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Breath detection using short-time Fourier transform analysis in Electrical Impedance Tomography

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Abstract

Spectral analysis based on short-time Fourier transform (STFT) using Kaiser window is proposed to examine the frequency components of neonates EIT data. In this way, a simultaneous spatial-time-frequency analysis is achieved.

1. Introduction

Electrical impedance tomography (EIT) is a relatively new non-invasive bedside tool in which impedance/voltage changes reflect changes in regional ventilation and allows monitoring the functionality of lungs. Numerous studies have been published in lung function monitoring for adults [1-6]. However, assessment of lung function in pediatric population is more challenging due to the patient movements and artifacts which have come under investigation only recently [7-10]. The main goal of this study is to design a bedside breath detection method for neonates and premature newborns which can estimate regional ventilation in order to do monitoring for apnea alarm detection.

Computerized Tomography (CT) and magnetic resonance imaging (MRI) could achieve this goal but not at the bedside. For online monitoring purposes, patients may be exposed to an increasing amount of ionizing radiation during required repeated chest X-rays. Further, these imaging modalities are incompatible with unstable patient/neonate that does not cooperate. Furthermore, MRI is not allowed to be used for patients with temporary pacemaker wires or other technical equipment unless they are MRI safe equipment. In addition, the non-real time character of CT and MRI does not allow to continuously monitor regional lung ventilation in Neonatal Intensive Care Unit (NICU). Unlike conventional radiography or CT, EIT allows continuous real-time radiation free monitoring of the lung function which can be applied for monitoring mechanically supported neonate or during surfactant administration. Online precise quantification of EIT signals requires taking many factors into account, including real time analysis of acquired EIT signal, pre knowledge information about the shape and model of the thoracic area. We propose to employ the short-time Fourier transform (STFT) to benefit from the high temporal resolution provided by EIT. Since EIT has relatively low spatial resolution, it is more suitable for assessing dynamic impedance changes in time. However, in this paper we have used a FEM model to take advantage of the shape of the lungs to compensate the poor spatial resolution of the EIT images [6].
Section 2 of this paper describes material and methods of the study. Results of the proposed method together with a discussion are presented in section 3.

2. Materials and methods

EIT monitoring is performed in a prospective study comprising 5 pediatric patients provided by Emma Children's Hospital, Academic Medical Center (AMC), in the Netherlands under the ethic ID number of NCT02962505 in ClinicalTrials.gov. The raw EIT data is acquired by Swisstom EIT system with 32 electrodes at the frame rate of 48 Hz.

We use spectral analysis based on STFT to examine the frequency components of the acquired series of EIT data. The STFT algorithm is simple to implement and the core of the algorithm may be expressed in Matlab code as

$$\mathrm{Xfft} = \mathrm{abs}(\mathrm{fft}(\mathrm{h}. * (\mathrm{x} - \mathrm{mean}(\mathrm{x})), \mathrm{Nfft})). \quad (1)$$

Here, a sliding time window is employed where x is the temporary data to be analyzed, h the corresponding window weight function, Nfft the size of the FFT, and where the processing is carried out at the frame rate of 48 Hz. For the basic frequency estimation for respiratory rate, the vector x is obtained from the time series of linearly combined sensor signals - see details in [6]- which gives a sum voltage signal in EIT that is shown in Figure 1. We choose four seconds time window yielding a window length of 192 samples at a sampling rate of 48 Hz.

A zero padding is used with the parameter Nfft set to 1024 yielding an FFT frequency resolution of 2.8 b/m (breaths per minute). A Kaiser window is employed to achieve an optimal trade-off between the width of the main-lobe

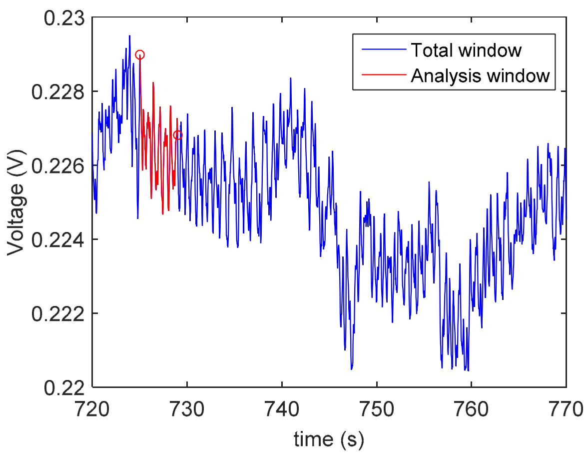

Figure 1. Measured EIT signal as sum of all voltages. Four seconds time window for analysis is shown in red color.

