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Engineering assisted medical training: development of an auscultation simulator

Abstract

Simulation is an important part of medical training which allows students and examinees to face unfamiliar problems with familiar devices. Auscultation is a major aspect of medical training as heart and lung sounds need to be properly diagnosed to provide appropriate healthcare. The Auscultation Simulator combines these two concepts to instruct and potentially test medical students and practitioners on a broad spectrum of cardiac and lung ailments. The development of an Auscultation Simulator is presented. A stethoscope was adapted as the mechanical frame for the simulator. Records of heart and lung sounds are acquired from a database. These audio samples were pre-processed to increase the time span and improve the signal to noise ratio. A computer program was developed to choose and play a heart or lung sound which is picked and transmitted to the receiver module in the simulator. Two expert cardiologists assessed the quality of sounds of the Auscultation Simulator and 11 resident doctors and consultants of the University College Hospital, Ibadan completed questionnaires on their user experiences. The cardiologists were mostly satisfied with the quality of the heart sounds with a 95% satisfaction rate and lung sounds with a 70% satisfaction rate. The residents and consultants had a net positive review on the build and sound quality of the auscultation simulator. The Auscultation Simulator proves to be a useful engineering tool in medical training exercises while keeping itself affordable and easy to use for most teaching hospitals in Nigeria.

Keywords: Biomedical device, cardiac murmur simulation, audio signal processing, medical training, recycling of hospital waste

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Introduction

Simulation as a teaching aid is an active part of medical training at both the undergraduate and postgraduate levels.[1-6] Traditional medical simulators are expensive to obtain and operate. There is an increasing demand for medical simulations in teaching hospitals.[7-9] Heart sounds simulation is a typical example. An Auscultation Simulator is an electronic device (shaped like a stethoscope) that can transmit heart, lung and abdominal audio samples from a transmitter to a receiver that is embedded within the "stethoscope" (Auscultation Simulator) to provide an accurate representation of the condition it attempts to mimic audibly. It can be used on healthy simulators and enhance the clinical learning experience rather than using a mannequin. The alternative will be to use real patients that are few and far between that will get fatigued in the process. It is difficult and cumbersome to discover and request for patients with specific cardiac diseases and complications, or to obtain very expensive equipment to achieve the same goal. A more cost-effective solution is required to provide safe and controlled training simulations as well as the prospect of being able to test and observe all cardiac (but not restricted to) conditions that affect patients today.[10]

Every teaching hospital carries out simulations for training and examinations many times a year. With the provision of the Auscultation Simulator, medical simulations will be more accurate, controlled and concise to be able to give a more uniform experience across all users. The major issue in Sub-Saharan Africa is the importation of these medical simulation tools which are both expensive and cumbersome to deliver in bulk.[11] Also due to the poor exchange rate, simulators become expensive and unavailable in most teaching hospitals in Africa.[11] With the sourcing of local materials, a stable and properly designed Auscultation Simulator can be made locally to greatly reduce the general cost of obtaining this equipment. This will also make the possession of a significant number of Auscultation Simulator units possible in teaching hospitals in Nigeria.[11-13] The development and testing of an affordable and functional Auscultation Simulator for use in cardiac medical simulations in teaching hospitals is presented.

The auscultation simulator is a modified stethoscope that has pre-recorded sounds of cardiac murmurs and other body sounds for use within medical training situations.[14,15] It is particularly useful when a patient with a specific condition cannot be provided or is indisposed for such training situations. The teaching of recognition of various heart sounds in Nigeria is often through chance interaction with patients possessing the certain conditions to be identified.

A difficulty arises when patients (with certain conditions) aren't available in the clinics or on the ward to be diagnosed. The patient with a particular cardiac sound may not be available when that particular subject is being taught in the curriculum. Another issue that arises is when there's a single patient for the entirety of the students within the unit which is tiring to the patient. It is usually students with great self-motivation that struggles to get the opportunity to listen to the various conditions. To make up for the difficulty of learning heart sounds, some students search the internet for the sounds they are being taught so that they can keep up with the classroom. Some of these sites are very useful to the students as not only do they have heart sounds but they also have visual aids showing the heart pumping and a pulse meter so they can observe what they hear.

