Acoustical Design of Digital Stethoscope for Improved Performance

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Abstract: Stethoscopes are in use for more than 200 years for medical diagnostics, especially for auscultation in the healthcare domain. Recently, unprecedented growth in mobile technology has revived the use of stethoscopes for Telehealthcare. Digital or electronic stethoscopes are increasingly researched for use in Telehealthcare within the healthcare domain. Cardiovascular diseases have become highly prevalent worldwide, especially in the subcontinent. Improvements in diagnostics will improve the quality of life and prevent the loss of life. This research paper mainly focuses on the acoustical and multiphysics design aspects of the stethoscope for improved acoustical performance. A COMSOL model of the stethoscope chest piece was developed. The model was setup to investigate the effects of geometry, material of construction, noise and input pressure. The sound transmission efficiency of the components was investigated with multiphysics models by coupling the acoustical and structural performances. The effect of ambient noise on the performance was also studied and reported. This COMSOL model wasis further used to investigate the effects of shape, size and material parameters on the performance and improvement in the acoustic transmission and noise isolation. The frequency response of the system was also investigated for resonance and performance in relation to auscultation of cardio, lung and other sounds. Through this research paper the researchers share the initial findings for the development of acoustical and multiphysics design aspects of the stethoscope. The ultimate objective is to leverage the improvement in the acoustics of the stethoscope for use in Telehealthcare.

Keywords: Telehealthcare, Telemedicine, auscultation, stethoscope, acoustics, fluid structure interaction, noise level, cardiology, fluid structure interaction.

1. Introduction

Stethoscopes are used for auscultation of heart, lung and murmurs for over two centuries [1]. Recent developments in mobile healthcare or telemedicine for remote and rural areas revived the use of the stethoscope [2]. Numerical Investigations are targeted to improve the acoustic performance of digital stethoscopes by studying the contribution of the components and materials on performance. Conventional acoustic stethoscopes sound levels are extremely low and there are some shortcomings for use in telemedicine and telecardiology. Improvements in performance are targeted to increase the performance of the stethoscope and the diagnostic capability in telemedicine environment [3-5].

2. Telemedicine

There's a huge, unmet healthcare need in India. The challenge is to make healthcare affordable for the masses and attractive to the providers. Telemedicine is a good strategy to face this challenge. Access to healthcare in India is limited by the affordability factor and hence the remote diagnosis, monitoring and treatment of patients via videoconferencing or through the ICT infrastructure in a telehealth environment can be quite useful and effective. For example, the health centers can use remote diagnostic devices for measurement of basic parameters such as blood pressure, heart rate and pulse rate. The patients are then connected to doctors with medical facilities via computers in a video conferencing environment. Patients who require surgery, inpatient care or specialized procedures can be referred to the nearest healthcare clinic.

Though India is one of the early adopters of telemedicine in developing countries, it has the potential to develop innovations that can be adopted in other parts of the world. Driven by extreme need, India is inventing new ways to use information technology to improve healthcare. Innovations in telemedicine will accelerate in India due to shortage of healthcare professionals in rural and remote areas, very high patient volumes, widespread availability of mobile networks, rapid growth in the availability of low-power hand-held medical monitoring devices, and the shift away from local area network-based medical image archiving and communications systems to a networked tele-enabled system. Critical issues in telemedicine will be access and cost. In the early days, satellite technology was the only means of managing the telemedicine program and keeping satellite connectivity was expensive and not very easy to maintain. However, now with free videoconferencing software like Skype there are many options available. With the innovations in technology platforms, the growth potential of the use of digital innovations in the healthcare industry is lucrative.

Conventional devices converted to digital format can help to accelerate the telemedicine penetration in India, but their reliability and quality still need further scientific research.

3. Use of COMSOL Multiphysics

The acoustic wave propagation in the stethoscope is governed by the wave propagation equation. The pressure acoustics interface in frequency domain in COMSOL [4] was used for this investigation. Sound waves in a lossless medium are governed by the following inhomogeneous Helmholtz equation for the differential pressure *p in* (N/m^2),

$$\frac{1}{\rho_0 c_s^2}\frac{\partial^2 p}{\partial t^2} + \nabla \cdot \left(-\frac{1}{\rho_0}(\nabla p - \mathbf{q})\right) = Q$$

Where, ρ_0 in kg/m^{3,} refers to the density and c_s, m/s, is the speed of sound and Q, 1/s^2, is the source.

The sound wave propagation through the stethoscope components was modeled with the appropriate boundary conditions and material properties. The typical material properties used for the simulation are shown in Table 1.

