

STETHAID: AN ELECTRONIC STETHOSCOPE CONNECTED TO IOS MOBILE APPS FOR AI-ASSISTED AUSCULTATION

Youness Arjoune¹, Tyler Salvador¹, Trong N. Nguyen², Anha Telluri³, Titus John^{1,2}, Jonathan C. Schroder¹, Dinesh K. Pillai¹, Stephen J. Teach¹, Shilpa J. Patel¹, Robin W. Doroshov^{1,2}, Raj Shekhar^{1,2}

¹Children's National Hospital, Washington, District of Columbia, United States

²AusculTech Dx, Silver Spring, Maryland, United States

³George Washington University, Washington, District of Columbia, United States

ABSTRACT

Auscultation is a critical component of a cardiopulmonary examination; however, several studies have shown that many physicians lack proficiency in it. With the development of artificial intelligence (AI)-augmented auscultation tools, physicians could improve their auscultation skills and provide accurate diagnoses, even approaching the expertise of seasoned clinicians. Although a few AI auscultation platforms have been created, none have been adopted widely in clinical settings. Our goal is to develop a comprehensive digital auscultation platform, termed StethAid, to supplement the value of auscultation.

StethAid is a comprehensive auscultation platform that comprises of an electronic stethoscope, mobile applications, and website portals. The StethAid stethoscope enables streaming and recording of heart and lungs sounds. It features 100 levels of sound amplification, digital filtering, active noise cancellation, and wireless connectivity. The StethAid stethoscope is similar to FDA-approved stethoscopes in its frequency response. Our mobile apps deliver various auscultation tools, as well as an AI suite and remote auscultation capabilities. The AI suite includes deep learning-based automated wheeze detection from auscultated lungs sounds. StethAid has been rigorously validated technically and clinically. StethAid could assist physicians in making more informed decisions, potentially leading to improved patient outcomes.

Keywords: Electronic Stethoscope, Auscultation, 3D printing, Wheeze detection, Deep Learning

1. INTRODUCTION

The conventional acoustic stethoscope has been an essential one for the cardiopulmonary examination since its invention by René Laennec in the 19th century [1]. Despite widespread use,

physicians struggle because of the low intensity of auscultated sounds originating from this tool [2].

Acoustic stethoscopes have undergone several technological advances and refinements, yet these stethoscopes suffer from the tubular resonance effects and the subjective nature of the diagnosis made with them. To consistently reproduce the body sounds and amplify them for an improved listening experience, electronic stethoscopes emerged. Despite having limited adoption in the clinic, electronic stethoscopes provide a framework to build heart and lung sound libraries to teach students the art of auscultation. Notwithstanding these efforts, the mastery of auscultatory skills continues to be a challenge.

Many eminent cardiologists touted mastering auscultation skills despite advances in medical imaging such as hand-held ultrasound, and cited many examples in which auscultation was the superior, if not the only, solution [3]. In addition, there is a need to reduce unnecessary specialty overreferrals and overuse of echocardiography and medical X-ray imaging to optimize use of resources. Proficiency in auscultation can enable the primary practitioners to act as a “gatekeeper” and assist in achieving this goal.

Given that auscultation remains central in today's physical examination, Thompson called for what could be done to enhance the value of auscultation [4]. One of the answers was to augment auscultation using advanced signal processing and artificial intelligence capabilities to assist clinicians with interpretation of heart and lung sounds in real time, and therefore have a uniform level of proficiency.

The cardiopulmonary sound libraries, which have been built primarily for teaching purposes, are being used to develop artificial intelligence (AI)-assisted auscultation [5]. A few AI-assisted auscultation tools exist such as Eko Core, Felix, and

ThinkLabs One combined with eMurmur. However, these auscultation platforms are not ready to be adopted clinically but with more efforts to build large AI libraries, these are expected to improve.



FIGURE 1: STETHAID.

StethAid is a digital auscultation framework consisting of an electronic stethoscope, iOS mobile applications, custom cloud storage, and website portals (Figure 1). This unique stethoscope connects to the StethAid apps via Bluetooth. The StethAid device features digital filtering and allows for active noise cancellation. StethAid supports AI-assisted auscultation. The platform has been validated technically and clinically through several studies.

To validate the StethAid stethoscope, we used a technical characterization method [6] and compared its frequency response to those of 3M Littmann 3200, Eko Core, and Thinklabs One digital stethoscopes.

Furthermore, we deployed the StethAid platform in the Emergency Department at Children's National Hospital (CNH) for data collection. Trained research assistants collected lung sounds with ground truth labels given by physicians at the bedside using their acoustic stethoscopes. Through this use case, we aim to demonstrate that StethAid enables deep learning-assisted auscultation.

