RESPIRATORY SOUNDS AS A SOURCE OF INFORMATION IN ASTHMA DIAGNOSIS

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Abstract

Around 300 million people all over the world at all age level suffer from asthma [1]. Patients with this disease have primarily difficult breathing with wheezing in respiratory sounds, cough and feeling of constricted chest. Therefore their physical activity is strongly limited [2]. Nowadays, there are several methods for asthma diagnosis, for example spirometry, measuring of peaks of expiratory velocity or measuring of bronchial reactivity. Although these methods are sufficiently reliable in most cases, they have also some imperfections, which are obvious especially by diagnosing of badly collaborating patients, e.g. small children aged up to three years. These infants can't provide operations required for diagnosis, so results performed diagnosis are not reliable. For this reason, there is an idea of developing non invasive method of asthma diagnosis and other pulmonary diseases that would not need collaboration of patient [3]. One of the most probably working usable principles is comparison of air flow in airways of healthy and ill person. The difference of the air flow is caused by bronchial obstruction and constriction of airways of patient. There are other sounds and wheezing in the respiratory sounds detectable during breathing as a typical manifestation of the disease [4]. These phenomena can be detected by hearing of sound or by harmonic analysis.

Keywords

asthma, air flow, wheezing, harmonic analysis, Fourier transform, inspiratory phase, expiratory phase

Background

Asthma is a chronic inflammatory airway disease. Inflammation is associated with a bronchial hyper-activity, which causes a bronchial obstruction [1]. This bronchial obstruction is an allergy response of airways to substance that causes reaction (saws, mites, physical activity – knowledge of these substances is important to determine of correct diagnoses). The diameter of airways changes to be smaller during bronchial obstruction, thus the air flow in airways becomes more difficult. Patients with this disease have primarily difficult breathing with wheezing in respiratory sounds, cough and feeling of constricted chest. Therefore their physical activity is strongly limited [2].

It is important to discover asthma soon. Early diagnosis can help to set up more efficient treatment with correct drugs and therefore a patient can be better stabilized. However, symptoms of asthma can be confused with other respiratory diseases and therefore to diagnose asthma exactly is quite complicated [2].

One of the most methods used for asthma diagnosis is spirometry [1]. As result, this offers respiratory curve. This method can discover differences between exhalation curves of diseased and healthy person. This method needs a special device and patients' cooperation.

Unfortunately, small children aged up to three years can't perform operations required for diagnosis (inhalate and expirate as more as possible) reliably, so reached results cannot be unconditionally used for diagnosis and physicians have to rely on auscultatory examination in these cases. Listening tests provide information based on acoustic manifestations of obstructions as e.g. wheezing, but their reliability and sensitivity depend strongly on intensity of obstructions and physicians practice. As very helpful here, the automatic or semiautomatic identification on searched phenomena based e.g. on harmonic analysis of respiratory sounds is found.

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Swelling of the airways (bronchial obstruction) causes a smaller volume of flowing air to and from the lung. The expiration can not be spontaneous to sufficient air change in the lung (as it is at the healthy lung), but the exhalation has to be supported using respiratory muscles. These muscles are primarily to inspiration therefore there is provided a less performance during expiration [3]. The swollen ends of bronchiolis are pulled in to airways due to the negative pressure during expiration [3]. Also the exhalation is more difficult than the inhalation for patients with asthma and the searched phenomena in respiratory sound appear at the end of the expiration phase based on these reasons.

From these reasons it is needed an ability of detection of inspiratory and expiratory phases in respiratory sound recording and an ability to plot these phases to results of harmonic analysis recording.

Foundations

Respiratory sound from physical and mathematical point of view

Sound is an oscillation of acoustic pressure composed of many sine oscillations characterized by various frequencies. A timbre and character of sound detectable by human ear originates from number of oscillated frequencies. The sound composed of integer multiples of the base frequency (the lowest frequency) with clearly defined period is perceived as a musical tone. On the contrary the sound including non integer multiples of the base frequency and without clearly defined period is perceived as noise.

The respiratory sound is sound in frequency range from 20 Hz to 2000 Hz and higher. The energy of this sound drops off sharply between 100 and 200 Hz [4]. However it can still be detected at or above 2000 Hz with proper sensitive microphones in a quiet room according our experience. The normal lung sound spectrum is devoid of discrete peaks and is not musical [4].

As the main cause of the normal respiratory sound, the air turbulences in airways are considered [4]. The flow turbulence produces sounds at higher frequency level usually.

The changes in respiratory sound caused by asthma are represented by wheezing and crackles. For wheezing the frequencies in the range of 300Hz–1000 Hz with higher amplitudes in comparison with neighboring areas are typical. The duration of these areas is normally from 0.5 s to 0.75 s. These searched phenomena in the respiratory sound could be emphasized using an intensive breathing caused e.g. by physical activity.

