EAN 2020
58th conference on experimental stress analysis

Properties of Respiratory Sound and Their Use

SKALICKÝ D.[1,a], KOUCKÝ V.[2,b], VÍTĚZNÍK M.[3,d], LOPOT F.[1,c]

[1]Department of Anatomy and Biomechanics, Faculty of Physical Education and Sport, Charles University in Prague, José Martího 31, 162 52 Prague 6, Czech Republic

[2]Department of Pneumology, 2nd Faculty of Medicine, Charles University in Prague and Motol University Hospital, V Úvalu 84, 150 06 Prague 5, Czech Republic

[3]Faculty of Biomedical Engineering, Czech Technical University in Prague, nám. Sítná 3105, 272 01 Kladno 2, Czech Republic

[a]skalickydavid@seznam.cz, [b]Vaclav.Koucky@seznam.cz, [c]flopot@seznam.cz, [d]martin.viteznik@gmail.com

Keywords: Respiratory sound, Signal processing, Filtration, Analysis, Respiratory phases

Abstract. Sound as an oscillation of acoustic pressure is a manifestation that accompanies every mechanical movement in the Earth's atmosphere. Every change of mechanical system movement causes change in the progress of acoustic pressure and therefore recorded sound contains lot of information about movement of the specified system. If the sound recording is processed and analyzed correctly, it is possible to detect changes in the system, analyse a source of these changes and thus find reason of change of movement. Method of system's disorder detection using analysis of generated sound is used also in medicine. Auscultation - examination of the patient by listening – is often used method for lung function examination and the first used method for respiratory disease diagnosis (e.g. asthma). This method is performed using phonendoscope. Unfortunately this method has its limitations, such as the low sensitivity of human ear and also congestion of recording due to unwanted noise. Therefore, both the detection of small changes in the respiratory sound and diseases diagnosis in their initial phase is quite difficult. But early disease diagnosis is important because it means more efficiently treatment [1]. To obtain better and more reliable data on the patient's condition and for easier disease diagnosis using breath sound analysis, it is necessary to use sufficiently sensitive sensor to sound record, to process the record well and precisely.

Respiratory sound

The respiratory sound is sound in frequency range from 20 Hz to 2000 Hz [2]. This sound arises due to flowing air in the airways.

The amplitude of each sound frequency is different depending on the area of sound listening. The sound with frequencies up to 600 Hz go through lung parenchyma better than the sound with frequencies over 600 Hz. These frequencies can be detected on jugulum in better way, while the convenient area for lower frequencies detection is lung lobe. The respiratory sound can be affected also by size of patient's body and his health condition [1].

Breath system of healthy man produces a normal respiratory sound – sound without strange artifacts. If the man suffers from some respiratory disease, abnormal breath sounds and foreign artifacts (called also like bronchial sounds [3]) can arise in his breath sound. These artifacts are produced by turbulent flow that arises in airways due to bronchial obstructions [2]. Bronchial obstruction arises like a consequence of airway inflammation [4]. Bronchial sounds - sounds with abnormal high amplitude of specific frequencies are typical in many diseases with airway obstruction, like in asthma and in chronic bronchitis [3]. The bronchial sounds are defined sometime like wheezing, crackles and snores [3]. Frequency range and duration time of these artifacts is different - the literature states the frequency range from 100 Hz to 2000 Hz [2, 3]. Discovering of these artifacts in the breath sound is important to correct diagnosis.

Respiratory sound recording

Respiratory sound recording is necessary for its detailed analysis and correct diagnosis. It is important to use quality record equipment for obtain recording suitable for analysis – sensitive sensor and quality sound card. Unfortunately is impossible to obtain recording only with respiratory sound that is described in previous part, because the sound is always affected by unwanted noise. This noise can be produced by patient's body or by its surrounding.

Patient's body noise. Movement of muscles and working of organs is a large source of noise. For elimination of noise of muscles movement is necessary to limit body movement as much as possible. The noise produced by organs (mainly cardiovascular sound) is a low-frequency sound that occurs in frequency range up to 50Hz. For elimination of this noise in a sound recording is possible to use high-pass filter [5].

