Wavelet Analysis and Morphology for the Detection of Wheeze in Cough Sounds

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Abstract **Wheeze detection by physicians is of practical importance in the diagnosis and management of a number of lung diseases. To optimize the utility of lung sound assessment, accurate characterization of the wheeze is essential. The goal of this study was to develop objective computer aided analysis that detected temporal location and frequency of wheeze in cough sounds through wavelet analysis and mathematical morphology.**

Keywords: Wheeze, Wavelet Analysis, Mathematical Morphology, Image Processing

1. Introduction

Wheezes are continuous lung sounds, which are superimposed on normal respiratory sounds. Wheeze is clinically defined as a musical sound that can be characterized by location, intensity, pitch, and duration in the respiratory cycle. Wheezing is thought to be due to the fluttering of the airway walls and fluid, which is induced by a critical airflow velocity. The pitch of the wheeze is dependent on mass and elasticity of airway walls and the flow velocity. The 10^{th} International Conference on Lung Sounds and the American Thoracic Society define wheeze as high-pitched continuous sound with a dominant frequency greater than 400 Hz [1].

Wheezing is heard in many types of disease. For example, wheezing can be a clinical sign of chronic obstructive pulmonary disease or an asthma episode.

Attempts have been made to characterize wheezing by performing analysis in the frequency and time domains. Computer aided signal processing and analysis is used to provide more objective information on wheeze characteristics. Researchers have studied the automated detection and characterization of wheezes based on spectral representation. Baughman et al. [2,3] analyzed breath sounds recorded over the chest using Fast Fourier Transform (FFT) techniques and identified the wheezes as sharp peaks in the power spectrum with amplitudes three times the average signal and between 150-1000 Hz. Duration of the wheezes was also recorded. Pasterkamp et al. [4,5] automated the spectral characterization of wheezing by analyzing the power spectrum of sounds recorded over the trachea and lung. The peaks were found to have frequencies between 110-1200 Hz with amplitudes fifteen times the average signal. Pasterkamp et al. [6] also compared automated wheeze analysis and clinician assessment, and found the techniques to give similar results. Schreur et al. [7] automated the analysis of wheezes recorded over the chest using FFT techniques to find the power spectrum. The peaks had frequencies greater than 150 Hz with amplitudes three times the average signal. Beck et al. [8] also used FFT techniques to find the power spectrum of forced expiratory wheezes.

Other researchers [9-13] have used one-dimensional wavelet analysis for the characterization of respiratory sounds including wheeze, by analyzing recorded time signal. For the work presented in this paper, a two-dimensional wavelet transform, along with mathematical morphology, was used to analyze the two-dimensional image of the spectrogram for wheeze characteristics found within the recorded cough sound.

2. Methods

Participation was requested from patients who were awaiting testing at the West Virginia University Hospital pulmonary function laboratory. The protocol was reviewed and approved by the local institutional review board, and each volunteer gave written informed consent. The subject was then asked to 1) inhale to total lung capacity, 2) relax and exhale, 3) inhale again to total lung capacity, 4) form a seal with teeth and lips around a mouthpiece connected to a metal tube, and 5) cough. A Bruel & Kjaer Model 4136 ¼ inch microphone was positioned with its diaphragm tangent to the inner surface of the metal tube. A flexible 13-ft hose with 1-inch inner diameter was connected to the metal tube just past the microphone and at the end opposing the mouthpiece.

The microphone signal generated during a cough sample was digitized at 12.8 kHz and recorded using a Bruel & Kjaer Model 2033 sound analyzer. The signal was transferred to the computer for analysis.

3. Technical Approach

When a cough sound pressure wave was recorded in the time domain, it was difficult to analyze anything by visual inspection as seen in Fig.1. To facilitate the assessment, a spectrogram of the pressure wave from one test subject was computed to give an estimate of the short-term, time-localized frequency content of the signal as shown in Fig. 2. In this example of the spectrogram of the cough sound pressure wave has frequency on the vertical axis, time on the horizontal axis, and amplitude, or intensity of the individual joint time-frequency components shown in terms of a color scale. Wheezes, consisting of stable or slowly changing tones, appeared in the spectrogram as narrow bands of high intensity. In Fig. 2 the wheezes start at roughly 0.1 sec and last until 0.4 sec, with frequencies approximately between 600 to 3500 Hz.