Harmonic analysis and Fourier transform

Using harmonic analysis (e.g. Fourier transform), such a sound can decomposed thus the important frequencies of wheezes can be discovered. The visualized result of the Fourier transform is called the frequency spectrum [5] and its example is shown on Fig. 1.

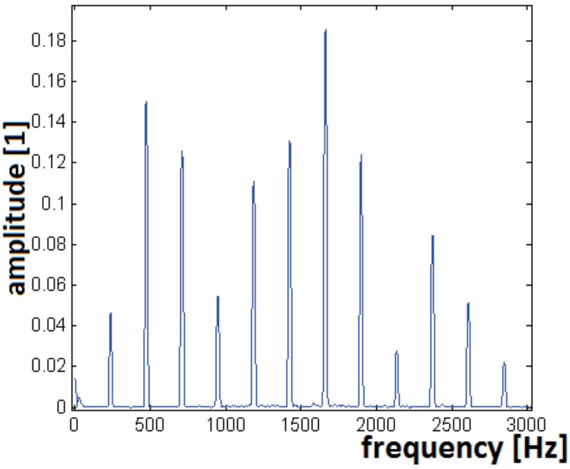

Fig. 1: Frequency spectrum of the analyzed music sound in defined time range – the horizontal axis is a frequency scale and it indicates harmonic frequencies in this sound, the vertical axis indicates an amplitude level of every frequency in the sound. The frequencies can be clearly defined in this case because the analyzed sound is a musical sound.

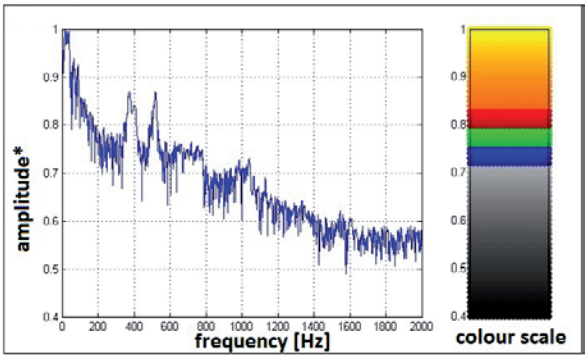

Fig. 2: Colour scaling of obtained frequencies. The colour scale matches special colours according to values of all amplitudes.

For the purposes of our study, a software for respiratory sounds recordings was designed. The software operates on the principle of mentioned 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 (Fig. 3).

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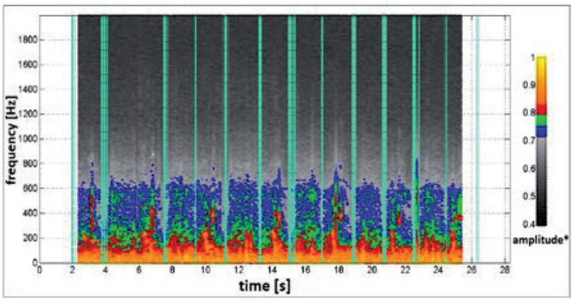


Fig. 3: The frequency spectrum of sound recording of patient's breath. The pale blue vertical lines indicate moment of transitions between inspiration and expiration phase. The lines repeat in 2 sec. time interval. It corresponds to the length of respiratory cycle (inspiration + expiration) for ordinary human in defined age.

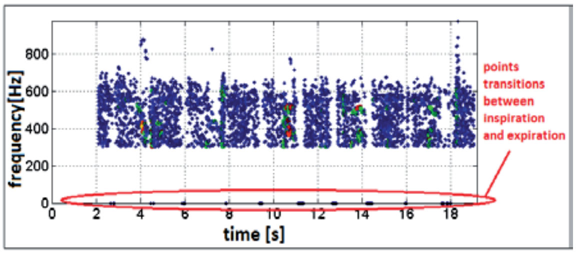


Fig. 4: The representation of decrease number of plotted frequencies due to decrease in amplitude. The sharply decrease of number of plotted frequencies during transitions between inspiration and expiration phase is well marked in the frequency range 300 Hz above. Points in the red ellipse represent time moments without frequencies over minimal amplitude (minimal amplitude level is exactly defined) in this frequency range. There are no frequencies with higher amplitude in such moment and it indicates a minimal air flow movement. These points could be used for localization of moment of transitions between inspiratory and expiratory phase. It is needed to define observed frequency range and minimal amplitude for correct results. The observed frequency range and minimal amplitude is different for every sound recording. The respiratory sound is changed every moment and amplitude decrease is always different, therefore the number of points in transition moment (and wide of vertical lines) is also always different.

By this approach, the oscillations of acoustic pressure are presented by progression of the frequency spectra of the sound recording in time.

