a microcontroller. It also has a button to adjust the volume, an audio jack, and a headphone port. The battery to be used is a rechargeable 3.7 V battery. In addition, the stethoscope will be equipped with an OLED so that it can display the heart rate in a minute. The next component is the speaker or headset. The speaker of the headset and the box are connected by wire using an audio jack cable. The designed digital stethoscope work as follows:

1. The heartbeat and lung sound is captured by the surface of the diaphragm and bell. The sound wave spreads inside the tube, creating the vibration. The condenser mic gets the vibrations as the input and converts to the voltage value.
2. Furthermore, The amplifier circuit using gain the signal using the dual op-amp IC TDA2822.
3. A High Pass Filter (HPF) and a Low Pass Filter (LPF) process the signal.
4. The microcontroller displays the heart rate frequency per minute and forwards the signal to the speakers or headphones to produces sound.

2.4. Amplifier Circuit

Since the mic condenses only features a peak to peak voltages of around 200 millivolts, it needs a decent amplifier to increase the voltages. The amplifier circuit consists of two inverting circuits so
that the results in the last output will have the same phase value as the input value. The schematic of
the amplifier circuit is shown in figure 3. This circuit also has additional circuit that is intended to
activate the condenser mic.

Figure 3. Schematic of an amplifier circuit.

In the circuit, R1 and C1 is the component to activate the mic condenser. The gain value in the
amplifier circuit is obtained by the inverting gain formula in equation (2). $V_{out}$ indicates the voltage
output of the circuit, and $V_{in}$ indicates the voltage input of the circuit. Gain can also be obtained from
the resistors R11, R12, R21, and R22 based on equation (2). The resistors R11 and R12 are the
resistors to determine the gain from the first amplifier, while the resistors R21 and R22 are the
resistors to determine the gain from the second amplifier. Both resistor R15 and R16 are used as the
voltage divider on the noninverting input. It is utilized to create an offset voltage at which the output
to voltage will oscillate around.

$$Gain = \frac{V_{out}}{V_{in}} = \left( \frac{R12}{R11} + 1 \right) \left( \frac{R22}{R21} + 1 \right)$$  (2)

2.5. Band Pass Filter Circuit

In the bandpass filter, the cut-off frequency will be selected according to the analysis of the FFT chart
of heartbeat signals and breath sounds. The amplifier bandpass filter circuit is made with the circuit
shown in figure 4.

Figure 4. Schematic of band pass filter circuit.
A bandpass filter is a filter that combines a low pass filter and a high pass filter in one circuit. In figure 4, both low pass and high pass filter that used are second order. It contains two resistors and two capacitors in each circuit. The values of the capacitors and resistors are determined based on the cut-off frequency, which is obtained using equation (3)

$$f_{\text{cutoff}} = \frac{1}{2\pi\sqrt{C_1C_2R_1R_2}}$$  \hspace{1cm} (3)

Equation (3) can be used in both low pass and high pass filters. Low pass filter suppressed the frequency that more than the cut-off frequency value, while high pass filter stopped the frequency that less than the cut-off frequency value.

3. Results and discussion

This research includes the results of the analysis of the FFT graph on the sound recording, the gain for the amplifier circuit, the determination of the capacitor and resistor values used in the filter circuit the heart rate counter features.

3.1 Gain of Amplifier

The amplifier circuit uses dual operational amplifier in this research. The final output of the circuit has the same phase as the input because both are made in the form of an inverting circuit. In the first op-amp, the value of resistor R1 and R2 are 1K\,\Omega and 10K\,\Omega. In the second op-amp, the value of resistor R1 is 2K\,\Omega and R2 is a potentiometer with a maximum value of 33K\,\Omega. By using equation (2), the maximum gain of the first op-amp is $11\times$, and the maximum gain of the second op-amp is $17.5\times$. Therefore, the maximum gain that can be achieved in this circuit is 192.50 multiplies. In the noninverting input, the voltage divider is set to oscillate the output around 2.5 V, so both resistor R15 and R16 have a value of 10K\,\Omega.

3.2 Band Pass Filter

The Fast Fourier Transform is used to analyze the distribution of the frequency of the noise, heartbeat, and lung sound. The researcher used noise reduction tools in software Audacity to separate the noise from the desired sound. The frequency distribution of heartbeat and lung signal before and after filtered is shown in figures 5 and 6.

![Figure 5](image_url)

Figure 5. The heartbeat FFT signal (a) before filtered and, (b) after filtered.
From the comparison before and after noise reduction in the heartbeat data sound in figure 5, the noise spread from the frequency 0 - 80 Hz and above 334 Hz. The frequency estimate of the heartbeat sound is 258.4 Hz.

The lung sound from the FFT plot in figure 6 has the frequency estimate at 258.39 Hz with a frequency distribution between 100 Hz until 370 Hz. From the FFT plot analysis, the lower frequency of the band pass filter is around 70 Hz, and the upper cut-off frequency is around 370 Hz.

Equation (3) is used with the approach value of the resistors and capacitors that sold in the market. The value of all capacitors in this circuit is 100nF to make it easier to find resistor values. For the low pass filter, the value of resistors are 5K Ω and 3.6K Ω. The upper cut-off frequency in the low pass filter circuit is 375.13 Hz. The resistors for high pass filter are 100K Ω and 1M Ω so the lower cut-off frequency is 5 Hz.

3.3 Heart rate counter
The digital stethoscope provides the heart rate per minute counter feature. The heart signal that enters the microcontroller is then processed using the threshold method. Then the heart rate frequency obtained is then obtained from the interface in the form of an OLED. The display on the OLED is shown in figure 7.
4. Conclusion
The research aims to design a digital stethoscope that can be used even the head of medical practitioners covered by safety clothes. Based on the analysis of FFT signal of heartbeat and lung sound, the band pass filter is designed to reduce the lower cut-off frequency is 5 Hz and the upper cut-off frequency is 376.13 Hz. The amplifier circuit has a maximum gain of 192.50 with the output voltages oscillate around 2.5 V. The result shows that this stethoscope can detect the number of heartbeats and give a clear sound of lungs. This device can help medical practitioners examine patients while keeping their distance from patients.

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