

# Visualization of Lung Sounds Based on Multilevel Wavelet Analysis

Y.G. Gorshkov<sup>1</sup>

Bauman Moscow State Technical University, Russian Federation

<sup>1</sup> ORCID: 0000-0003-0483-4603, [y.gorshkov@npo-echelon.ru](mailto:y.gorshkov@npo-echelon.ru)

## **Abstract**

This article presents results of research in the field of high-precision visualization of lung sounds based on the technology developed by the author for multilevel wavelet analysis of acoustic biomedical signals. A review of publications on the study of lung sounds in recent years has been made. Based on the analysis of records of domestic and foreign databases, parameters are given, on the basis of which respiratory sounds should be attributed to complex non-stationary signals. At the same time, in almost all used phonospirographic complexes and software tools for analyzing pulmonary sounds, spectral characteristics are calculated using the Fourier transform or FFT, which leads to errors in the diagnosis of diseases.

The possibilities of the developed software tool for high-precision analysis of the sounds of lungs WaveView-MWA are considered. 40 records of two textbooks «Auscultation of the lungs» were processed using high-precision wavelet analysis algorithms. Examples of obtained acoustosonograms and frequency-time characteristics of pulmonary sounds in various diseases are presented. It is shown that acoustosonograms of multilevel wavelet analysis have an increased time-frequency resolution compared to Fourier spectrograms and provide visual high-precision visualization of lung sounds.

**Keywords:** analysis of lung sounds, phonospirogram, multilevel wavelet analysis, acoustosonogram.

## **1. Introduction**

Respiratory diseases are the third leading cause of death worldwide. With the growth of respiratory diseases, methods based on audio analysis of lung sounds are of increasing interest. Computer analysis methods have significant potential in the study of respiratory sounds to detect problems in the respiratory tract. Audio analysis simplifies the timely diagnosis of respiratory diseases in the early stages of respiratory dysfunction [1].

Auscultation still remains one of the well-known and widely used in clinical practice research methods for lung diseases. One of the disadvantages of auditory evaluation of acoustic signals of the lungs is that it is subjective. In addition, the latest data obtained by domestic and foreign researchers show that lung sounds are complex non-stationary signals. Recent studies show that the spectral components of sounds and respiratory noises of the lungs occupy the frequency range from 3-5 Hz to 5000 Hz. The acoustic auditory tract of a person does not physically perceive the low-frequency region of signals.

The development of computer technologies opens up new opportunities in the study of the acoustics of respiratory sounds, their processing, archiving and standardization [2, 3]. International research funded by the European Commission for Standardization of Computer Analysis of Respiratory Sounds CORSA (Computerized Respiratory Sound Analysis) is actively conducted. In 2017, the largest publicly available database on respiratory sounds ICBHI (Sound database of the international conference on biomedical and health informatics) was compiled, which contributed to the development of algorithms for determining common ab-

normal breathing sounds (wheezing and crackling) in clinical and preclinical conditions [4, 5].

The involvement of modern computer analysis technologies in the therapeutic clinic made it possible to obtain new information about the signs of pulmonary sounds. Automatic audio analysis of pulmonary sounds became possible using an electronic stethoscope [6, 7]. Devices have been created for automated diagnostics of respiratory noises, which is important at the early stages of recognition of critical patient conditions in pulmonology, acoustic mapping of respiratory noises, modeling of respiratory noises, as well as studying their origin. In this regard, the objectification of information obtained by new methods of computer digital auscultation of human breathing sounds is an urgent topic in biomedical acoustics.

The purpose of this study is a comparative analysis of the characteristics of auscultative signs (time-frequency parameters) of sounds and respiratory lung noises based on Fourier spectrograms of computer phonospirographic complexes that have become widespread in recent years and acoustic phonograms or "visible sound" images calculated using a new technology of multilevel wavelet analysis of signals.

## 2. Analysis of breathing sounds

A significant number of papers have been devoted to the computer study of lung sounds in recent years. The first respiratory noises that were subjected to computer analysis were crepitation and dry wheezing. Scientists started studying acoustic signs of main respiratory noises later, after objective signs of secondary respiratory noises were described and, most importantly, technical possibilities of separation of respiratory noises appeared, i.e. separation of the fraction of the main respiratory noises from the side noises layered on them [8-12]. For the auditory analyzer of the human brain, as you know, this problem has never existed.

