ON AUTOMATIC DETECTING OF THE INSPIRATION / EXPIRATION PHASES OF RESPIRATORY CYCLE BY TIME-FREQUENCY SPECTRAL PROPERTIES OF BREATH SOUNDS

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A technique for automatic detection of inspiration, expiration and respiratory pause is algorithmically implemented by tracing of intervals corresponding to the minima of the respiratory sound acoustic intensity in frequency band typical for a vesicular breathing. An approbation of the method on respiratory signals corresponding to the different types of breathing and receiving devices confirms high effectiveness of the proposed approach.

INTRODUCTION

An almost bicentennial history of the instrumental auscultation was accompanied by gradual improvement of the devices for perception of life-activity sounds having the diagnostic value. The attempts to develop the stethoscopes on the base of various acoustoelectric transducers providing the efficient signal amplifying, filtering and correction of the frequency response were the logical step in this direction [1, 2]. However, in spite of the above features, for a long time using of the electronic stethoscopes was limited by scattered experimental researches. The decisive advantages of such devices before the traditional mechanical stethoscopes could be exhibited only with the appearance of digital sound recording technologies that ensure the reliable long-term storing of audio data in the compact form and suitability of their immediate or posterior analysis using the modern signal processing techniques [3].

Connection of an electronic sensor for the respiratory or cardiac sounds to a netbook (or a smartphone, in the nearest future) along with the possibility of an operative transmission of a phonogram through the Internet allows both the space and time decoupling of the stages of auscultative data recording, and their analysis, processing and interpreting by the diagnostician. All this creates the preconditions for an active inclusion of the electronic digital auscultation techniques to the e-health and telemedical applications. So, it is natural that in recent decade the electronic stethoscopes were finally able to occupy their niche in the market of medical equipment in the form of portable hardware-software complexes [4].

Studying of the solutions proposed in this segment shows that all software provided with the stethoscopes are intended exclusively for analyzing of cardiac sounds. Besides the undoubtedly prior importance of cardiological diagnostics, such state of affairs may be explained by the relative simplicity of the mentioned signal and long-term phonocardiographic tradition that is actually revived now on a new hardware and algorithmic basis.

Meanwhile, numerous studies show that analysis of the objective acoustic characteristic of respiratory sounds has the significant potential for increasing the effectiveness of diagnosing of the respiratory diseases [5, 6]. The same applies to silicosis and pneumoconiosis, the professional pathologies that are accompanied by vivid changes of respiration parameters [7]. A special case is the problem of chronic obstructive pulmonary disease (COPD), which gained special urgency among the elderly population in Western Europe [8]. Preliminary results achieved for this pathology also give the hope for successful applying of the phonospirography for COPD dynamics monitoring [9].

IDEA OF THE METHOD

At the present stage of development of medicine, the task of algorithmic detection of the most characteristic features of normal and pathological respiratory signals becomes urgent. Earlier, several attempts were made for automating the detection of wheezes [6] and crackles [6, 10] according to their frequency or time characteristics. Moreover, changes in the absolute and relative inspiratory/expiratory and whole respiration cycle durations can be quite informative indicator of severity for many pulmonary diseases. In clinical conditions, these parameters may be recorded by a pneumotachograph that can be additionally synchronized with channels of the sensors receiving the phonospirogram. However, such technique is inapplicable in portable devices used for home and field examination of the patient. In publication [11], the possibility to separate the inspiration and expiration exclusively by analyzing of frequency characteristics of generated respiratory sounds was announced. In this study, we propose the approach with using of similar idea based on search for the moment of changing respiration phases by the minimum sound level in time-frequency spectrum (spectrogram) of the signal.

Let us consider in more detail the operation principle of the algorithm, which is the basis of such detection. First of all, it should be noted that conventional technique of silence finder by minimum of signal amplitude in time domain, which is widely used when working with music and speech audio tracks, is almost inapplicable for analysis of the records of respiration. Evidently, it is explained by significant noising of respiratory phonograms, for which you can not find an appropriate background threshold. Meanwhile, it is well known that the rhythmics of respiratory cycle is explicitly depicted on the spectrograms of breath sounds (see Fig. 1). It can be seen from the graph that high-frequency components of these sounds form in fact a kind of envelope allowing for quite distinct tracing of alternating breaths.

