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Using mathematical analysis for bronchial obstruction detection

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Abstract. Around 300 million people all over the world suffer from asthma [1]. This disease affects all ages and patients have primarily difficult breathing with wheezing in respiratory sounds, cough and feeling of constricted chest. Therefore their physical activity is strongly limited [2]. For better treatment and relieving the disease symptoms the early diagnosis of the disease is needed. For asthma (and other pulmonary diseases) diagnosing, we have some reliable methods: spirometry, measuring of peaks of expiratory velocity or measuring of bronchial reactivity. Unfortunately, these methods have their limits: they are not reliable for badly collaboration patients like infants to 3 years old, because these patients can't provide operations required for the diagnosis method (e.g. maximal inhalation and expiration). In this case, the standard diagnosing methods can't be used and therefore it is necessary to develop other diagnosis method without need for difficult cooperation of these patients. One of the most probably working usable principles is observing changes in the breath sound of ill person and detection of wheezing and other sounds which are the typical manifestations of the disease [3]. These typical phenomena can be detected by auscultation or by observing changes in frequency spectra of breath sound recording, which is created by harmonic analysis. This method could be more sensitive and without need patient's collaboration.

Introduction – disease and its manifestation

Asthma is a chronic inflammatory airway disease, which causes a bronchial obstruction [2]. The bronchial obstruction arises as reaction of bronchial tubes on inspiration of foreign substance causing asthma. The bronchial obstruction causes difficult air exchange in lungs and therefore patients with asthma have primarily difficult breathing, caugh and feeling of constricted chest. Patients with asthma have wheezing and crackles (different sound artefacts) in respiratory sound too.

It is important to discover asthma soon, because early diagnosis can help to set up more efficient treatment and therefore patient can be better stabilized [4]. One of the most reliable methods used for asthma diagnosis is spirometry [1]. Spirometry works with patient's breath (maximal inhalation and expiration) and using these data creates a spirometry curve. According to these curves it can be distinguished healthy and ill person. For reliable results of this method it is necessary a patient's cooperation. Unfortunately, small children age up to three years can't provide this operation and reached results are not suitable for reliable diagnosis.

Respiratory sound

Sound is an oscillation of acoustic pressure composed of many sine oscillation characterized by various frequencies. The human ear is able to detect pressure oscillation in frequency range 20 Hz – 20 kHz. The respiratory sound is sound in frequency range from 10 Hz to 1500 Hz [3]. The sound with frequencies up to 600 Hz goes through lung parenchyma better and therefore it is detected the most at lung areas (back or chest). The sound with frequencies over 600 Hz is detected better on jugulum. The normal lung sound spectrum is devoid of discrete peaks and it is not musical [3].
The airway obstruction generates turbulences in air flow, which produces different sounds at higher frequency level. These changes (in breath sound) are represented by wheezing and crackles. For wheezing the frequencies in the range of 300 Hz – 1000 Hz with higher amplitudes in comparison with neighboring areas are typical [4]. The duration of these areas is normally from 0.5 s to 0.75 s [4]. These searched phenomena in the respiratory sound could be emphasized using an intensive breathing e.g. by physical activity [4]. It is important to be able to detect the wheezing in respiratory sound because they accompanying the origin and course of bronchial obstruction. For wheezing detection is used auscultation method. Unfortunately, only quite a large obstruction can be discovered by auscultation, because human ear isn't sufficiently sensitive. Therefore it is necessary to have sufficiently sensitive device for discovering small obstructions, because it is likely, that small bronchial obstruction causes a little loud sound. This little loud wheezing is inaudible during auscultation, but the sound can be decomposed using harmonic analysis (e.g. Fourier transform) and thus these frequencies of wheezes can be discovered - Fig. 1.

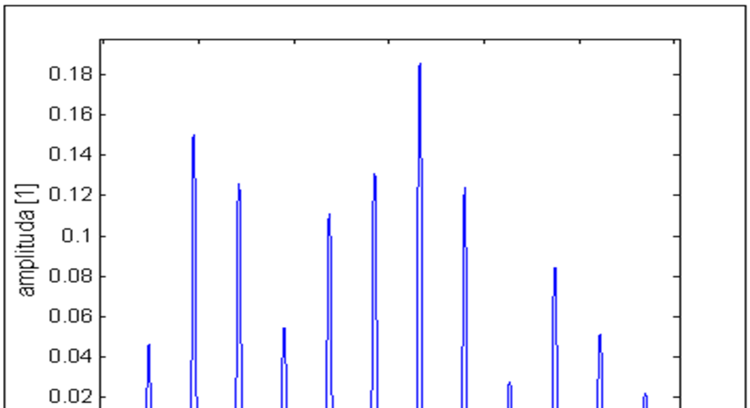

Fig.1: Frequency spectrum of the analyzed and decomposed music sound – the horizontal axis is a frequency scale, the vertical axis indicates an amplitude level of every frequency in the analyzed part of the sound