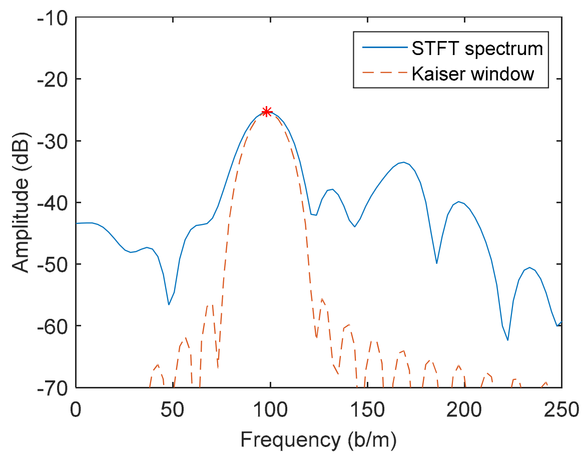

Figure 2. STFT spectrum of the EIT data (blue line) and Kaiser window (dashed line). The respiratory rate estimate is defined as the frequency for which the STFT has its maximum (red star).

(actual frequency resolution) and the side-lobe rejection in the frequency domain. The Kaiser window is designed in Matlab using h = kaiser (192, 4) yielding a main-lobe width of about 50 b/m and a side-lobe rejection better than 30 dB. Finally, the respiratory rate estimate is simply defined as the frequency for which the STFT has its maximum. Figure 2 shows the spectrum presentation of Kaiser window and EIT sum voltage where peak of Kaiser window shows the respiratory rate.

3. Results and discussions

We used spectral analysis based on STFT to examine the frequency components of the acquired series of EIT data. As shown in Figure 2, breathe rate is separated in the frequency domain. The respiratory rate is about 100 b/m. Therefore, the pixel time courses can be digitally filtered in the band of the breathing rate. STFT benefits from the high temporal resolution provided by EIT and is capable of giving stable and robust time-averaged respiratory rate estimates and hence a reliable apnea alarm. In this way, there is no need for holding the breath like previous conventional methods performing the measurements [5, 11]. The STFT is also simple to implement and benefits from the high computational efficiency of the Fast Fourier Transform (FFT) algorithm. The Fourier transform of the Kaiser window shown in Figure 2 with a dashed line is used to define and separate the breath-related component of the EIT signal. The strongest spectrum defines the frequency band that will be used for the pixel based STFT image analysis. The lower cutoff frequency was set at 15 beat/min to filter DC related components. In this way, the breathing related signal dominates the EIT signals.

Thereafter, the most dominated spectrum defined by Kaiser window is used to define breath rate detection for apnea alarm. Further, the pixel based STFT image analysis operates directly on the time series of reconstructed image pixel data creating slowly varying images that are

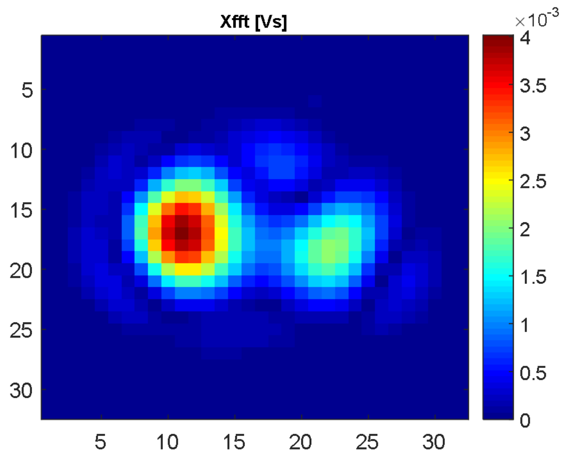

Figure 3. Localization of the Left and right lungs by presenting active thorax region at the frequency of respiratory rate defined by STFT analysis.

separated in space and frequency. This separation facilitates an analysis relating to different activity levels of the chest, such as the functional information of the right- and left lung. Furthermore, adjustment of the color scale for EIT voltage images is used to visualize functionality information of different parts of thoracic area. Figure 3 shows the positions of the activities in the right and left lungs that are visible at the breath rates.

Finally, it is noteworthy mentioning that in this study data were analyzed off-line. However, the proposed algorithm has a potential to be used in a real-time fashion, and automatically analyzes data to allow online monitoring. Our study demonstrates that online breath detection is possible, even in the small neonatal chest in order to design an apnea alarm avoiding the drawbacks of the previous off-line attempts. The approach is based on spectral analysis using STFT. The proposed method does not depend on ECG or other priori knowledge except FEM model while enables us to monitor both variation of the breath and the cardiac signal.

This study is an ongoing research and the next planned step is validation study to compare with a suitable gold standard.

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7. References

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