Ambient noise. It is clear that for quality sound recording is necessary to make recording in quiet environment. Unfortunately quiet environment doesn't ensure quality sound recording because due to manipulation with record equipment arise defects in sensor that generate a lot of noise. Elimination of this noise depends on doctor's skill and experience.

Signal processing

Breath sound includes many properties and artefacts that could be suppressed by unwanted noise. Correct signal processing is important step to discover suppressed artefacts and to obtain relevant results from sound analysis. To discover all significant frequencies in the sound, it is necessary to use sampling frequency twice higher as the highest frequency in the sound for sound recording (Nyquist–Shannon sampling theorem). In this research was used a phonendoscope Littmann 3200 for sound record. This stethoscope records sound with sampling frequency 4000 Hz. Now they are not expected higher frequencies than 2000 Hz in the recorded sound. For further recorded signal processing was used Matlab software.

Basic filtration. As the basic operation of signal processing, the filtration using high-pass and low-pass filter is applied. This signal modification is convenient for elimination of consistent disturbing elements with high amplitude. Such an unwanted sound with defined frequency level and high amplitude is primarily cardiovascular sound. Heart due to its position near lung affects the complete respiratory sound significantly. Such sound is much disorganized, searched properties and artefacts are drowned out and sound that is plotted as a progress of acoustic pressure is very chaotic - Fig. 1.

When this recording is modified using suitable filter, the sound is much clear and the progress of acoustic pressure is more visible. The definition of the correct filter depends on the application and the expected result. If the high-pass filter 500 Hz and low-pass filter 1600 Hz are used for recording filtration, some significant frequencies are removed from the sound, but in the new frequency range other sound properties like is alternation of inhalation and exhalation phases will appear - Fig. 2.

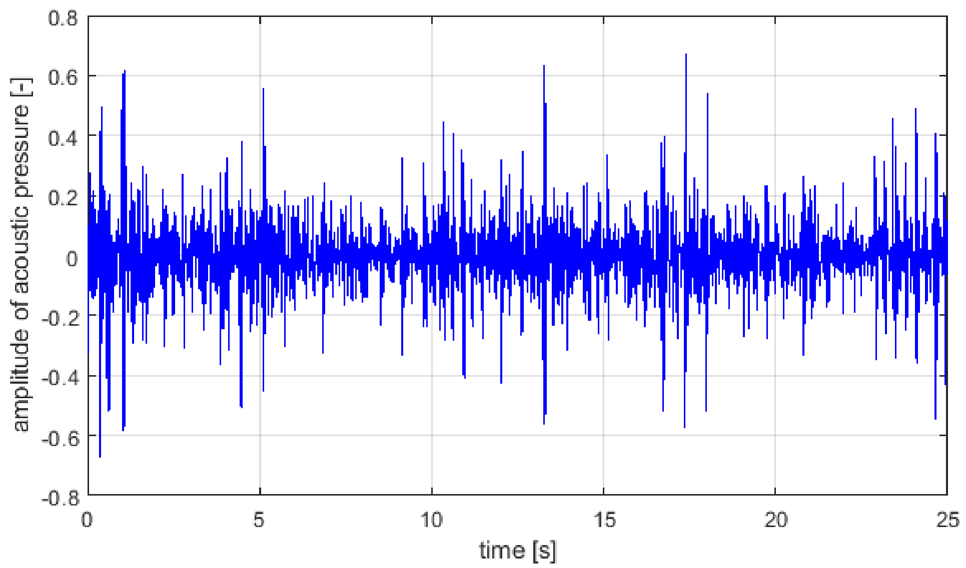

Fig. 1: Unfiltered respiratory sound of healthy man – chaotic progress of acoustic pressure due to noise in the sound