The reason is that the sounds accompanying the respiration are that of hydrodynamical nature and their level is directly related with airflow velocity in the broncho-pulmonary system [12]: the higher is velocity, the more intensive is produced sound. In the moments when inspiration is changed for expiration and during the pauses following every expiration both the flow, and sound generation stop. Like many of flow-induced sounds, the basic breath sounds belong to rather wide-band noise. For example, a vesicular breathing in the lower lung is auscultated at frequencies to (500 . . . 600) Hz, while the bronchial and tracheal ones up to (800 . . . 1400) Hz. Below 100 Hz, the cardiac sounds and interferences dominate that

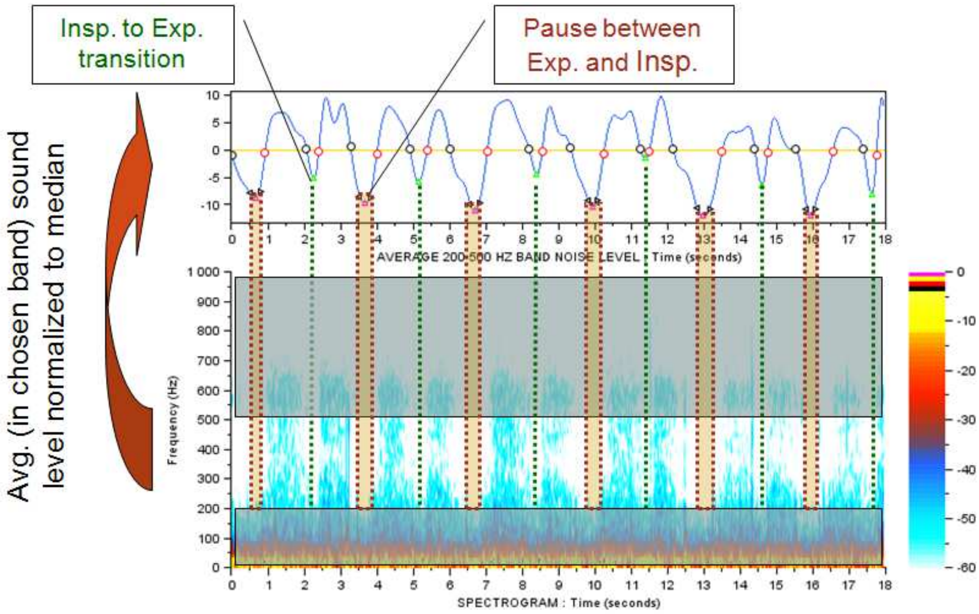

Fig. 1. An operation principle of the algorithm for distinguishing of individual phases of respiratory cycle

mask the respiratory rhythm here [3]. So, it is reasonable to follow the change in the intensity of the respiratory signal in a characteristic frequency band of (200 . . . 500) Hz, which minima will correspond the desirable time limits of individual respiratory phases.

Solving of the problem on discrimination of inspiration and expiration is less clear. It is believed that during normal breathing the noise on inspiration is more intense than on the expiration. However, tests showed that this rule applies mainly to the vesicular respiration, while the inspiratory and expiratory levels bronchial sounds listened in the upper lung may be almost identical. Even more confused picture one might receive in presence of intense expiratory wheezing, whose contribution to the total sound energy can be quite substantial. Therefore the level of the signal decay in the local minima was recognized as more reliable marker of respiratory phase. The post-expiration “dips” are expressed more clearly and demonstrate much lower sound levels. It is directly related to the existence of a short break, which is usually preceded by inspiration.

EXAMPLE OF APPLICATION

An example of operation of the described algorithm for distinguishing of respiration phases is shown in Fig. 2. For the analysis, we used the record of the breath sounds of the patient suffering with COPD of the 2nd stage of severity made in right supraclavicular zone by means of the phonospirographic complex CoRA-03M1 developed at the Institute of Hydromechanics of NASU. A complete respiratory spectrogram, a meander generated for distinguishing of the individual respiration phases, as well as clipped spectrograms for inspirations and expirations are presented in this picture. It should be noted that separate presenting of the phases of respiratory cycle provides the significant increase in readability of the spectrogram under consideration and simplifies the attribution of occurring regular pathological features of the signal with expirations.