The skill of auscultation however comes in two parts; identifying the sound and knowing the appropriate precordial point to find the sound with a stethoscope. Therefore, these internet sites are not sufficient for auscultation skill acquisition. Having an auscultation simulator (with a stethoscope) will enable the student to learn the actual sound and the proper precordial point position to hear that sound. The only Auscultation simulator (as a modified stethoscope) in the market currently is the Lecat's Ventriloscope®.[14,15] This auscultation simulator is capable of simulating heart, abdominal and breath sounds.

The ventriloscope is a device that allows users to perceive simulated patient sounds from Lecat's original ventriloscope library. Lecat's original ventriloscope library contains recorded sounds of patients that are diagnosed with different conditions that are perceptible by a stethoscope. Some of these sounds include heart sounds, lung sounds, bowel sounds, bruit, and blood pressure.[16] This allows for medical simulation training to occur without any risk involved with using a real patient such as patient fatigue, patient unavailability or professional error.

Due to poor rate of exchange of Nigeria Naira with USA Dollar, Lecat's Ventriloscope is not available in sufficient numbers locally.[11] COVID-19 has taught the developing countries the lessons of self-sufficiency. Importation of medical devices is not easy during lock-down. Each nation has to depend on what can be made available locally during the pandemic.[13,14] Therefore, it is a good idea to develop an auscultation simulator.

Methodology

A. Hardware

Figure 1 shows the block diagram of the proposed Auscultation Simulator. The digital personal computer has a cardiac murmur storage containing heart audio samples for different health conditions and situations. The computer plays an audio sample which is picked up by the FM Transmitter and transmitted at a certain frequency to a receiver which is connected to an ear piece. Both the receiver and the ear piece are within the stethoscope module. Apart from the digital computer, the hardware has three main parts, the mechanical frame, the transmitter module and the receiver module.

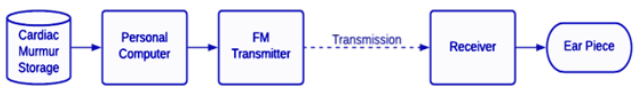

Figure 1 Block Diagram of Auscultation Simulator.

B. Mechanical frame

A stethoscope was selected as the basis for the mechanical frame of the hardware. This is an opportunity to recycle old stethoscopes. The Auscultation simulator structure comprises in itself two major parts, the Stethoscope body and the housing for the FM receiver module at the Y junction of the stethoscope as shown in Figure 2. The stethoscope was taken apart by hand to allow for the passage of earphone cables through each of its tubes. An incision was made on the sides of the soft tubes to pass the cables from the earpieces down to the Y junction. The earphone cables had to be cut at the junction to allow for each ear piece to pass through its corresponding tube. Reattaching the earphone cables required a fire source to burn off the protective coat around the signal and ground wires for each ear cable. After all the cables were passed through, the stethoscope was reassembled.

The casing for the FM receiver module was designed using a Fusion 360 platform and printed with a 3D printer. Figure 3 shows wireframe views of the casing with measurements. The button controls are in a circular fashion with a diameter of 30mm as shown in Figure 3(c). The display LCD rectangular opening in Figure 3(c) is 32 mm by 21 mm with bevelled corners for style. The total height of the casing is 94 mm.

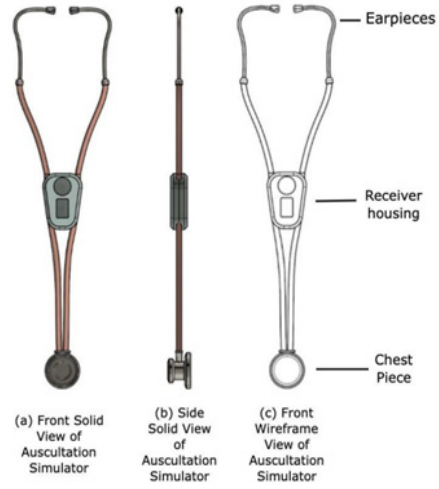

Figure 2 Solid and wireframe views of the Auscultation simulator.