Data recording and processing

For verification of this hypothesis and for the purposes of our study, software for recording and processing of respiratory sounds was designed. The software operates on the principle of Fast Fourier Transform using Matlab background and creates frequency spectra throughout the length of the analyzed recording working with defined time intervals. The length of the time intervals corresponds to the duration of wheezing approximately. For better clarity of outcomes of performed analysis a specific suitable color scaling for frequencies in obtained frequency spectra was applied - Fig. 2. Finally, the coloured data were rearranged back to the timeline of original recording and so we get a frequency spectrum of the respiratory sound - Fig. 3.

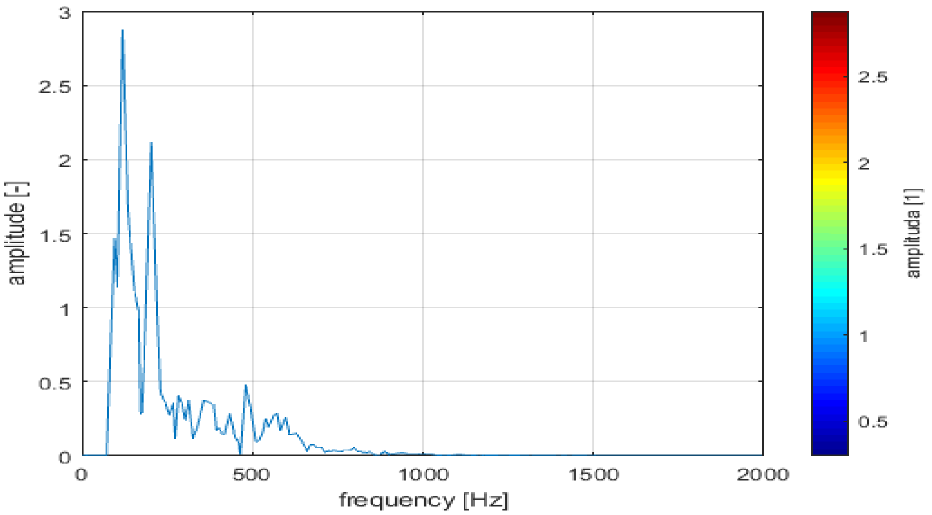

Fig.2: Colour scaling of obtained frequencies

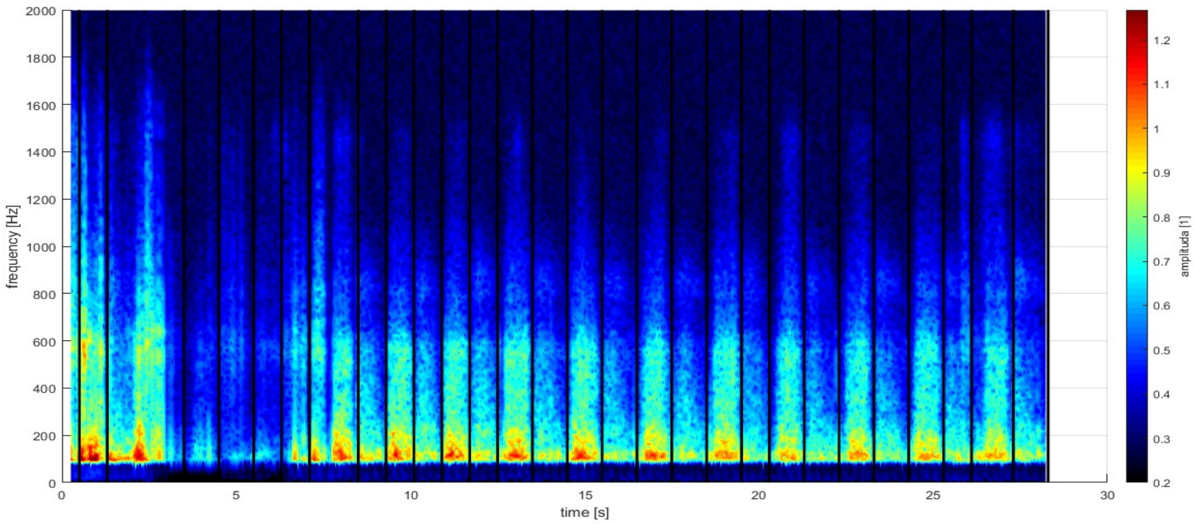

Fig.3: Frequency spectrum of the respiratory sound - displayed as a time course of frequency spectrum and amplitude of each frequency is represented by color. For better orientation the black vertical lines indicate inhalation and expiration phases

For better orientation in the spectrum the ability to detect areas of inhalation and expiration is necessary. Our software can detects these areas using filtration of the sound in specific frequency range and averaging of sound pressure oscillations. Then the software separates these areas in the spectrum using black vertical lines - Fig.3. This approach allows you to compare only inhalation phases and only expiration phases and their levels of amplitudes in various frequency ranges.