The proposed processing technique was tested on respiration phonograms received from different sensors in various points of human thorax. Besides the complex CoRA-03M1, recording was made by electronic stethoscopes 3M Littmann 3200 (USA), EPHON-07 and 08 (Institute of Hydromechanics of NASU). It has been shown that in spite of the essential difference of frequency responses of the above devices, in most cases the individual phases respiratory cycle could be successfully separated and identified.

In addition to simple visualization of spectrograms for inspirations and expiration, the possibility of deriving of their time-average spectra was offered along with computing of mean durations of inspiration, expiration, pause and complete respiratory cycle. The developed software interface is planned to be as instrument at group examination and monitoring of status in the COPD patients for early detection of pending disease exacerbations.

CONCLUSIONS

- We propose a simple method of an automated recognition of inspiration, expiration and respiratory pause by tracing the intervals in respiration audio records that correspond to the minima of acoustic intensity in frequency band typical for vesicular breathing.

- An algorithm for distinguishing of the individual phases of respiration cycle and interface for visual representation of their frequency and time-frequency characteristics are implemented in the Scilab 5.4 programming environment.

- An approbation on the set of respiratory signals corresponding to the different types of breathing and stethoscope sensors has confirmed the relatively high effectiveness of this approach providing the stable work of the algorithm at changing frequency response of the receiving device.

- For impaired or significantly arrhythmic respiration, if cough or intense impulse interference are present (such as friction sounds, external crackles, cable shocks) there is a significant deterioration in the quality of phase separation. In these cases, to improve the reliability of the algorithm, one should use the special methods of signal filtering or excluding of the problematic parts of record from the analysis.

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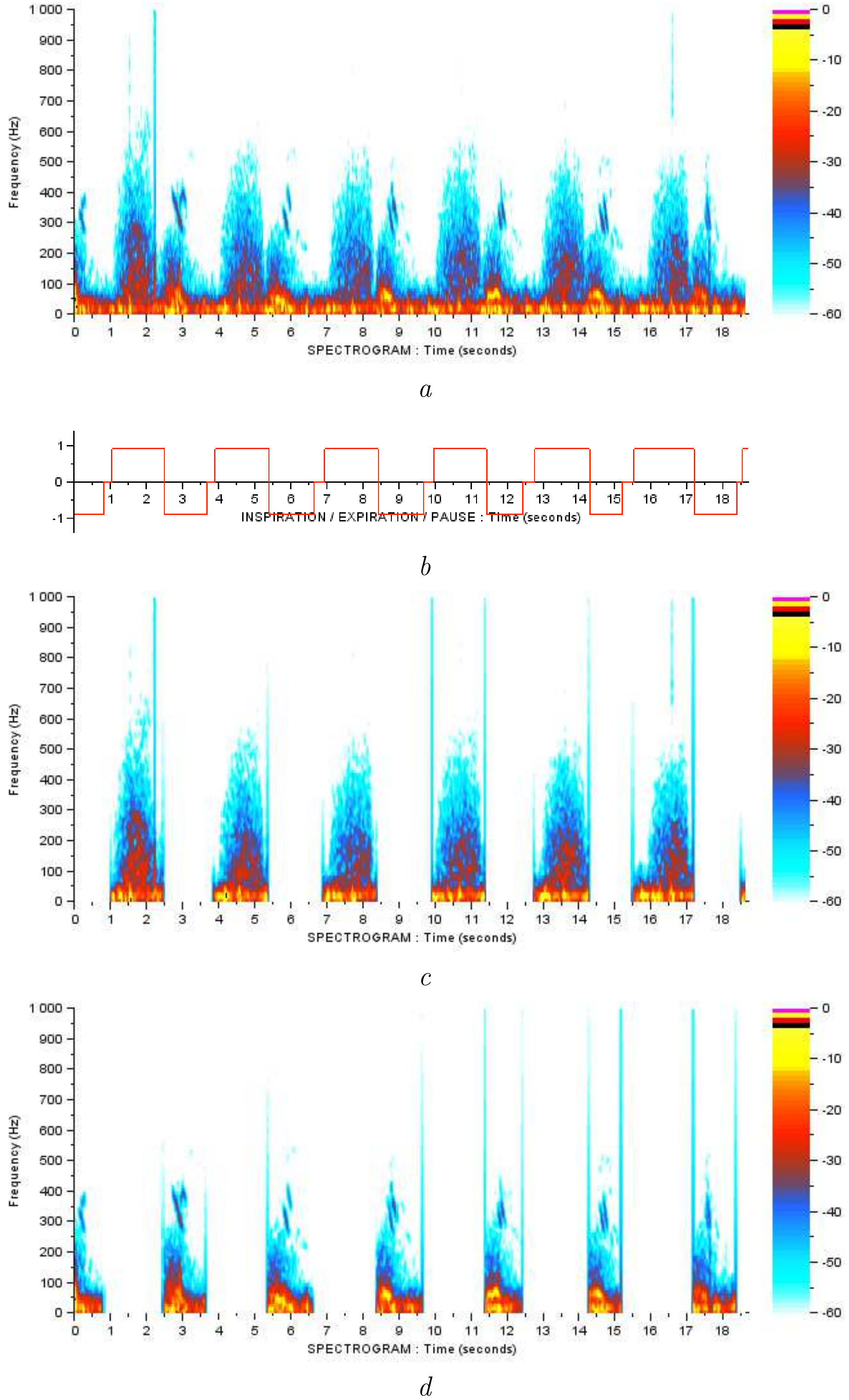