In order to identify the presence of wheeze in the spectrogram, an image of the spectrogram was transformed into the wavelet domain using a discrete wavelet transform. This wavelet transform was used to build an approximation of the two dimensional signal by using a wavelet basis function.

The basis function allows the signal, f(t), to be broken into shifted and scaled versions of the mother wavelet, Ψ, by applying a wavelet transform to the signal:

$$C(\text{scale}, \text{position}) = \int_{-\infty}^{+\infty} f(t)\, \Psi(\text{scale}, \text{position}, t)\, dt \qquad (1)$$

A threshold was applied to the wavelet coefficients, C, to emphasize the high intensity information in the spectrogram image and remove the low intensity information in the spectrogram image. The coefficients were then reconstructed back into the original domain as seen in Fig. 3.

The resultant image contained some discontinuities and noise that was removed with mathematical morphology. Mathematical morphology is a robust post-processing tool used in image processing to extract components that are useful in the representation and description of a region shape. It is based on set theory, where the state of any given pixel in the output image is determined by applying a defined operation to the neighborhood of the corresponding pixel in the input image [14].

In this analysis, the operations of dilation and thinning were performed on the resultant image of the spectrogram.

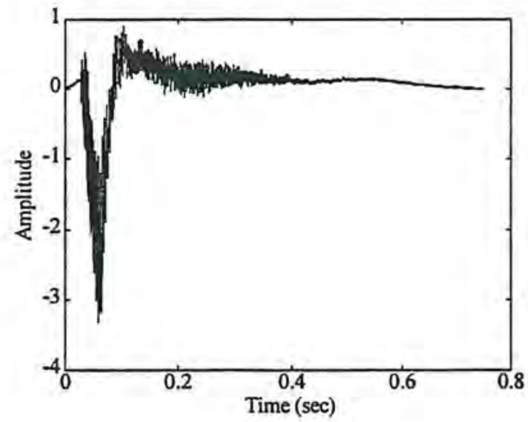

Figure 1: Cough Sound Pressure Wave

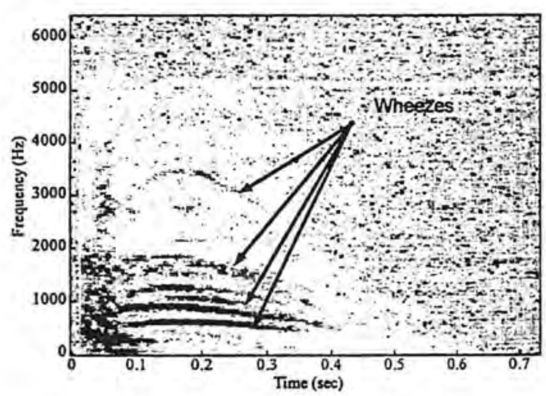

Figure 2: Spectrogram of Cough Sound Pressure Wave

Figure 3: Reconstructed Wavelet Coefficients

Dilation

The operation of dilation adds pixels to the boundary of an object using a specified neighborhood called a structuring element and is defined below.

With A and B as sets in two-dimensional integer space Z^2 and with $\varnothing$ representing the empty set, the dilation of B by A, is denoted by

$$B \oplus A = \{x \mid (\hat{A})_x \cap B \neq \varnothing\} \qquad (2)$$

Thinning

The operation of thinning removes pixels from an object using a specified structuring element and is defined below.

The thinning of a set B by a structuring element A is denoted by

$$B \otimes A = B - (B \circledast A) \qquad (3)$$

The results of the mathematical morphology can be seen in Fig. 4.