The total width of the casing is 29 mm with bevelled edges for a comfortable hand fit as shown in Figure 3(b). The holes in the top and bottom of Figure 3(b) are for the stethoscope tubes to pass through unhindered. Figure 4. Shows the solid view of the 3D printed casing for the receiver module.

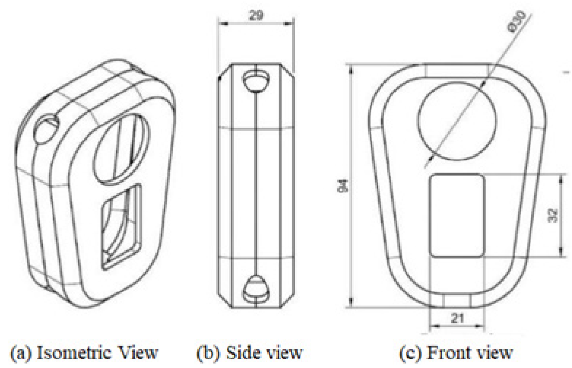

Figure 3 Wireframe views of the casing for the FM receiver module.

Figure 4 Solid view of the 3D printed casing for the FM receiver module.

The final look of the Auscultation Simulator is shown in Figure 5. The casing will be able to display the FM frequency screen and a controller to modify the gain and the frequency of the communication channel.

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C. The FM transmitter

Figure 6 shows the FM Transmitter selected for the Auscultation simulator.[17] It was discovered that transmitting at high volumes would distort the signal at the receiving end, so a decent amount of volume on the computer was estimated at the 15-20 % range.

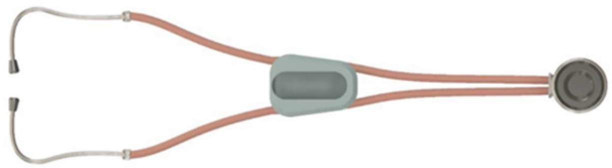

Figure 5 The Auscultation Simulator.

Figure 6 The FM Transmitter.

D. The FM Receiver

Figure 7 shows the FM Receiver selected for the Auscultation simulator.[18] The Receiver module is housed inside the casing at the Y junction of the stethoscope.

Figure 7 Receiver Module.

E. Computer program

A computer program named "Auscult" was developed in C# with Microsoft Visual Studio as a 'Windows Form Application' and it consists of an array of N number of buttons, each of which points towards a particular cardiac or respiratory sound. Clicking on one of these sounds as identified by name will proceed to play the sound which can be halted by pressing the stop button on the windows form application.

The structure of the Windows Form Application is shown in Figure 8. Each button corresponds to a heart or lung sound which the examiner/instructor would like the examinee/student to listen to through the device. Each sound can be halted with the singular "Stop" button at the bottom right.

F. Heart and lung sounds acquisition

The Audio samples used for the heart and lung sounds were obtained from http://www.thesimtech.org/audio under the care of Andy Howes and are stored in the Cardiac Murmur Storage of Figure 1.[19] Although the heart and lung sound library was expansive and included the background foley of the hospital, a specific number was selected for the scope of this project as listed in Table 1.

Table 1 The Heart and Lung Sounds

S/N	Description
1	Normal Split S1
2	Normal Split S2
3	Opening Snap
4	Pansystolic Murmur
5	S3
6	S4
7	Diastolic Rumble
8	Early Systolic Murmur
9	Ejection Click
10	Late Systolic Murmur
11	Inspiratory Stridor
12	Normal Vesicular
13	Pleural Friction
14	Wheezing
15	Coarse Crackles

G. Heart and lung sounds pre-processing

Audio editing was done on the individual clips to boost their gain and reduce ambient noise. The length of the clips was also extended to 1 minute long since the audio clips are relatively of short time duration (5-15 seconds). The audio editing process involved compressing the signals at -14.9 dB to reduce the dynamic nature of the signal and to increase its gain (by 7.6dB) and clarity. After which a Multiband compressor (Figure 9), acting as an ambient reducer, reduced the static and ambient noises present in the audio recordings. The audio editing was done in software called "Ableton Live 10" which is a digital audio workstation that can modify audio and MIDI clips in different ways.

