The Effect of Recording Methods on the Frequency Response of Breathing Sounds Measured with an Electronic Stethoscope

Andrew Spiewak, Brittany Alphonse, Erik Walder, Gary Comtois, Eugene Chabot, PhD, and Ying Sun, PhD
Department of Electrical, Computer, and Biomedical Engineering
University of Rhode Island, Kingston, RI 02881-0805 USA
andrew_spiewak@my.uri.edu, balphonse@my.uri.edu, erik_walder@my.uri.edu, comtoisg@gmail.com, eugenechabot@gmail.com, sun@ele.uri.edu

***Abstract*— The stethoscope has been used for almost two centuries mainly for listening to the lung and heart sounds. This study was conducted to characterize the frequency contents of the breathing sounds recorded with an electronic stethoscope under different conditions. These conditions included different levels of pressure applied to the probe and the use of a double-sided adhesive tape for interfacing. The goal of this study was to quantify the differences in frequency response and assess the attenuation of high and low frequencies caused by the probe-skin interface during testing. Various pressures were applied and quantified using a pressure-sensing handle developed in conjunction with this study. The signal was analyzed by using the Fast Fourier Transform (FFT) implemented in MATLAB. The data showed significant differences in frequency response with varying recording methods. The result of this study is useful for controlling the recording method when the acoustic signal from the stethoscope is used in a quantitative way.**

Keywords- stethoscope; frequency response; probe-skin interface; applied pressure

I. INTRODUCTION

The long-term objective of this project is concerned with the potential use of breathing sounds for detecting obstructive sleep apnea (OSA). OSA is caused by the collapse of the tongue and soft palate onto the posterior pharyngeal wall, which obstructs the airway intermittently during sleep [1]. It is estimated that about 20% of the adults in the United States have OSA, of which only about 10% have been formally diagnosed [2]. Pasterkamp et al. [3] measured the tracheal sound intensity (TSI) related to flow resistance in the trachea. Their analysis of the data involved determining an average power spectrum of tracheal sounds within low (0.2 to 1 KHz), medium (1 to 2 KHz), and high (2 to 3 KHz) frequency bands for each subject. Their study found that at the same inspiratory flow, the increase in tracheal sound intensity from upright to supine position was greater in OSA patients than in control subjects. The frequency response of such acoustic measurement system could be greatly affected by the probe-skin interface, which has not yet been systematically studied. Therefore, the present study was focused on the probe-skin interface for measuring the breathing sound with an electronic stethoscope. Specifically, we characterized the frequency spectra of breathing sounds recorded under different conditions, which included different levels of applied pressure and the use of a double-sided adhesive tape.

II. METHODOLOGY

A. Instrumentation

As shown in Fig. 1, an electronic stethoscope (Jabes Life Sound System) was used to measure the breathing sound. The stethoscope probe was positioned at the suprasternal notch around the cricoid cartilage. The analog signal from the electronic stethoscope was digitized and recorded via a digital recorder (Zoom H4N). The data were stored as WAV files and uploaded offline to a PC for further analysis.

The primary interest of this study was the probe-skin interface. With a customized pressure sensor system, the pressure applied to the stethoscope probe was measured. Since a pressure sensor placed directly at the interface would block the sound propagation through the interface, the pressure sensor was placed behind the probe. A handle with an embedded pressure sensor was built and used to quantify the applied pressure. The sensor measured the pressure applied by the hand to the stethoscope probe. Development of the pressure sensor system is reported in a different paper in this conference [4].

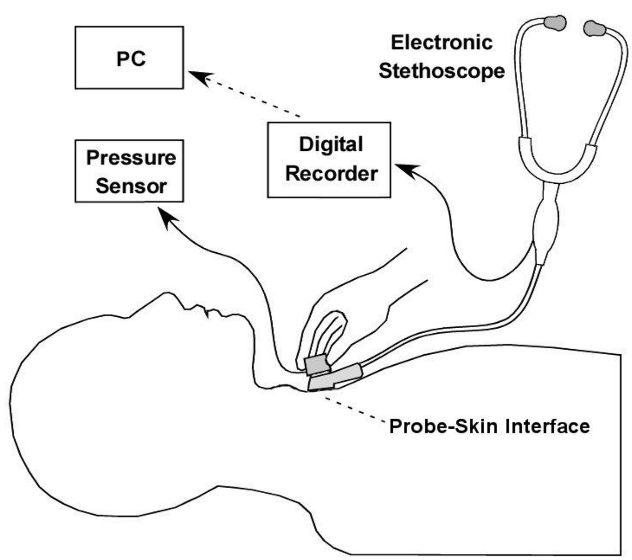

Figure 1. Schematic diagram showing the instrumentation system. Breathing sounds were recorded by use of an electronic stethoscope with a customized probe handle for measuring the applied pressure.