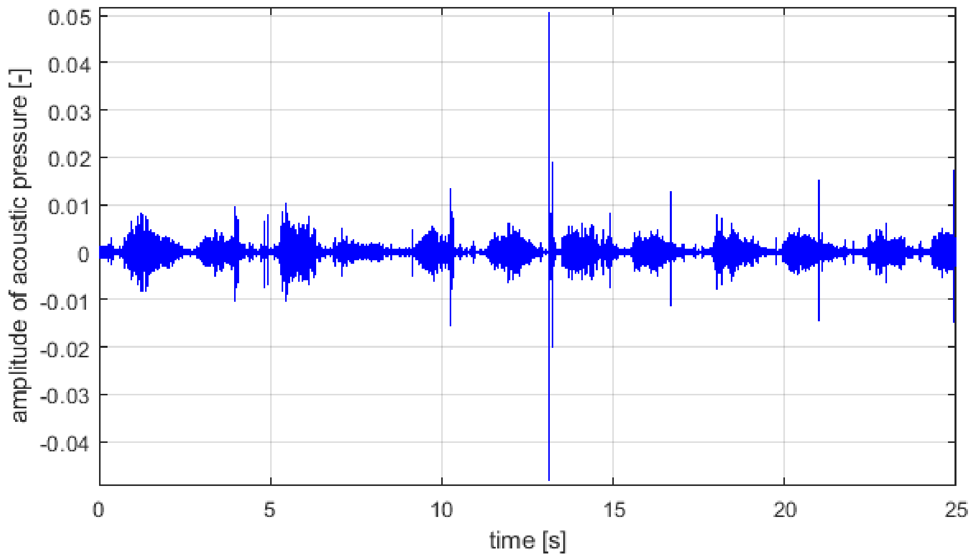

Fig. 2: Respiratory sound filtered using high-pass (500Hz) and low-pass filter (1600Hz) – the same healthy man. The filter eliminates high amplitude part of sound and recording contains now breath sound mainly. In the pressure progress, the alternation of inhalation and exhalation phases is obvious. Now, this part of the signal is located on low amplitude level

Ability of these phases detection is important for easy orientation in frequency spectrum and for creation of average curves of inhalation and exhalation. With these phases also sound defects generated due to manipulation with record equipment are obvious in pressure progress - e.g.: hitting the sensor or rubbing the sensor against the skin. These sound defects arise aperiodically in sound recording and they are very short (time of duration around 0,02s) with high amplitudes and wide frequency ranges. Therefore, the standard filtration can't be use for their elimination – Fig. 3. Unfortunately, these artefacts make above mentioned detection more difficult.

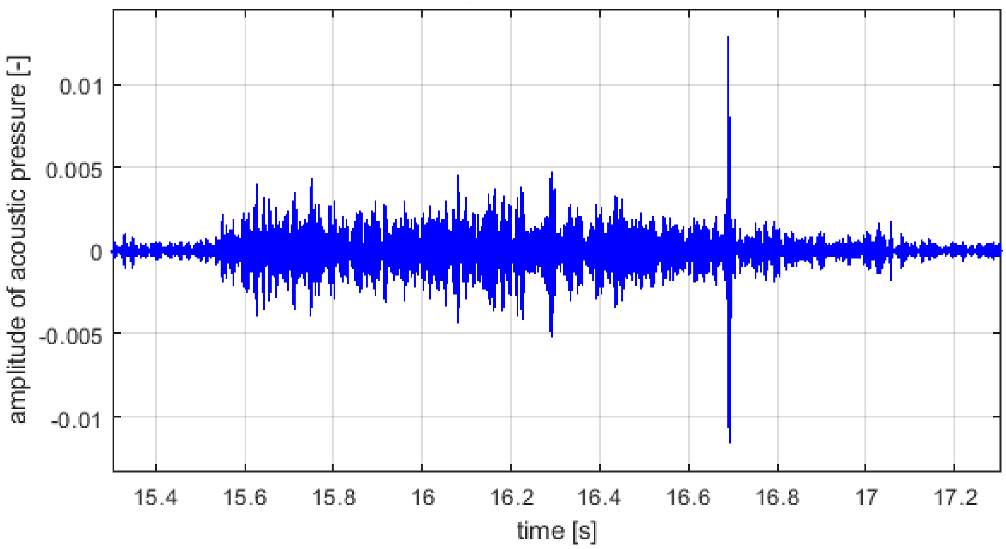

Fig. 3: The short and amplitude distinct sound defect (in time 16,7s) caused by manipulation with record equipment