Figure 8 Auscult Computer Program User Interface.

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H. Quality assurance

The auscultation simulator was tested primarily with two Cardiologists, Akinyemi Aje M.D and Adewole A. Adebiyi M.D, who after consenting to test the Auscultation Simulator, attested to the quality of the heart and lung sounds within the computer program.

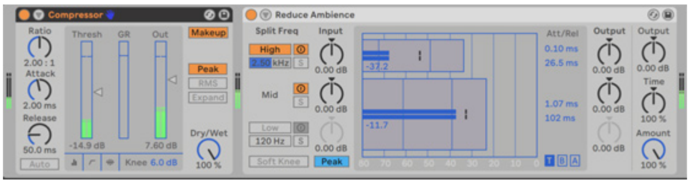

Figure 9 Multiband Dynamic Compressor.

I. Qualitative field test

The auscultation simulator was tested in the field with a Qualitative study. The qualitative study is focused on user satisfaction because the simulator has to produce sounds as authentic as real auscultation. The study was directed towards resident doctors and consultants. The user satisfaction form posed the following seven questions with response options in brackets.

1. Do you agree to participate in this study? (Yes, No)
2. I found using the auscultation simulator ______ . (Very Easy, Easy, Normal, A bit tricky, Difficult)
3. I found the sound quality compared to my stethoscope ______ . (Very Good, Good, Decent, Poor, Very Bad)
4. Identifying the different sounds was ______ . (Very easy, Easy, Not Bad, A bit tricky, Very difficult)
5. Using the auscultation simulator felt ______ . (Just like the real thing, Good, Decent, A bit strange, Very weird)
6. Did you find the Auscultation simulator heavy or uncomfortable? (Yes, No, May be)
7. What is your overall impression? (Excellent, Great, Decent, Poor, Very Bad)

Results & discussion

A. Expert Validation Test Results

According to the Table 2, the experts, Akinyemi Aje M.D and Adewole Adebiyi M.D, commented positively on the functionality of the Auscultation Simulator with major criticism being on the noise generated within the channel.

Table 2 Quality Assurance Test Results for Heart sounds

	Akinyemi Aje M.D	Adewole Adebiyi M.D
Normal Split S1	Satisfactory	Satisfactory
Normal Split S2	Satisfactory	Satisfactory
Opening Snap	Satisfactory	Satisfactory
Pansystolic Murmur	Satisfactory	Satisfactory
S3	Satisfactory	Satisfactory
S4	Satisfactory	Satisfactory
Diastolic Rumble	Satisfactory	Unsatisfactory
Early Systolic Murmur	Satisfactory	Satisfactory
Ejection Click	Satisfactory	Satisfactory
Late Systolic Murmur	Satisfactory	Satisfactory

They noted that the sounds were accurate and comparable with what is present in real life but that some conditions (such as the Opening Snap) are rare to find in common practice.

They also noted that the volumes of the heart sounds were appropriate and satisfyingly adjustable as well. The auscultation simulator was also tested on respiratory sounds with Adewole Adebiyi M.D who attested to the quality of the lung sounds within the computer program as shown in Table 3. The experts' percentage satisfaction for both the heart and lung sounds are presented in Figure 10.

Table 3 Quality Assurance Test Results for Lung Sounds

Inspiratory Stridor	Satisfactory
Normal Vesicular	Satisfactory (but longer than usual)
Pleural Friction	Unsatisfactory
Wheezing	Satisfactory
Coarse Crackles	Satisfactory

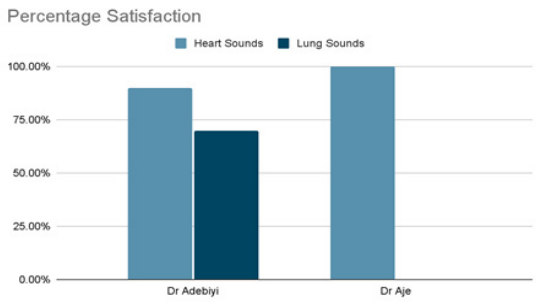

Figure 10 Bar Chart for Quality assurance test results on percentage satisfaction as reported by the experts.