Fig. 2. An example of distinguishing of inspiration, expiration and pause for the COPD patient:
a – initial spectrogram of respiratory sounds; *b* – generated meander “inspiration – expiration – pause”;
c – clipped spectrogram (inspirations only); *d* – clipped spectrogram (expirations only);

REFERENCES

1. *Frederick H. A., Dodge H. F.* The “Stethophone”, an electrical stethoscope // Bell Syst. Thech. J..– 1924.– **3**, № 4.– P. 531–549.

2. *Artemiev A. M., Makarenkov A. P., Makarenkova A. A.* Studying the efficiency of electroacoustic transducers of electronic stethophonendoscopes // Acoust. Bul.– 2009.– **12**, № 1.– P. 3–10 [in Russian].

3. *Pasterkamp H., Carson C., Daien D., Oh Y.* Digital respirosonography. New images of lung sounds // Chest.– 1989.– **96**, N 6.– P. 1405–1412.

4. *3M Littmann 3200.* Available from: http://www.littmann.com/wps/portal/3M/en_US/3M-Littmann/stethoscope/stethoscope-catalog/

5. *Vovk I. V., Dakhnov S. L., Krizhanovskiy V. V., Oliynik V. N.* Changes of acoustical characteristics of breath sounds of pneumonic patients while recovering // Int. J. Fluid Mech. Res.– 2001.– **28**, № 6.– P. 772–786.

6. *Bouzakine T., Carey R., Taranhike G.* Distinguishing between asthma and pneumonia through automated lung sound analysis / Proj. MQP-RKS-0401.– Worcester, MA: Worcester Polytech. Inst., 2005.– 123 p.

7. *Makarenkova A. A.* Acoustic characteristics of breath sounds in patients ill with pneumoconiosis // Acoust. Bul.– 2008.– **11**, № 1.– P. 51–59 [in Russian].

8. *Global Strategy* for the Diagnosis, Management and Prevention of COPD, Global Initiative for Chronic Obstructive Lung Disease (GOLD). – 2013. Available from: http://www.goldcopd.org/

9. *Makarenkova A. A.* Investigation and objectifying of adventitious breath sounds in the patients with chronic obstructive pulmonary disease // Acoust. Bul.– 2010.– **13**, № 3.– P. 31–41 [in Russian].

10. *Kahya Y., Yilmaz C.* Modeling of respiratory crackles // Eng. Med. Biol. Soc. IEEE-EMBS.– 2000.– **1**.– P. 632–634.

11. *Moussavi Z. K., Leopando M. T., Rempel G. R.* Automated detection of respiratory phases by acoustical means // Proc. 20th Ann. Int. Conf. IEEE Eng. Med. Biol. Soc..– 1998.– **20(1)**.– P. 21-24.

12. *Vovk I. V., Grinchenko V. T., Dakhnov S. L.* Effect of physiological features of upper airways on the respiratory sounds characteristics // Int. J. Fluid Mech. Res.– 2004.– **31**, № 2.– P. 176–189.