4. Numerical Design of Experiments

The objective of the numerical design of experiments was to explore the acoustic wave propagation and the effects of various parameters on the performance. A parametric CAD model of the stethoscope was developed in COMSOL. A typical CAD model and FEA mesh is shown in Figure 1. The air column inside the stethoscope, Aluminum or stainless steel casing and the surrounding air were modeled as separate domains. The model was equipped to investigate the effects of geometry, construction material, and environment variables on the acoustic performance for optimization. The frequency response of the stethoscope from 10 to 2000 Hz was also investigated. The sound pressure input was modeled as an acoustic pressure input of 1 Pa around the diaphragm area. The external noise was modeled using the surface boundary conditions with pressure input of 0.06 Pa.

Table 1. Material properties used for the simulation.

Material	Density (kg/m2)	Speed of sound (m/s)
Aluminum	2700	6420
Brass	8480	390
Stainless Steel	7850	6100

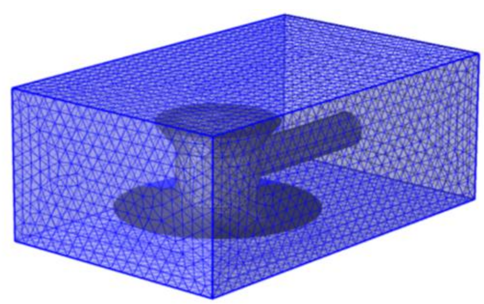

Figure 1. Typical CAD model and FEA mesh

5. Results and Discussion

The numerical experimental design results are discussed in this section. The sound pressure level results as a function of stethoscope construction material, effect of input pressure, interaction of noise level and input pressure, and effect of noise level are shown in Figures 2 to 6.

Figure 2 shows the propagation of sound waves in the air column inside the stethoscope for two different frequencies. Figure 3 shows the sound propagation performance of the stethoscope with the air column and casing at the low and high ends of the frequency spectrum. Figure 3b shows that at high frequencies the sound waves are propagated to the acoustic tube efficiently.

Figure 4 shows the frequency response of the aluminum stethoscope. The sound pressure level increases with increasing frequency. The acoustic amplification is highly pronounced at higher frequencies. Figure 4 shows the frequency response of the aluminum stethoscope. The sound pressure level increases with increasing frequency. The acoustic amplification is highly pronounced at higher frequencies.

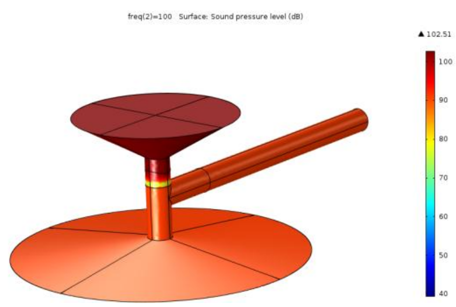

Figure 2a. Sound Pressure level of the air column inside the stethoscope at 100 Hz.

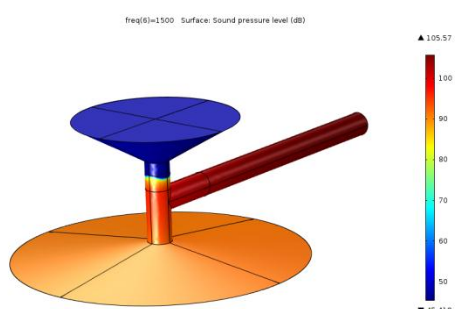

Figure 2b. Sound Pressure level of the air column inside the stethoscope at 1500 Hz.

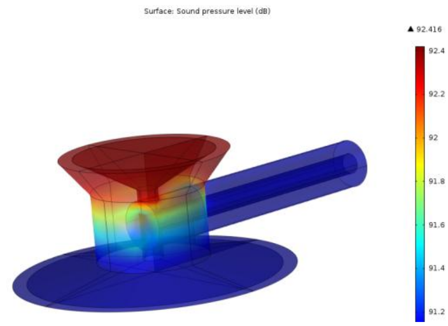

Figure 3a. Sound Pressure level of the aluminum stethoscope at 100 Hz.

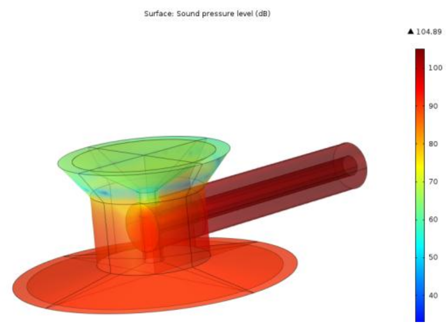

Figure 3b. Sound Pressure level of the aluminum stethoscope at 1500 Hz.