To resolve the issue of noise generated in the channel, a wireless transmitter of greater signal will be helpful. Another potential solution for improved signal to noise ratio is Bluetooth transmission (which is around 2.45 Ghz) as it is of a greater frequency and higher fidelity than typical FM transmissions (which are typically between 88 Mhz to 108 Mhz).

B. Qualitative field test results

Eleven resident doctors and consultants participated in the Qualitative Field Test of the Auscultation simulator. They listened to the heart and lung sounds and provided feedback. Most of the resident doctors were able to properly identify the heart sounds as they listen to heart sounds more frequently than the consultants do. The results are summarised and presented in Figures 11-16.

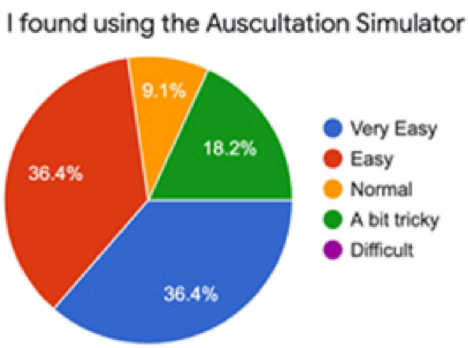

Figure 11 Pie Chart of response to Question No. 2 "I found using the auscultation simulator ______ .".

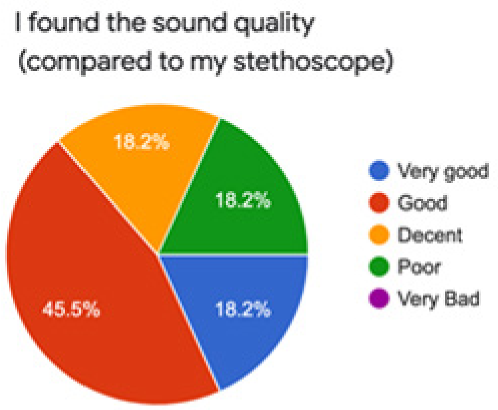

Figure 12 Pie Chart of response to Question No. 3 "I found the sound quality compared to my stethoscope ______.

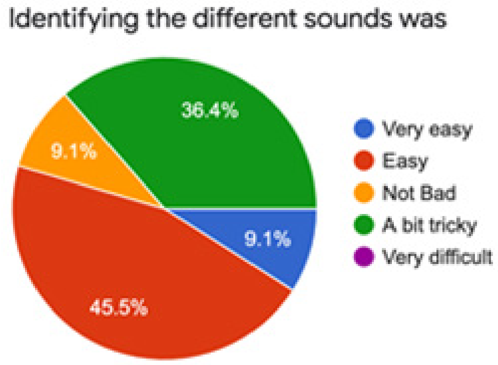

Figure 13 Pie Chart of response to Question No. 4 "Identifying the different sounds was ______ .".

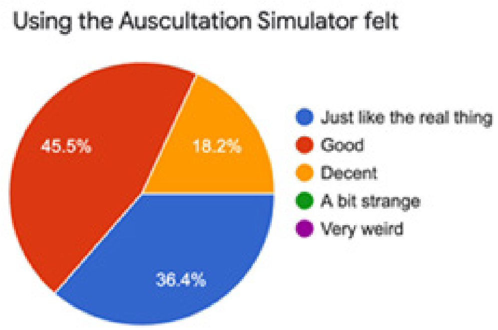

Figure 14 Pie Chart of response to Question No. 5 "Using the auscultation simulator felt ______ .".

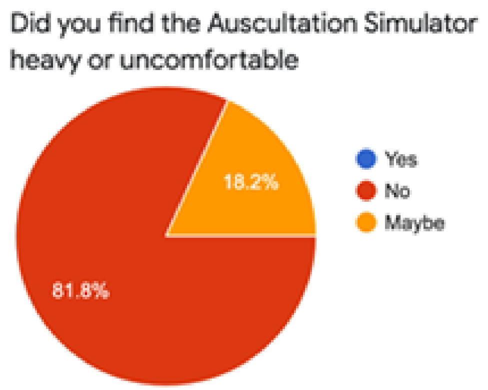

Figure 15 Pie Chart of response to Question No. 6 "Did you find the Auscultation simulator heavy or uncomfortable?".