Own filtration and respiratory phases detection. The alternation of inspiratory and expiratory phases is closely related to the movement of air in the airways. The air flows through the airways during inspiration and expiration, while at the time of the respiratory phases change, air movement is minimal. Because the air movement in the airways generates sound, hold true that the larger (faster) movement of air generates a louder sound. This louder sound has higher amplitude deviation in the pressure progress than quietly sound during time of phases change – Fig. 4. This feature is basic for respiratory phases identification.

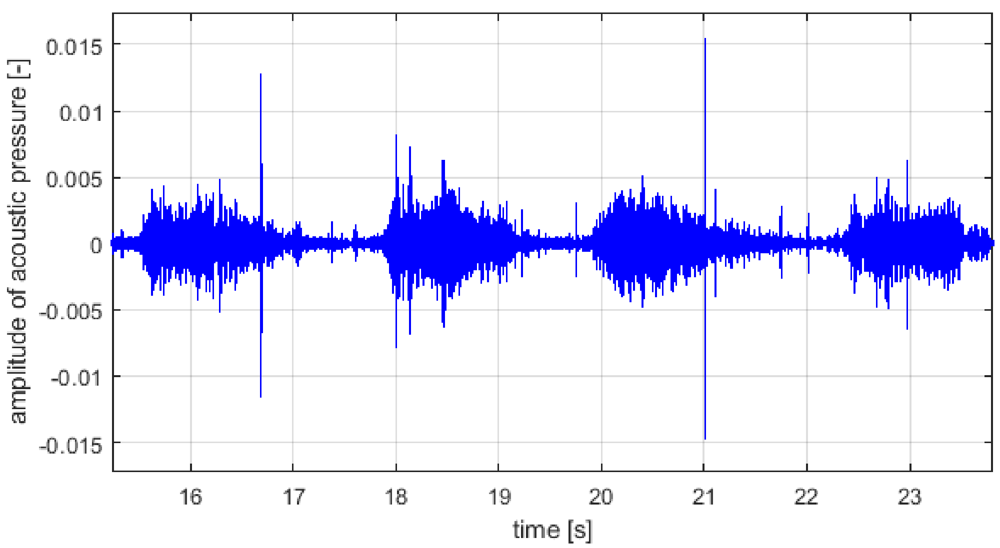

Fig. 4: Inspiratory and expiratory phases alternation - at the time of the respiratory phases change is amplitude of acoustic pressure minimal

For easier identification maximal and minimal deviation of pressure amplitude, it is appropriate to create envelope of the signal. The upper part of the envelope includes positive values of amplitudes only, while the whole signal oscillates between positive and negative values, and therefore it can be effectively smoothed. Subsequently, the boundaries of the respiratory phases as the minima of the smoothed curve can be defined and found.

Unfortunately, this curve is greatly affected by defects caused by sensor manipulation. Therefore, it is necessary in suitable way to adjust the curve and eliminate effect of the sound defects – Fig. 5.