In the study of breathing noises, the separation of sounds (side respiratory noises) into cod, pleural friction, dry and wet wheezing is most often used. They differ in frequency composition, duration and frequency of occurrence in the sound tract of respiration. Each of these phenomena is heard against the background of the main breathing – bronchial and vesicular, the presence of which in general is not a pathology [13]. Below is a summary table 1, which presents data on the frequency ranges of various breathing sounds obtained as a result of spectral analysis of signals based on the Fourier transform [14].

Table 1. Data on frequency ranges of lung sounds

Types breathing	Frequency, Hz													
	160	250	350	400	450	500	550	600	650	700	750	800	900	1500
Bronchial														
Vesicular														
Crepitus														
Pleural friction														
Dry wheezing														
Wet wheezing														

From the analysis of values of frequency boundaries of lung sounds, it follows that the main respiration (bronchial and vesicular) occupies a fairly wide frequency range. This causes the main difficulty in analyzing the sounds of breathing. In most cases, it is quite difficult to distinguish side respiratory noises against the background of the main breathing due to the overlap of frequency ranges and a small difference in amplitudes. It is determined that spectrograms using Fourier transform or fast Fourier transform (FFT) are calculated in almost all used phonospirographic complexes and software tools for analyzing lung sounds. At the same

time, it is proved that Fourier analysis in the study of complex non-stationary signals, which include sounds and respiratory noises of the lungs, leads to significant errors in their time-frequency representation.

## 2.1 Receiving phonospirograms

When obtaining phonospirograms or spectrograms based on the Fourier transform, power spectra are calculated, displayed as graphical dependencies of levels of spectral components on frequency. This method of processing allows to determine the level and frequency range of the most pronounced auscultative signs contained in the sounds of breathing but has a number of limitations. These include averaging signals over time and level, which levels out low-level auscultative signs. In fact, this is an ordinary spectrogram, which in respiratory acoustics is commonly called a phonospirogram (phono-sound; spiro-breathing; gram-drawing). Phonospirogram is a three-dimensional spectrogram of breathing sounds, displays "instantaneous spectra" in time in a polychrome color scheme.

Studies of breathing sounds conducted at the "KoRA-o3M1" complex have shown that the transformation of sound images into visual images allows objectifying auscultative signs characterizing a specific type of bronchopulmonary disease. Figures 1, 2 show examples of phonospirograms obtained on the basis of the Fourier transform [12].