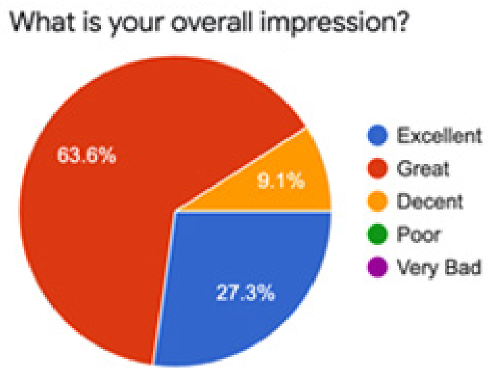

Figure 16 Pie Chart of response to Question No. 7 "What is your overall impression?".

Figure 11 shows the qualitative test result for Question No. 2: "I found using the auscultation simulator ______ . (Very Easy, Easy, Normal, A bit tricky, Difficult)". 72.8% of respondents found the Auscultation Simulator easy or very easy to use. This shows that the auscultation simulator is user friendly.

The qualitative test result for Question No. 3 is presented in Fig. 12: "I found the sound quality compared to my stethoscope ______ . (Very Good, Good, Decent, Poor, Very Bad)". Compared to their usual stethoscopes, 63.7% of respondents found the auscultation simulator's quality to be good or very good. 18.2% found the sound quality to be decent while another 18.2% found the quality to be bad. A major concern most respondents had were with the noise within the channel and the audibility of the sounds. Some of them would have preferred if the gain was greater for ease of identification. This shows that the audio quality, as previously assessed by the cardiologists, is consistent with the residents and consultants. This also shows that the sounds are accurate to what they are like in real scenarios.

Figure 13 shows the qualitative test result for Question No. 4: "Identifying the different sounds was _____ . (Very easy, Easy, Not Bad, A bit tricky, Very difficult)". 54.6% of respondents found that identifying the different heart sounds was easy or very easy. 36.4% found it a bit tricky to identify the sounds. This is evident from the mode of testing as a simulator was provided without any medical history which is usually a major factor in identifying what underlying conditions a patient has. It would be important to have re-tests as it takes some time for medical practitioners to identify sounds when using equipment that they aren't used to.

The qualitative test result for Question No. 5 is presented in Figure 14: "Using the auscultation simulator felt ______ . (Just like the real thing, Good, Decent, A bit strange, Very weird)". 36.4% of respondents found using the auscultation simulator similar to a real working stethoscope. 45.5% of respondents found using the auscultation simulator felt good to use. 18.2% of respondents found the use of the auscultation simulator decent. This shows that the auscultation simulator feels like a real stethoscope and only differs in its operation.

Figure 15 shows the qualitative test result for Question No. 6: "Did you find the Auscultation simulator heavy or uncomfortable? (Yes, No or May be)". 81.8% of respondents didn't find the auscultation simulator heavy or uncomfortable despite its form. The construction of the auscultation simulator was made with style in mind but there were concerns about the bulkiness of the Receiver module. This shows that the form of the auscultation simulator is convenient for use.

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The qualitative test result for Question No. 7 is presented in Figure 16: "What is your overall impression? (Excellent, Great, Decent, Poor, Very Bad)". 27.3% of respondents had an excellent impression of the auscultation simulator. 63.6% of respondents had a great impression of the auscultation simulator. This shows that the auscultation simulator can assist medical education and training with reference to auscultation in the teaching hospitals.

Conclusion

An Auscultation Simulator has been developed as an engineering tool to assist medical education and training in teaching hospitals in Nigeria and can be applied in other countries. The development involves recycling of an old stethoscope which is a contribution to hospital waste management; a waste to wealth effort. Most users that participated in the field test of the Auscultation Simulator found the device functional, convenient, user friendly, and satisfactory.

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Conflicts of Interest

None.

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