Automatic Identification of Wheezing in Auscultated Lung Sounds

S. Kang[1], Y. Karpate[1], S. Almulla[2], S. Teach[3], and R. Shekhar[1]
[1]Sheikh Zayed Institute for Pediatric Surgical Innovation, Children's National Health System
[2]Electronic and Electrical Engineering, Khalifa University of Science, Technology and Research
[3]Department of Pediatrics, Children's National Health System
skang@cnmc.org, ykarpate@cnmc.org, 100038683@kustar.ac.ae, steach@cnmc.org, rshekhar@cnmc.org

Asthma is a chronic lung disease, occurring in about 10% of children and 8% of adults [1]. It inflames and tightens the airways, and causes wheezing, coughing, breathlessness, and chest tightness. Without proper management, asthma can result in frequent emergency department (ED) visits, hospitalizations, and premature deaths. In 2010, almost 1.8 million patients visited an ED for asthma-related care and 439,000 people were hospitalized in the United States [2]. The high number of ED visits and hospitalizations underscores that asthma management remains a problem.

A technology that could help asthma patients and families detect early signs of an impending asthma attack and thus control it could have a far-reaching impact. To this end, we have developed and tested a novel algorithm to identify wheezing in lung sounds. When combined with a mobile stethoscope, a stethoscope connected to a smartphone (see Fig. 1), to record lung sounds, this algorithm has the potential to offer a low-cost, easy-to-use mobile technology for home-based self-management of asthma and thereby minimizing the current rates of ED visits and hospitalizations.

Figure 1. The stethoscope accessory with the recording application.

Wheezing is described as a musical sound because of its unique auditory characteristics. Wheezing has one or more high-pitched sinusoidal components, with duration greater than 100 ms [3]. Taking advantage of the unique temporal and spectral pattern of wheezing, we have developed a signal processing algorithm to identify wheezing with high accuracy. The algorithm extracts three features from each breath cycle using short-time Fourier transform (STFT). Adaptive thresholding is applied to detect dominant sounds. Based on the signal length and the intensity of all connected signals in the spectrogram, we select one dominant sound and extract the mean intensity, signal duration, and mean of the peak frequency (Fig. 2). We modified the segmentation method of Taplidou et al. [4] to segment the dominant sound. Using three features, we apply support vector machine to identify wheezing. The data used in this study comprised of 27 breath cycles with wheezing and 94 normal or other abnormal breath cycles without any sign of wheezing. Using the leave-one-out cross-validation approach, we obtained 85.2% sensitivity and 95.7% specificity (Fig. 3).

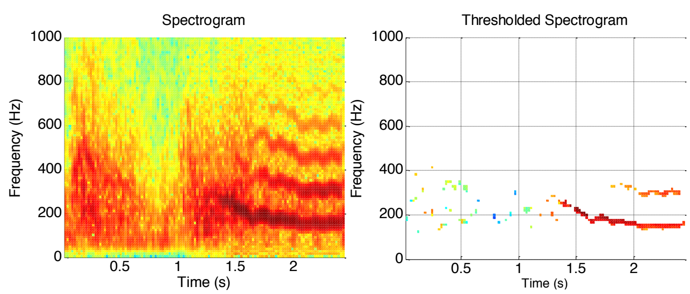


Figure 2. (left) Spectrogram of wheezing (right) Spectrogram with adaptive thresholding.

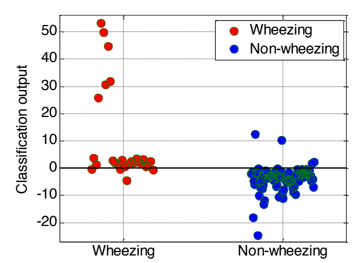


Figure 3. The classification performed by the current signal processing algorithm.

Our results, limited data set notwithstanding, show the potential of our solution in identifying wheezing from all other lung sounds with high accuracy. Our solution could help non-experts detect and control asthmatic episodes before symptoms deteriorate considerably. Our future efforts will include algorithmic enhancements and training and testing of the improved algorithm on a much larger set of lung sound recordings with definitive clinical diagnoses.

References

[1] "Asthma Statistics | AAAAI." [Online]. Available: http://www.aaaai.org/about-aaaai/newsroom/asthma-statistics.

[2] "CDC - Asthma - Data and Surveillance - Asthma Surveillance Data." [Online]. Available: http://www.cdc.gov/asthma/asthmadata.htm.

[3] R. Palaniappan, K. Sundaraj, N. U. Ahamed, A. Arjunan, and S. Sundaraj, "Computer-based Respiratory Sound Analysis: A Systematic Review," *IETE Tech. Rev.*, Sep. 2014.

[4] Taplidou, Styliani A., and Leontios J. Hadjileontiadis. "Wheeze detection based on time-frequency analysis of breath sounds." Computers in biology and medicine 37.8 (2007): 1073-1083.