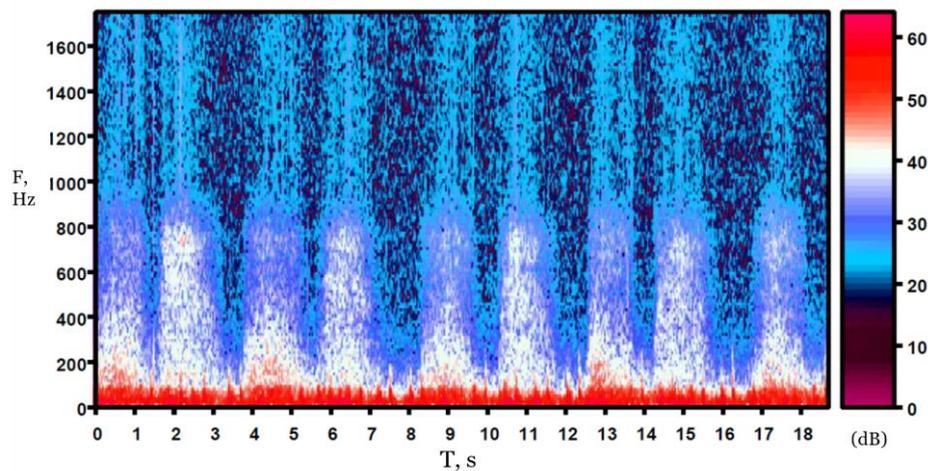


Fig. 1. Phonospirogram of a patient with hard breathing and wet wheezing

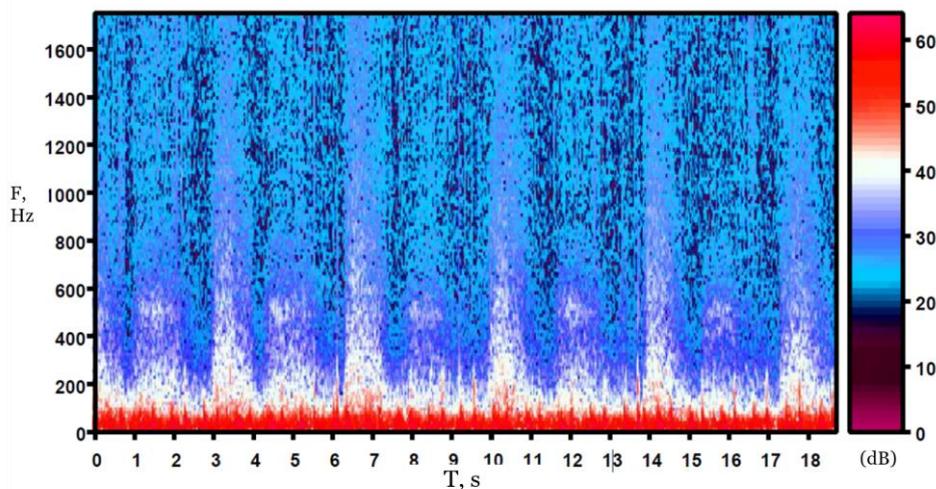


Fig. 2. Phonospirogram of breathing sounds with wheezing in the form of "clouds" and separate broadband wet wheezing

From the analysis of phonospirograms (spectrograms) of Figures 1, 2 it follows that the low-frequency range of pulmonary sounds of 3-200 Hz is presented with an insufficient level of time-frequency resolution.

### 2.2 Obtaining "visible sound" images of lungs based on the wavelet transform

The author has been conducting research in the field of computer analysis of lung sounds using wavelet technologies since 2013 [15-18]. WaveView-MWA software tools for high-precision processing and visualization of acoustic biomedical signals using multilevel wavelet analysis (MWA) have been developed [19-23]. A visual representation of the obtained set of frequency-time parameters of the analyzed signals – acoustic sonograms ("visible sound" images or wavelet sonograms) has been achieved. WaveView-MWA testing showed the ability to isolate and visualize pulmonary sounds of a small level up to -60 db.

Audio files of 40 recordings of two textbooks "Auscultation of the lungs" presented on Russian Internet sites were processed [24, 25]. Acoustic sonograms of the sounds of the sections "Basic respiratory noises. Additional breathing noises." A comparative analysis of spectrograms calculated by a computer phonospirographic complex based on Fourier transform and acoustic phonograms - time-frequency representations of the signal using multilevel wavelet analysis is carried out.

#### 2.2.1 Examples of acoustic phonograms of pulmonary sounds

Figures 3-7 show 5 out of 40 acoustic diagrams obtained as a result of processing audio files of recordings of two textbooks "Auscultation of the lungs" [24, 25].

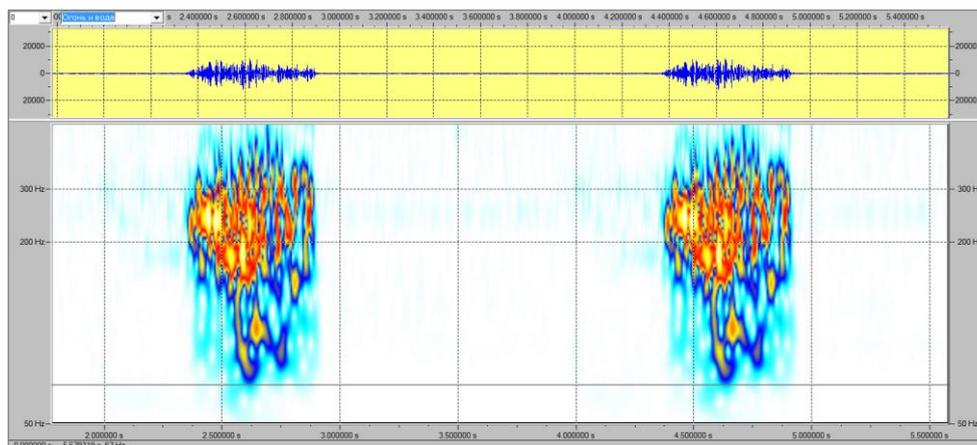


Fig. 3. Acoustic sonogram of the sound of vesicular respiration. Frequency range 67-600 Hz