Figure 4: Results after Mathematical Morphology

4. Results

The spectrogram of the recorded cough sample for a test subject appears in Fig. 2. After analysis, the results were superimposed on the spectrogram to produce Fig. 5. This can be done because of the direct correspondence between data obtained from the analysis and the pixel locations in the source spectrogram. The wheezes were found to start 70 milliseconds into the cough sample and end at 420 milliseconds seconds with duration of 350 milliseconds. The frequency of the wheezes was found to be between 400 Hz and 4000 Hz. Fig. 6 shows an example of a recorded cough from a different test subject. The results after analysis were superimposed on the spectrogram to produce Fig. 7. In this example, the wheezes were found to start 50 milliseconds into the cough sample and end at 670 milliseconds with duration of 620 milliseconds. The frequency of the wheezes was found to be between 500 Hz and 1750 Hz.

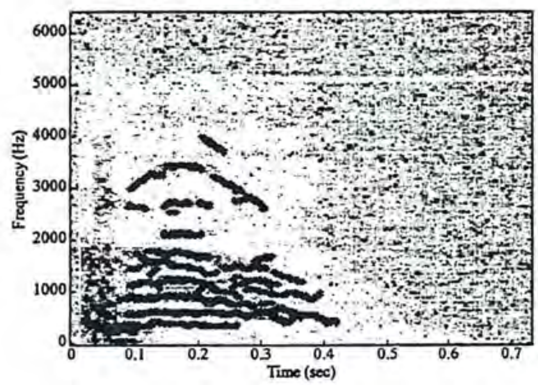

Figure 5: Results Superimposed onto Spectrogram of Cough Sound Pressure Wave

5. Conclusions

The results indicate that automated wheeze characterization by wavelet analysis and morphological image processing shows promise in improving the accuracy of wheeze characterization, and thereby assisting the clinician in the objective diagnosis and management of lung disease. To better characterize the utility of this approach, future studies should include the recording of cough sounds from patients with diverse lung disorders of varying degrees of severity, and also the evaluation different wavelet transforms.

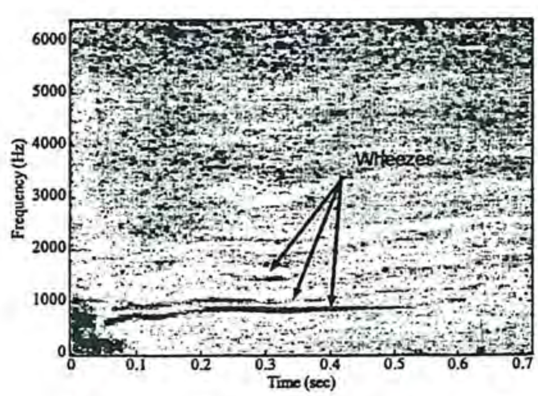

Figure 6: Spectrogram of Cough Sound Pressure Wave

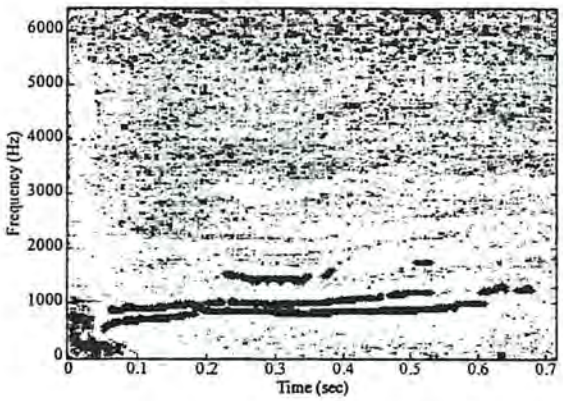

Figure 7: Results Superimposed onto Spectrogram of Cough Sound Pressure Wave

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IEEE EMB

Proceedings of the 3rd International Workshop on Biosignal Interpretation

Edited by

B. He, K. Yana, M. Akay and S. Cerutti

June 12 – 14, 1999

Chicago, USA