B. Human Study

A prior IRB approval was secured to conduct experiments with a total of 30 human subjects. Four interfacing conditions between the subject and the stethoscope were tested. These interfacing conditions were three different applied pressures (high, medium, and low) and the use of a double-sided adhesive tape. The pressure-sensing handle was used to position stethoscope probe on the subject. The levels of high, medium and low pressures were consistent among the different human subjects. The circular, double-sided tape between the probe and the skin ensured a hands-free constant contact. Additional medical tape crossing over the probe was applied to secure the probe in place. Thus, four conditions were tested; no tape-low, no tape-medium, no tape-high, and with tape-no pressure. Participants laid in the supine position. The stethoscope was set to the "wide" mode to incorporate both the low and high frequencies for the heart and lung sounds, respectively. Participants were randomly recorded for 20 out of a 40 second time period without knowledge of the start and stop. This was to prevent any abnormal breaths due to the patient's nerves with the commencement of the recording.

C. Data Analysis

A MATLAB program was designed to take the Fast Fourier Transform (FFT) of each recording. The original WAV file was sampled at 44.1 KHz. These data were down sampled by a factor of 8, resulting in a sampling rate of 5,512.5 Hz. The frequency spectrum for each 20-s data segment was obtained by averaging 1024-point FFT's using a non-overlapping, moving window. The magnitude of the averaged spectrum was plotted for each recording. The program compared all four trials simultaneously during analysis. Another MATLAB program was developed to find the power of each signal. This value was calculated by summing the squared magnitude of each point along the frequency spectrum, which represented the overall strength of each signal.

III. Results

Initial testing showed a notable difference in the frequency response between the varying recording conditions. Fig. 2 shows the FFT analysis of one test subject under the four testing conditions; no tape-high, no tape-medium, no tape-low, and with tape-no pressure. The top left graph shows the high pressure condition where both high and low frequencies were present. There was slight cut off of the high frequencies as well as more noise in the signal than the other non-tape pressure conditions. Unusual spikes in the magnitude of the high frequencies were observed. In the medium pressure condition, shown in the bottom left graph, all of the frequencies were present but some of the higher frequencies had a slightly reduced bandwidth. The top right graph shows the low pressure condition where only the low frequencies were present while significantly reducing the signal bandwidth and lowering the magnitude. With the double-sided tape, in the

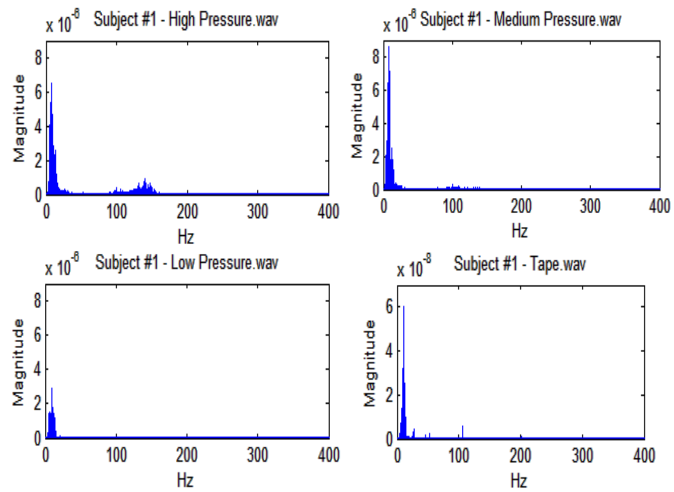

Figure 2. Subject #1 Frequency Response: (Top Right) no tape -high, (Top Left) no tape-medium, (Bottom Right) no tape-low, and (Bottom Left) with tape-no pressure.

bottom right graph, the magnitude of all frequencies were significantly attenuated by at least 3 orders of magnitude.

IV. Discussion

The stethoscope is a ubiquitous diagnostic instrument, but mainly used for qualitative purposes. For quantitative purposes, this study showed that the probe-skin interface could play an important role. The preliminary result indicated that with low applied pressure or with the tape, high-frequency components were significantly suppressed. A medium pressure without the tape allowed for effective transfer of acoustic energy and a broad range of frequencies. For future work, the human study will be completed to provide a more conclusive assessment of the variabilities in a statistical sense. The effect of the recording methods on the frequency response of the stethoscope should be important for quantitative applications such as acoustics-based diagnostics of obstructive sleep apnea.

Acknowledgment

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