The rest of this paper is organized as follows. Section 2 describes the StethAid platform and its features as well as the methods used to characterize the StethAid stethoscope technically and clinically. Results and discussion are presented in Section 3. Section 4 summarizes the paper and concludes it.

2. MATERIALS AND METHODS

2.1 StethAid Functionalities and Capabilities

The StethAid stethoscope can be turned ON/OFF using the Power button. If the stethoscope is inactive, it goes to deep sleep mode. The two LEDs are used to indicate the state of the stethoscope such as ready to pair, paired, low battery, charging, fully charged, streaming, and recording. These states are also accessible through the StethAid mobile app. The StethAid stethoscope supports both wireless connectivity and wireless charging. The StethAid device supports 100 levels of sound amplification. StethAid features digital filtering (bell, diaphragm, and wideband), and active noise cancellation. Additionally, our platform enables remote auscultation.

2.3 3D Printing

The StethAid stethoscope enclosure was designed in SolidWorks and optimized for printing on the Stratasys J5 MediJet 3D printer (Stratasys, Eden Prairie, MN, USA). For assembly simplicity and durability, pockets were printed for the location of standard nuts. Utilizing the printer's ability to print multiple materials, clear slots were printed directly into the outer case to focus the PCB's LED indicators. For improved haptics of pressing the PCB's on-board buttons, conical compression springs were manually looped into printed holes. The dimensions of StethAid are 177 mm x 50 mm x 54 mm (Figure 2).

The time to 3D print the enclosure of a StethAid unit was about 6 hours. Utilizing the entire build tray and the automatic tray arrangement, we could print three StethAid units in about 14 hours. The cost of printing materials for a single unit was approximately \$75.

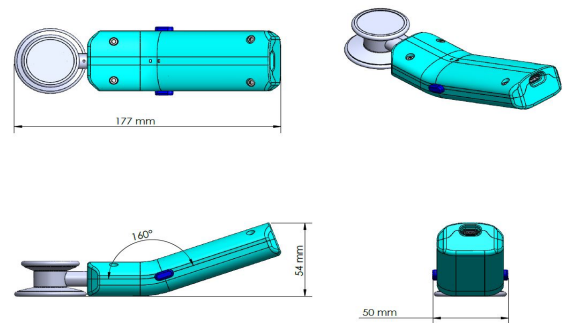


FIGURE 2: STETHAID STETHOSCOPE DIMENSIONS

2.4 StethAid iOS Apps and Website Portals

The StethAid stethoscope comes with different iOS apps which can be used to auscultate the heart, lungs, heart, and voice recordings at different chest locations (Figure 3). These apps pair to StethAid stethoscope via Bluetooth. These apps could be used either to stream heart and lung sounds in real time or to record the sounds from the most common chest locations. The apps are designed to provide labels such as the diagnosis, the respiratory rate, and the voice activity. The recordings are stored locally in the patient library. The patient recordings and their meta data are pushed to cloud storage if the smartphone is connected to Wi-Fi. StethAid apps features the AI Suite which are a set of deep-learning algorithms that are trained for heart and lungs sound classification. These algorithms run on a recording in real time. The apps feature Telehealth for remote auscultation.



FIGURE 3: STETHAID MOBILE APP

2.5 StethAid Technical Characterization

To measure the frequency response of the StethAid electronic stethoscope, we used a methodology that consists of playing white noise through a speaker and recording the waveform audio file “WAV”, from which the frequency response is derived. We used Audacity to generate and play white noise directly into the stethoscope. To hold the stethoscope head against the loudspeaker, we designed a rig (Figure 4). The StethAid stethoscope is mounted on this rig and closed. This allows for more consistent unit characterization in terms of the pressure applied to the diaphragm of the stethoscope. For comparison purposes, we also characterized Littmann 3200, Eko Core and ThinkLabs One stethoscopes. The complete methodology has been described in [6].