Such a method of sound recording acquisition of patients' breath, that is needed for frequency spectrum creation and for detection of wheezing in this spectrum is completely noninvasive and without need of cooperation of patient. For higher effectiveness of this method with the same simplicity and independence of patient's cooperation it is needed an ability define inspiratory and expiratory phases in the frequency spectrum of the sound recording.

The crucial role here plays the fact, that the airflow though airways during inspiration and expiration causes the respiratory sound. However, at the moment, when the respiratory cycle changes inspiratory phase to the expiratory one, the air flow changes an actual direction to quite the opposite direction and its velocity is near to zero. There is no movement of the air flow in the airways and therefore the amplitude of the sound sharply decreases in this moment. A decrease in amplitude is reflected by significantly reducing the number of plotted frequencies in the frequency spectrum in the defined moment. It detects a moment of transitions between inspiration and expiration phase (Fig. 4).

Experiment

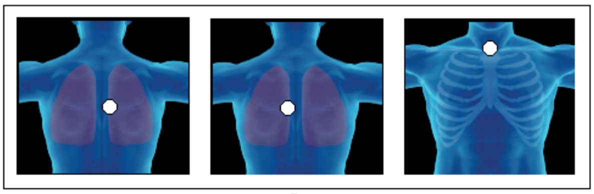
For verification and finalizing of designed software, a small initial study was performed.

All audio recordings of respiratory sounds were obtained in collaboration with Department of pneumology in UH Motol.

Nine volunteers aged from 9 to 18 years (both healthy men and asthmatic patients) participated on the study.

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. All recordings can be transferred to the computer for analysis via Bluetooth.

The quality of respiratory sound recording is affected by location, where the sound was recorded. Probably the best location for respiratory sound recording is on back on paravertebral line in the right and left side (lung lobes 'Fig. 5 a, b') and on jugulum ('Fig. 5 c') [3]. The sound with frequencies up to 600 Hz go through lung parenchyma better than the sound with frequencies over 600 Hz. These frequencies could be detected better on jugulum.



a b c

Fig. 5: Locations for sound recording.

The quality of respiratory sound can be affected also by the size of the patient body [4]. Children have a distinct quality of lung sounds, which is generally

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attributed to acoustic transmission through smaller lungs and thinner chest walls [4]. Acoustic measurements have shown higher median frequencies of normal lung sounds in infants than in older children and adults [4]. Scientific studies show, that higher median frequencies in infants were explained by less power at low frequencies, whereas the decrease in power toward higher frequencies was similar at all ages (infants, children and adults) [4].

Results

Fig. 6 brings illustrative comparison of recordings of asthmatic (upper) and healthy (lower) volunteer.

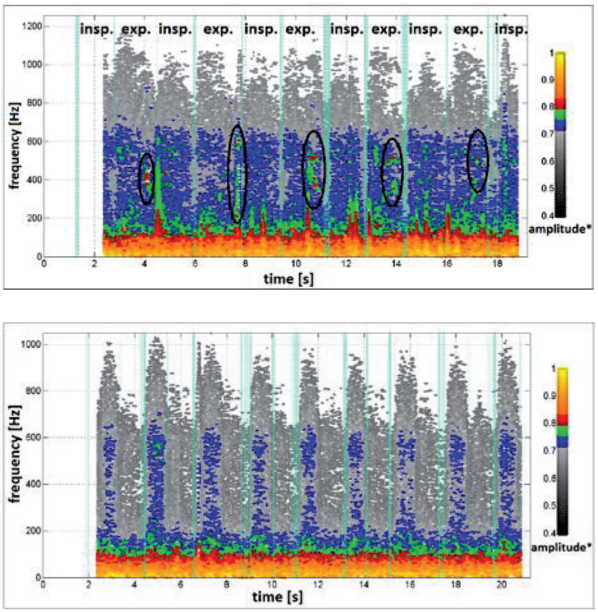

Fig. 6: Frequency spectrum of sound recording of asthmatic (upper) and healthy (lower) volunteers' breath.

There are more important findings to highlight in the figure:

First - because we have detected transitions between inspirations and expirations according to finding of practised physician in all investigated recordings, we can believe that our process operates well without dependency on noise level in the processed signal.

Second - suggested method of color scaling of frequencies according to value of their amplitudes offers illustrative results at the first glance. Interesting finding is in graph of asthmatic patient. There are well visible manifestations of present obstruction in expiration phases in frequency range from approx. 400 to 600 Hz hearable as wheezing in the recording (in Fig. 6 marked by black ellipses).

Third - there were only minor deviation from the pattern shown in Fig. 6 in other healthy and asthmatic volunteers participated.

Conclusion

Based on the data analysis we can conclude that the above presented approach allows reliably identify transitions between inspirations and expirations as well as the presence of breathing obstruction.

We hope that our approach could make diagnosis not only of asthma but of other various respiratory diseases more simple in the future.

Acknowledgement

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