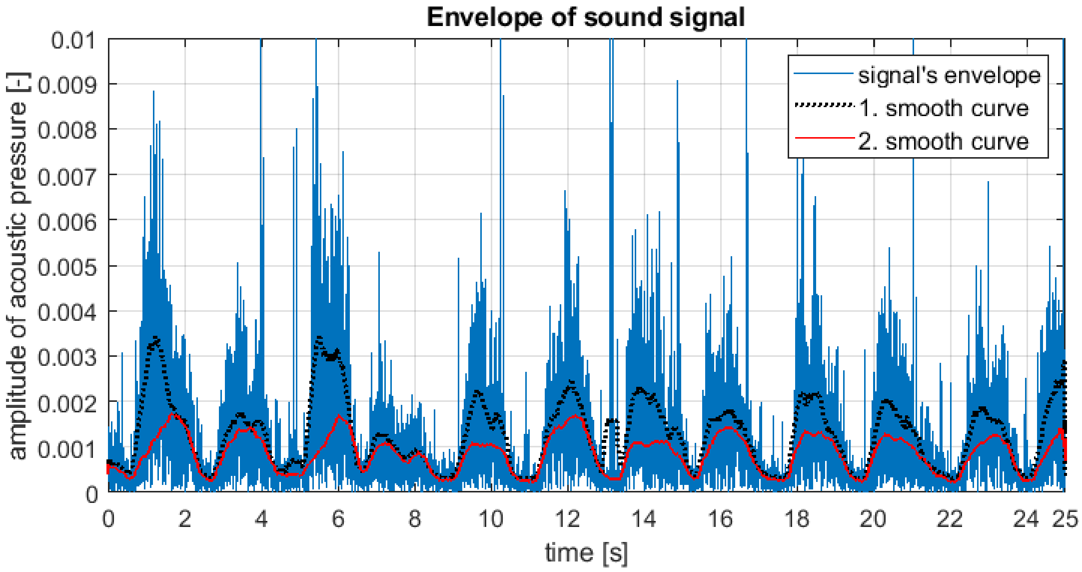

Fig. 5: Envelope of sound signal and its smoothed curves – the boundaries of the respiratory phases as the minima of the 2nd smooth curve

Because the breath sound is different for each person, it is necessary to specify more features of sound for correct identification of respiratory phases. A suitable and easily definable feature is the approximate rate of change of respiratory phases (duration of one phase). This feature varies according to patient's age and its healthy condition – Table 1. Therefore, it is necessary to define specific duration of one phase individually for each patient.

Table 1: Respiratory rate according to patient's age [6]

Age of patient	Respiratory rate
neonate	40 – 60 / min
1 month	40 – 45 / min
6 month	35 – 40 / min
1 year	30 – 35 / min
5 – 6 years	25 / min
10 – 12 years	20 – 22 / min
14 – 15 years	18 – 20 / min

If the envelope is properly adjusted and the respiratory rate is correctly defined, the boundaries of the respiratory phases can be determined – Fig. 6. The accuracy of boundaries definition depends on more factors mainly on respiratory rate. If this rate is low, a transition part between phases with minimal amplitude is not exactly defined. Nevertheless, this definition of the boundaries of the respiratory phases is well useful.

