

Enhancement of Recorded Respiratory Sound Using Signal Processing Techniques

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INTRODUCTION

Pulmonary auscultation has been the key method to detect and evaluate respiratory dysfunctions for many years. However, auscultation with a stethoscope is a subjective process that depends on the individual's own hearing, experience, and ability to differentiate between different sounds (Sovijarvi et al, 2000). Therefore, the computerized method for recording and analysis of pulmonary auscultative signals, being an objective way, are recently playing a more and more important role in the evaluation of patients with pulmonary diseases.

Noise interference is one of the most influential factors when dealing with respiratory sound recordings. By definition of (Rossi et al, 2000), any sound not directly induced by breathing is regarded as background noise (BN). BN is divided into two types: environmental noise, which consists of continuous noise and transient noise, and nonrespiratory sounds and body sounds (muscle contraction sounds, skin friction, and heart sounds). The adaptive filtering is usually used to reduce the background noise. However, the problem of existing proposed filtering methods are either not able to minimize the interference or provides distortion which is especially undesirable for biomedical signals (Donoho, 1992).

Furthermore, segmentation of the respiratory sound into its inspiration and expiration phases is also necessary in quantifying adventitious sounds in the analysis stage. Spirometer has always been used together with sound recording devices to provide the forced expiratory volume (FEV) readings (Taplidou et al, 2007) (Cortés et al, 2005) for segmentation purpose. But it could be difficult to carry out a spirometric test for wheeze patients with high obstruction in tracheal (Cortés et al, 2005). Not much work has been done on respiratory sound segmentation using sound signal alone. Most developed

approaches are in automatic speech segmentation, and they are based on the hidden Markov model.

In this article, we introduce a newly developed respiratory sound signal enhancement system. It consists of the implementation of the proposed signal preprocessing and enhancement scheme to produce clean respiratory sound waveforms without attenuating any useful signals. Heartbeat, as the major body sound, is first removed using notch filter. Next, by applying nonlinear energy operator (NEO), the system is able to detect and remove spikes which reflect the transient environmental noises. The wavelet denoising subscheme then suppresses the continuous environmental noise to minimum level without distortion. Last, we introduce a new segmentation algorithm to segment the signal into its inspiration and expiration phases for future analysis purposes without incorporating the FEV readings from spirometer. A graphical user interface (GUI) is provided by the system for clinicians to monitor the process of respiratory sounds recording, enhancement, and segmentation. By processing the raw recorded respiratory signals using the preprocessing system, the output signals carry only useful information and are ready for analysis.

MATERIAL AND METHODS

Test Dataset

Tracheal breath sounds signals from 10 healthy students of Nanyang Technological University are used as the dataset of the present study. The sample size of 10 consists of 6 females and 4 males, each producing two clips of 20-second recordings. All clips have been verified to be normal tracheal breath by Dr. Daniel Goh from National University Hospital of Singapore. At the same time, one standard preprocessed normal tracheal

breath signal and two preprocessed wheeze signals from (Lehrer, 2002)(Tilkian et al, 2001)(Wilkins et al, 2004) are used together with the recorded data to test the automatic segmentation method.

Acquisition of Respiratory Sounds

The recording environment and equipments are chosen based on the standard given by (Rossi et al, 2000). Short-term recordings are done in sitting position in audio laboratory which provides a quiet environment. One electret condenser microphone (ECM-77, Sony, Inc., Tokyo, Japan) is inserted into a hemispherical rubber chamber 2cm in diameter, and placed at suprasternal notch of the test subjects to record the tracheal breath sounds. Recording software WAVEPAD (V3.05, NCH Swift Sound Software) is used and the signal clips are recorded and saved as monochannel *.wav file at sampling frequency of 44.1 kHz. Test subjects are asked to breathe normally, and 20-second recording is saved each time.

The Proposed Enhancement Method

The proposed enhancement scheme is to remove background noise (BN) while keeping the useful information unaffected. This has been realized by staging through three steps: The first step is to remove the heartbeat using notch filtering. The signal would then be passed through the nonlinear energy operator to detect and remove spikes. The last step would be to remove very high frequency/small detail components in the signal, so as to preserve the underlying signal structures which might be corrupted by noise. A block diagram of the proposed enhancement technique is depicted in Figure 1. The scheme is realized in the following steps:

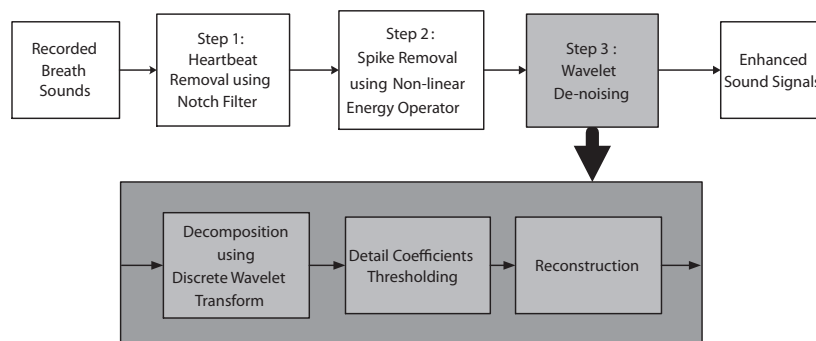
Step 1: Heartbeat Removal Using Notch Filter

The first stage of enhancement scheme involves removing the heartbeat from the respiratory sound signal. Heart sounds falls in the low frequency range of a few Hertz to over 200 Hz, but with predominant range below 100Hz. It has been suggested in (Sovijarvi et al, 2000) that a low-order highpass filter would be sufficient to remove heartbeat from the respiratory sounds. However, it also removes some of the important signals which may fall in the same frequency as the heartbeat. In order to avoid the loss of useful information, notch filter is applied here to solve the problem. The frequency response of a notch filter provides deep notches, which are useful to eliminate/attenuate some specific undesired frequency components of a signal (Haykin et al, 1988). The notches are made as deep as possible, so that ideally the undesired frequencies are totally eliminated. It is implemented using a second order (N=2) Butterworth filter. The stop band is defined in this case to be $f_{stop} = [f_1 f_2] / F_s$ where $f_1 = 10\text{Hz}$ and $f_2 = 300\text{Hz}$ with sampling frequency $F_s = 44.1\text{kHz}$.

Step 2: Spike Removal Using Nonlinear Energy Operator

Spike refers to both a localized high frequency and an increase in instantaneous energy in the signal processing point of view. The quantitative descriptions of the amplitude and spectrum of spikes vary from signal to signal, subject to subject; it even varies from time to time for the same subject. For this reason, detection and pathological implications of spikes become difficult. As the width of the spikes increases, energy is concentrated more in the low-frequency band where the energy of the background signal is also located.

Figure 1. Block diagram of the proposed enhancement scheme



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