All required audio recordings of respiratory sounds were obtained in collaboration with Department of pneumology in UH Motol. In this time, twenty volunteers aged from 5 to 20

years (both healthy men and asthmatic patients) participated on the study. The respiratory sound was recorded before and after the physical activity of the patients and at jugulum areas (previous studies have shown that it is probably the most suitable location for recording).
The commercially available electronic stethoscope recording the heard respiratory sound was utilized in the study. The stethoscope works on 4000 Hz, thus the risk of aliasing and/or other mistakes due to the low sampling frequency were consider as minor ones.
The quality of respiratory sound recording is affected by location, where the sound was recorded and clarity of recording too – the recording should be without ambient noise. The quality of respiratory sound can be affected also by the size of the patient body [3]. Children have a distinct quality of lung sounds, which is generally attributed to acoustic transmission through smaller lungs and thinner chest walls [3].

Results

In the obtained frequency spectra of the respiratory sound recordings we can observe differences between healthy person (Fig. 4) and person with asthma (Fig. 5). It is obvious that sound of patient with asthma (Fig. 5) has higher level of amplitude in the frequency range between 300 Hz – 600 Hz. In this spectrum can be observe wheezing too – it is represented like areas with higher amplitudes in comparison with neighboring (areas highlighted using red ellipses – Fig. 5 and Fig. 6). From this study follows that wheezes in the spectra can be circular or elliptical areas in the frequency range 300 Hz – 800 Hz typically and with length of duration 0.2 – 0.75s, it is depending on the size of the obstruction. We found the areas of wheezing at frequency level around 1200 Hz too (Fig. 6) – it is wider area of occurrence compared to previous studies. It is also probably that it is important to observe new symptoms in the spectra like different amplitude level in the definite frequency range.

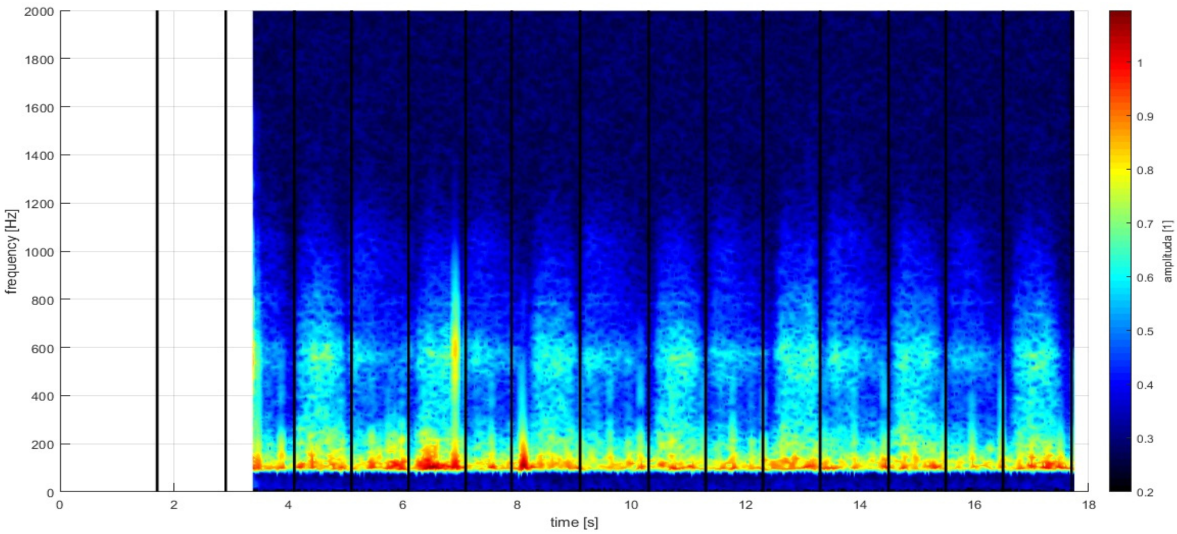

Fig.4: Frequency spectrum of breath sound recording of healthy person – the lower amplitude level of spectrum can be observed in this case