AUTOMATIC IDENTIFICATION OF WHEEZING IN AUSCULTATED LUNG SOUNDS

Sukryool Kang, Yogesh Karpate, Salim Almulla, Stephen Teach, and Raj Shekhar
Sheikh Zayed Institute for Pediatric Surgical Innovation, Children's National Health System

Background

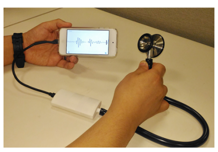
- Asthma is a chronic lung disease, occurring in about 10% of children and 8% of adults [1].
- It inflames and tightens the airways, and causes wheezing, coughing, breathlessness, and chest tightness.
- Without proper management, asthma can result in frequent emergency department (ED) visits, hospitalizations, and premature deaths.
- In 2010, almost 1.8 million patients visited an ED for asthma-related care and 439,000 people were hospitalized in the US [2].
- The high number of ED visits reflects that there still exists a problem in asthma management.

Objective

- To develop a low-cost, easy-to-use mobile technology for self-management of asthma by automated identification of wheezing.
- The technology may help asthma patients and families detect early signs of an impending asthma attack.
- The technology may minimize the current rates of ED visits and hospitalizations.

Methods – Hardware

- We have developed an Apple iPhone-based digital stethoscope.
- The stethoscope consists of an iPhone accessory, one end of which has a standard stethoscope head to listen to heart sounds and the other end plugs into the lightning port of an iPhone.
- The accessory converts analog sound to a digital signal after pre-amplification.
- The use of digital (lighting) port to receive audio signal bypasses built-in sound conditioning variable from one model of smartphone to another.



The StethAid mobile medical app with our low-cost, iPhone-based digital stethoscope attachment.

Methods – Software

- Wheezing is a high-pitched, musical, adventitious lung sound and it has unique auditory characteristics.
  - One of more high-pitched sinusoidal components
  - Frequency: musical, pure tone (narrow spectral width)
  - Duration > 100 ms

Algorithm Framework

1. Preprocessing

Band-pass filtering in the 50-2000 Hz range, the frequency range of most lung sounds, followed by intensity normalization.

2. Time frequency (TF) representation

Short-time Fourier transform (STFT) with 40-ms time window and 50% overlap.

3. Thresholding

At each time instance, an averaging filter with a length = 10 (approx. 100 Hz) is applied to smooth the signal. The smoothed signal is then subtracted from the TF signal and the difference is thresholded (threshold = 0) to identify dominant peaks.

4. Adaptive thresholding in different frequency bands

Frequency axis is segmented into four frequency bands: 100-300 Hz, 300-500 Hz, 500-800 Hz, 800-1000 Hz. For each band and for each time point, a threshold value is defined as:

$$\text{Threshold} = \text{mean} + w \cdot \text{STD}$$

where w = 0.3, 0.3, 0.2, and 0.2 for the four frequency bands, going from the lowest frequency band to the highest.

5. Peak selection and sound grouping

(1) Identify dominant signal peaks (local maxima) along Y axis, if present
(2) Group dominant signal peaks along time points (X axis) to identify sounds that last longer than a preset duration

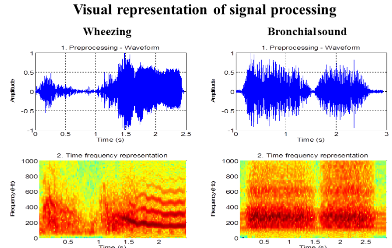
6. Feature extraction

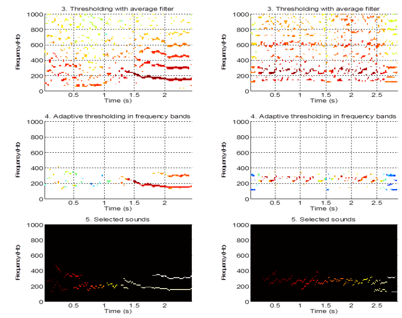
- Dominant sound features: (1) time duration, (2) mean frequency, (3) mean intensity, (4) mean spectral width, (5) standard deviation of spectral width with threshold (20% of the peak intensity)
- Other (non-Dominant) sound features: (6) standard deviation of mean frequencies, (7) standard deviation of mean intensities, (8) mean of mean intensities
- Other feature: (9) Number of sounds

7. Classification using support vector machine

We modified the sound segmentation method of Taplidou et al., 2007 [3].

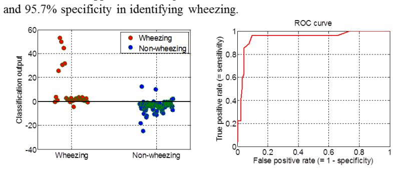
Visual representation of signal processing





Results

We trained our classifier using 121 breathing cycles of lung sounds (27 cycles with wheezing and 94 of cycles with no wheezing. Using the leave-one-out cross-validation approach, the algorithm was found to have 85.2% sensitivity and 95.7% specificity in identifying wheezing.



Classification results and ROC curve

Discussion

Our results, limited data notwithstanding, show the potential of our solution in identifying wheezing from all other lung sounds with high accuracy. Our solution could help non-experts detect and control asthmatic episodes before symptoms deteriorate considerably. Our future efforts will include algorithmic enhancements and training and testing of the new algorithm on a much larger set of lung sound recordings with definitive clinical diagnoses.

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[2] "CDC - Asthma - Data and Surveillance - Asthma Surveillance Data." [Online]. Available: http://www.cdc.gov/asthma/asthmadata.htm.
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