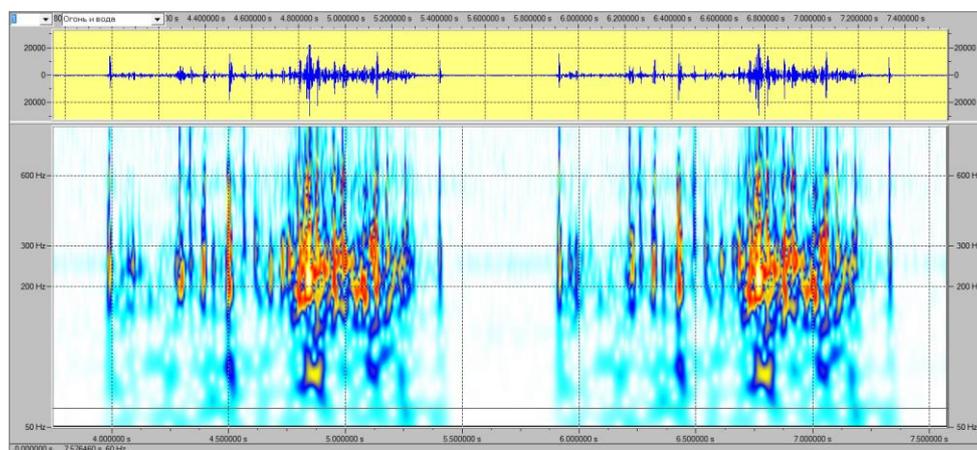


Fig. 4. Acoustic sonogram of the sound of medium-bubbly wet wheezes. Frequency range 60-900 Hz

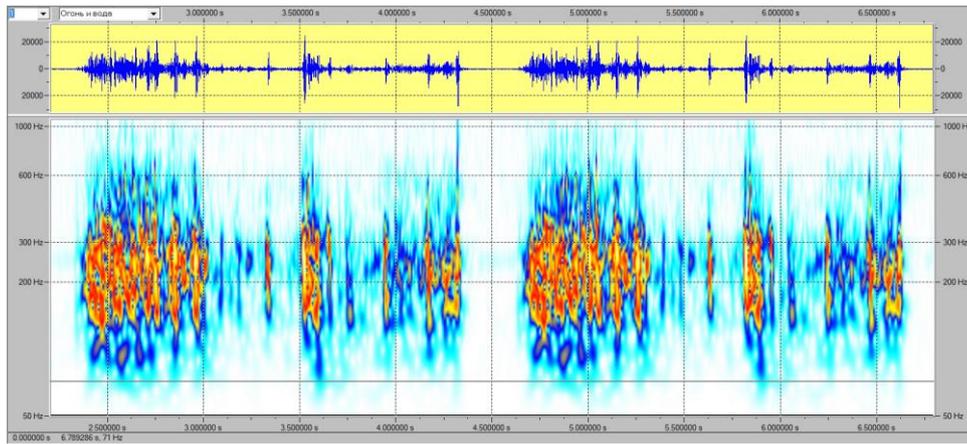


Fig. 5. Acoustic sonogram of sound is a rough noise of friction of the patient's pleura against the background of vesicular respiration. Frequency range 71-800 Hz