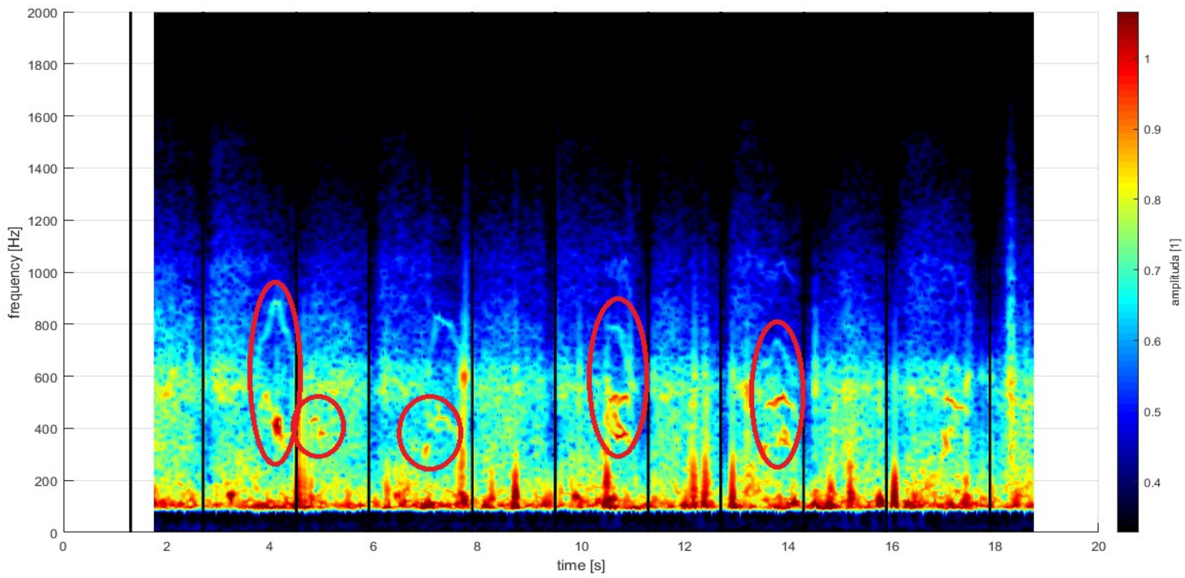

Fig.5: The frequency spectrum of breath of patient with asthma (typical wheezing in red ellipses and their harmonic frequencies)

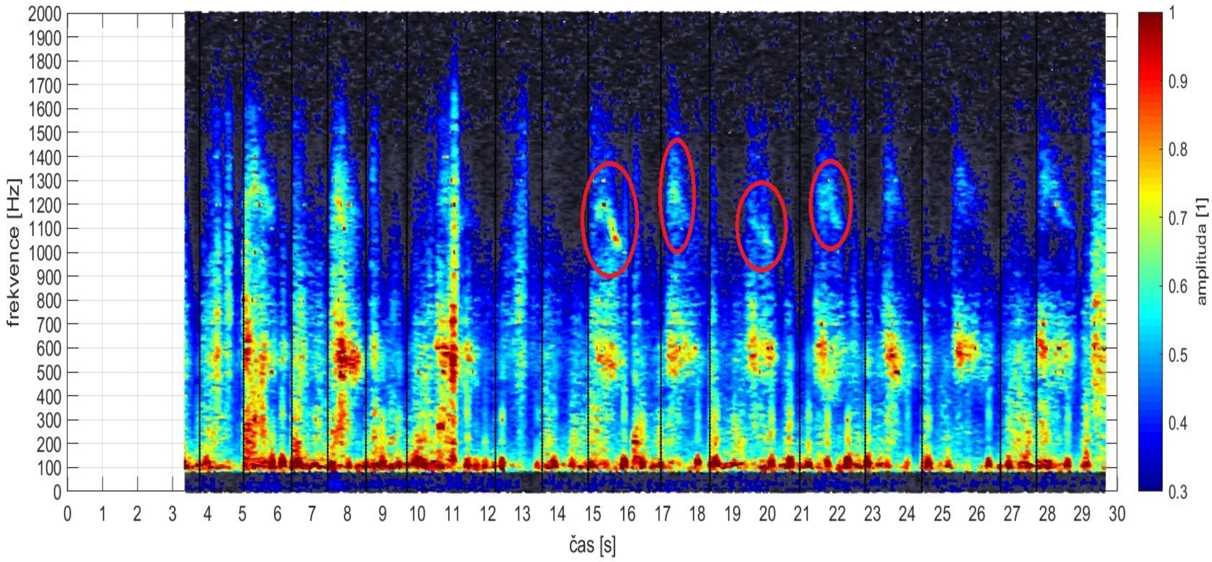

Fig.6: The frequency spectrum of breath of patient with asthma - wheezing around 1200 Hz (red ellipses)

Conclusions

Current results confirm that this method can discover the inaudible obstructions reliably and they also indicate that the method is usable exclusively for intraindividual medical examination. However, it isn't a disadvantage from clinical practice. Now it is necessary to collaborate with physicians to obtain more data and find a clinical significance of discovered phenomena.

Acknowledgements

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