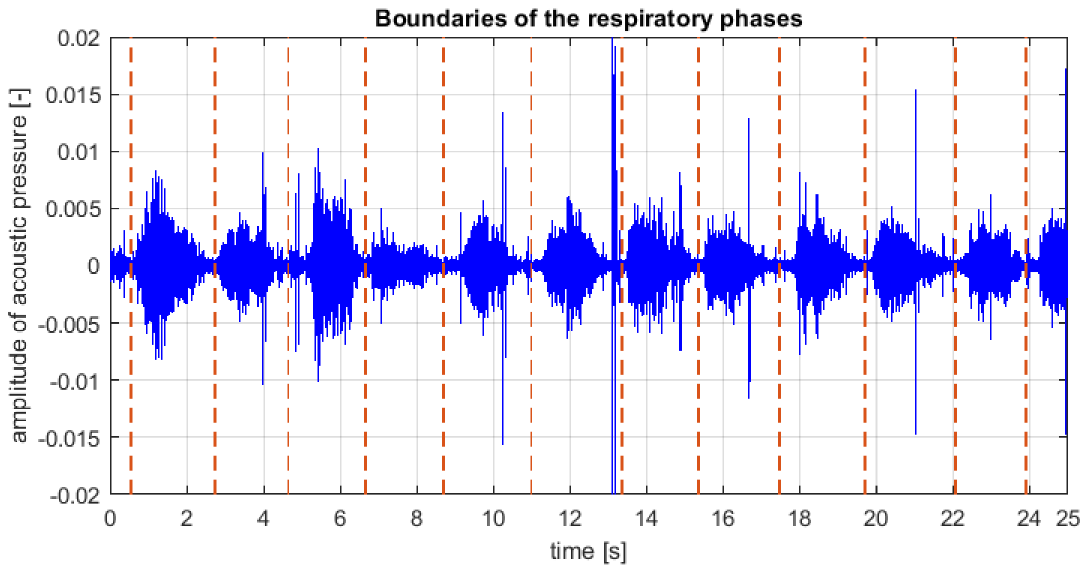

Fig. 6: Sound signal with border lines – dashed vertical lines

Table 2: Basic data of the measured patient

Sex	female
Age	13 years
Health condition	without bronchial obstruction
Recording location	jugulum

Results – use of the boundaries definition

These defined border lines are very useful for orientation in frequency spectrum of the respiratory sound – Fig. 7.

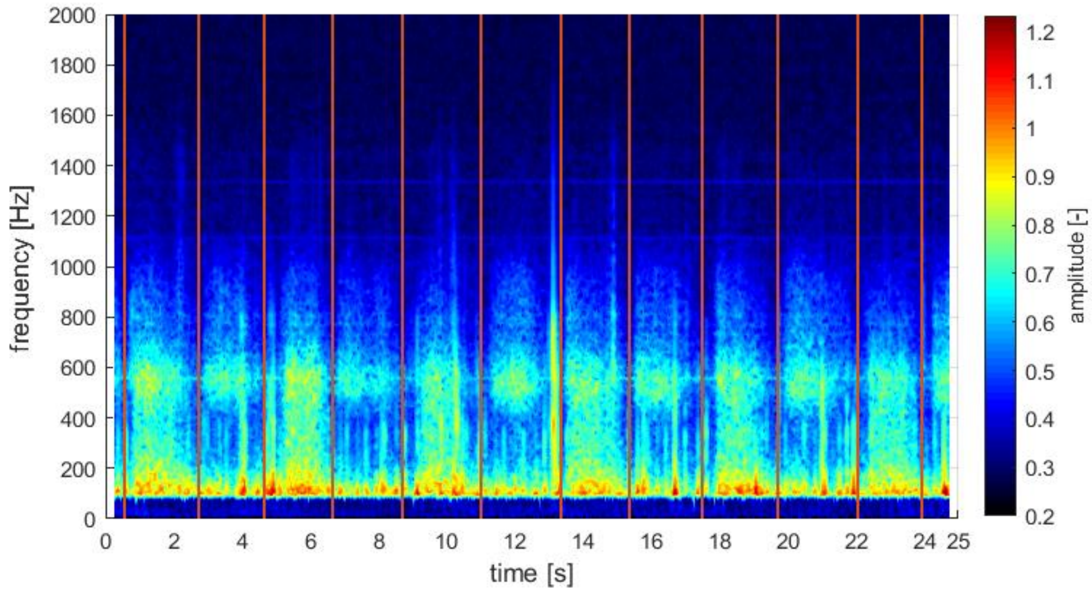

Fig. 7: The frequency spectrum of respiratory sound with vertical border lines. In the spectrum are distinct sound defects caused by manipulation with record equipment (amplitude distinct areas between 200 Hz – 600 Hz with time duration roughly 0,02s). In the spectrum are obvious also two distinct horizontal lines – 1110 Hz and 1330 Hz. These are with the highest probability an effect of background noise

If the boundaries of the respiratory phases are known, the average curves of inhalation and exhalation phases can be plotted – Fig. 8.