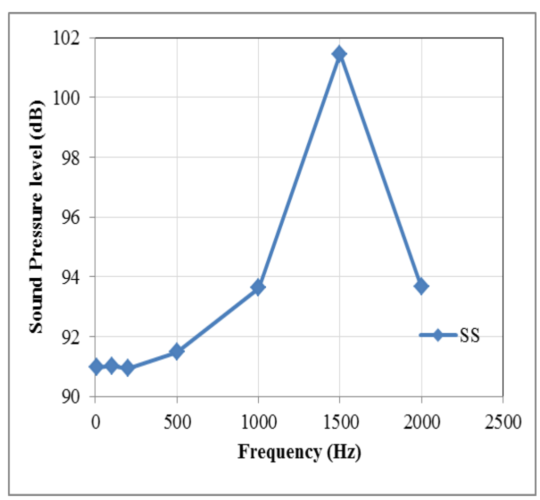

Figure 4 . Acoustics frequency response of the aluminum stethoscope

Figure 5a and 5b show the simulation results related to the coupled noise and pressure load performance as a function of the acoustic frequency response of the stainless steel stethoscope. Higher interaction of input pressure and noise level is observed at a higher frequency range.

Figure 6 shows the effect of the stethoscope casing material on noise performance. The external noise source was maintained at a constant level. The construction material of the stethoscope, aluminum (AL) and stainless steel (SS) is changed and the performance is shown. The figure also shows the sound pressure level at the acoustic tube. The overall noise transmitted by the stainless steel stethoscope is lower than that of the aluminum stethoscope. The simulation results were used as an input for the performance enhancement of the digital stethoscope for use in telemedicine; for example in tele-cardiology.

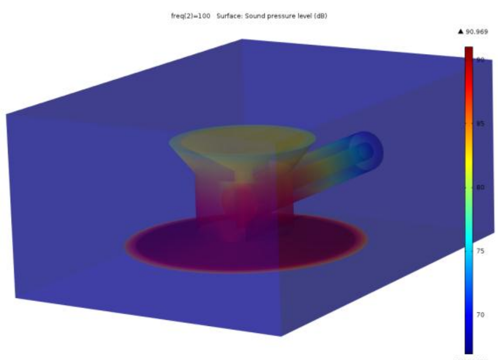

Figure 5a. Input pressure and noise interaction contour plots of stainless steel stethoscope at 100 Hz.

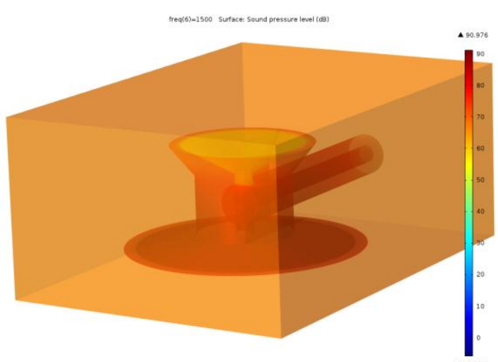

Figure 5b. Input pressure and noise interaction contour plots of stainless steel stethoscope at 1500 Hz.

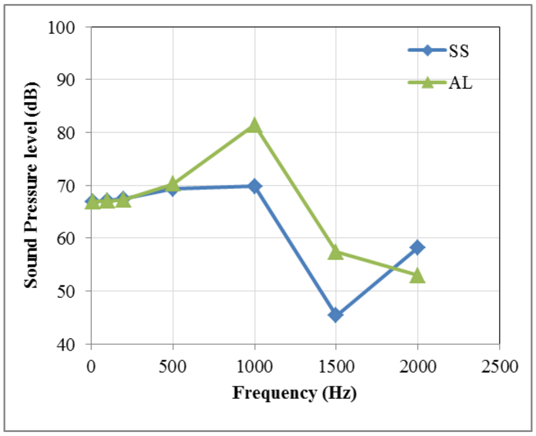

Figure 6 . Effect of stethoscope casing material on the noise performance as sound pressure level at the acoustic tube for stainless steel (SS) and aluminum (AL) Stethoscopes.

6. Conclusions

A brief introduction to the stethoscope and simulation need for performance improvement for use in telemedicine was presented in this research paper. A detailed overview of the telemedicine with a special reference to rural and remote health care implications was also discussed. The governing equations related to pressure acoustics and implementation in COMSOL was given. The numerical design of experiments and parameters of digital stethoscope such as material of construction, pressure input, noise level, frequency range details were given. The material properties and modeling methodology were detailed. The sound pressure level results were reported for the air column inside the stethoscope, specific to the material of construction. The results are given as a function of sound frequency. The contour plots are reported for the low and high ends of the frequency spectrum. The effect of pressure input on the performance was also reported. The noise and input pressure interaction effects were detailed. Lower noise level transmission was observed for the stainless steel stethoscope. The numerical design of experiments helped us to identify critical parameters for performance improvement of the stethoscope for use with telemedicine.

7. References

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