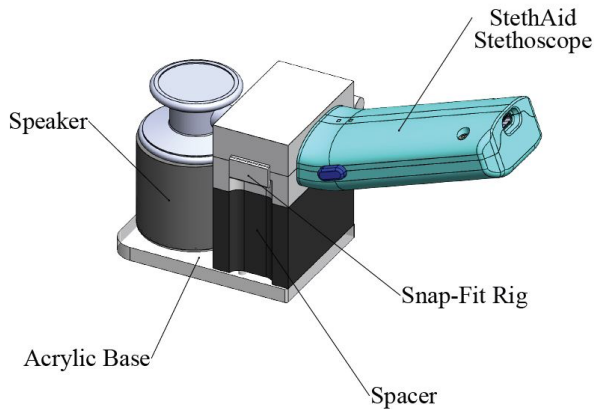


FIGURE 4: STETHAID STETHOSCOPE RIG

2.6 StethAid Clinical Validation

To validate our digital auscultation platform, we deployed StethAid at CNH, where we have been collecting lungs sound and voice recordings from children, age 2 to 18, presenting to the Pediatric Emergency Department. The recordings were of 15 seconds and originated from up to 11 chess and back locations. At the time of the recording, the clinicians at the bedside with their acoustic stethoscopes provided the ground truth for the lungs recording (wheeze or clear lungs sound). Spectrograms were extracted from the lung recordings using Librosa Python library. The dataset has been used to train and test two deep learning models using an 80:20 split. These two models have been implemented using the machine learning framework PyTorch installed on a Lambda workstation (Lambda, Inc. San Francisco, CA, USA) with four GPUs. The performance of these two models have been evaluated using the sensitivity, specificity, and accuracy.

3. RESULTS AND DISCUSSION

Figure 5 depicts the StethAid stethoscope frequency response versus that of Eko Core, ThinkLabs One, and Littmann 3200. The frequency response of the StethAid stethoscope is around 0 dB for frequencies below 1000 Hz and drops to about -

60 dB for frequencies above 1000 Hz. The StethAid frequency response rivals that of Eko Core's, except it is slightly higher than below 200 Hz. The Littmann 3200 stethoscope response experiences a continuous drop to reach -70 dB for frequencies higher than 1000 Hz. The ThinkLabs One frequency response starts at 0 dB and continuously rises to reach 25 dB before it starts to drop to reach 0 dB at 1000 Hz. All in all, the StethAid frequency response is close to the frequency response of the FDA approved stethoscopes.

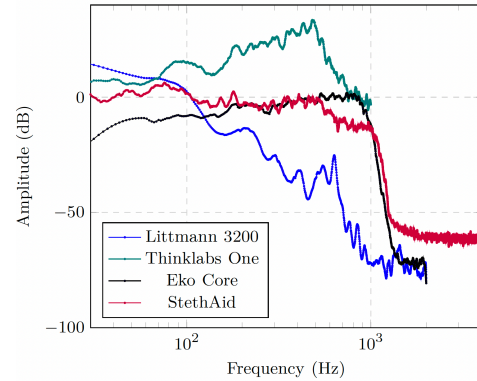


FIGURE 5: STETHAID STETHOSCOPE FREQUENCY RESPONSE VS. THOSE OF LITTMANN 3200, THINKLABS ONE, AND EKO CORE

Examples of wheeze detection preliminary results are shown in Table I. ResNet18 indicated a sensitivity of 77%, a specificity of 70%, and an accuracy of 74%, whereas the Harmonic networks model achieved a sensitivity of 78%, a specificity of 86%, and an accuracy of 84%. Harmonic networks outperformed ResNet18 in terms of both the sensitivity and the specificity. One possible reason is that the Harmonic network model is specifically designed for audio signal processing tasks, whereas ResNet18 is a general-purpose image classification model. The Harmonic networks model uses a harmonic convolutional layer, which is designed to capture the harmonic structure of audio signals and can therefore be better suited for detecting wheeze sounds, which are characterized by a specific frequency pattern.

TABLE I: PERFORMANCE OF DEEP LEARNING BASED WHEEZE DETECTION

	<i>Sensitivity</i>	<i>Specificity</i>	<i>Accuracy</i>
ResNet18	77%	70%	74%
Harmonic networks	78%	86%	84%

The performance of deep learning models often improves with more training examples. The sensitivity and the specificity of our deep learning-based wheeze detection have the potential to improve as the dataset expands. Our dataset includes also respiratory rate and some other clinical symptoms, which could be used for improving the performance of our models.

4. CONCLUSION

We presented a digital auscultation platform that consists of an electronic stethoscope, iOS mobile applications, and custom website portals interacting with a cloud storage for centralized data collection. The platform has been validated technically and clinically. We showed that the StethAid stethoscope has a frequency response that tracks Eko Core's response closely. Our deep learning models exhibited a high sensitivity and specificity in wheeze detection, which was one of the applications that used StethAid. We continue to advance the capabilities of the StethAid electronic stethoscope through further innovations in artificial intelligence and signal processing. By doing so, we could potentially improve the accuracy and efficacy of auscultation, ultimately improving patient outcomes and contributing to the progress of medical research and practice.

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DISCLOSURE STATEMENT

Robin W. Doroshow and Raj Shekhar are founders of AusculTech Dx.

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