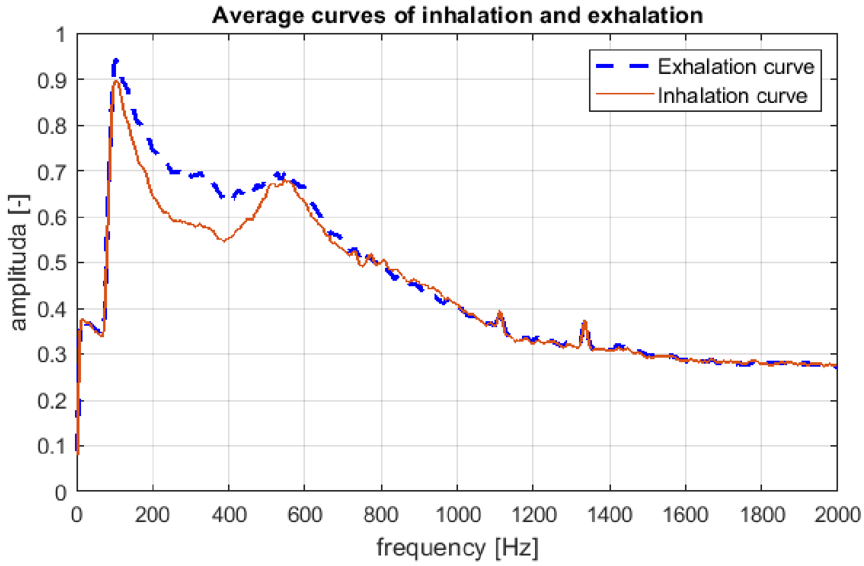

Fig. 8: Average curves of inhalation and exhalation – is obvious that the important frequency area is between 100 Hz – 600 Hz

Using these curves, it is possible to eliminate sounds defects in the frequency spectrum, at least partially and thus make the spectrum more transparent. Because of this elimination, it is possible to discover the searched artefacts in the frequency spectrum mentioned above.

Conclusions

It is obvious that the respiratory sound contains many features and artefacts which can be effectively used in medicine practise and research. For the best use, it is necessary to be able to discover and define these properties. This could outline a way to further process and use the signal efficiently.

The application of such audio signal processing in medicine is wide – from online monitoring of patient lung function to deep analysis of the sound and detection of artefacts in the breath sound recording, that are not detectable using auscultation. This method of the artefacts detection and so early discovering of bronchial obstructions in the airways would be very helpful for respiratory diseases diagnose in infants to 5 years old. In this case, the traditional methods – e.g. spirometry – are not effective. Moreover this diagnosis method is non-invasive and its using in practice is easy because for obtain of sound signal can be used device based on classic stethoscope that is able to make sound record. Therefore, no demands are placed on the cooperation of a small patient, the possibility of patient stress is reduced, and so it is possible to obtain more accurate data for analysis.

The discovering of the searched artefacts in the sound frequency spectrum is not easy, it depends on properties of sound and quality of the sound recording. Therefore, the semiautomatic or automatic differentiation of respiratory phases in the spectrum is important.

Acknowledgements

This text is supported by GAUK grant No. 9022/2018

References

[1] D. Skalický, F. Lopot, V. Koucký, Respiratory sounds as a source of information in asthma diagnosis, Clinician and Technology 2017, vol. 47(2), ISSN 2336-5552.

[2] H. Pasterkamp, S. S. Kraman, G. R. Wodicka, Respiratory Sounds, American Journal of Respiratory and Critical Care Medicine. 1997, ISSN 1073-449x.

[3] A.R.A. Sovijärvi, L.P. Malmberg, G. Charbonneau, J. Vanderschoot, F. Dalmasso, C. Sacco, M. Rossi, J.E. Earis, Characteristics of breath sounds and adventitious respiratory sounds, ©ERS Journals Ltd 2000, ISSN 0905-9180.

[4] J. G. Ayres, Astma, 1. vyd. Praha: Grada 2001, ISBN 80-247-0091-3.

[5] J.E. Earis, B.M.G. Cheetham, Current methods used for computerized respiratory sound analysis, ©ERS Journals Ltd 2000, ISSN 0905-9180.

[6] D. Skalický, Využití elektronického fonendoskopu v diagnostice astmatu, ČVUT Praha 2016.