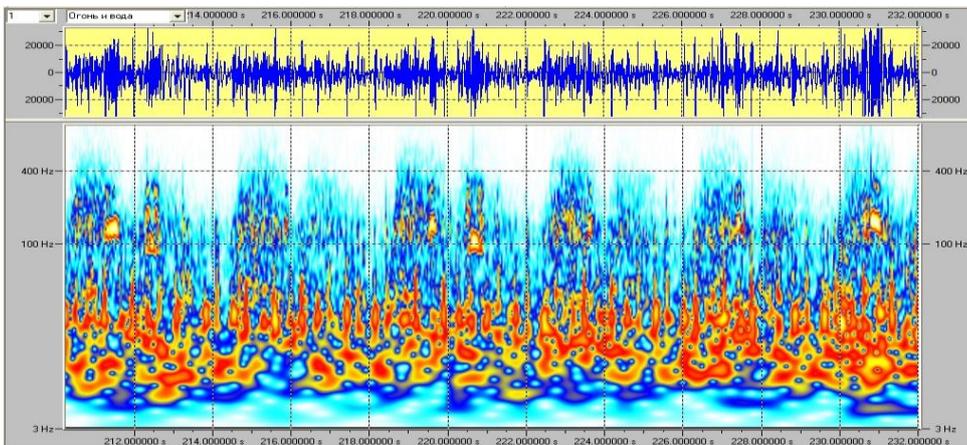


Fig. 6. Acoustic phonograms of dry bass wheezes. They are most often heard in patients with bronchitis. Frequency range 4-800 Hz

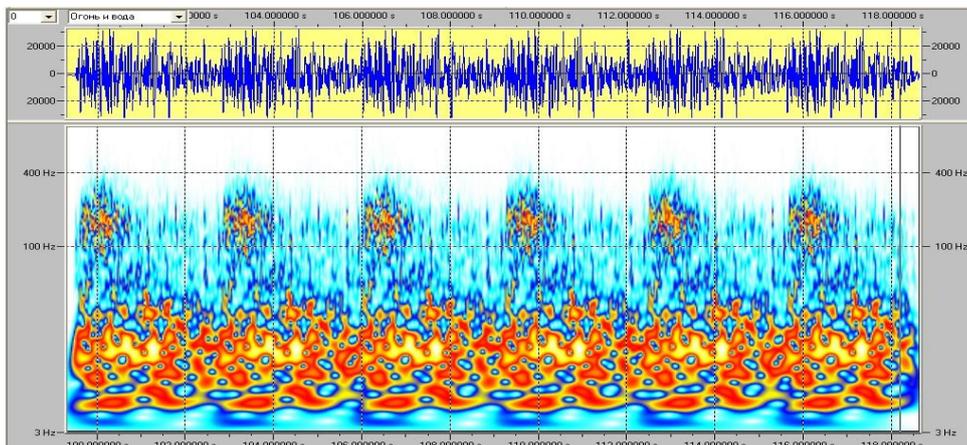


Fig. 7. Acoustic sonogram of puerile respiration recorded in a 4-year-old child. Frequency range 3-500 Hz

### ***2.2.2 Comparison of time-frequency resolution of acoustic phonograms and phonospirograms***

Figure 8 shows a Fourier spectrogram (phonospirogram) of the sound of puerile breathing of an infant [24]. There is an unsatisfactory frequency-time resolution of lung sounds in the low-frequency region.

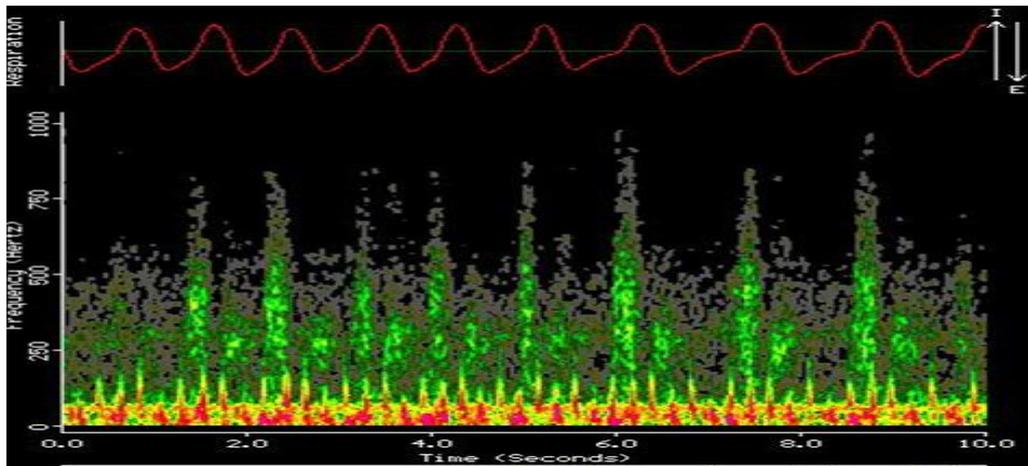


Fig. 8. Fourier spectrogram (phonospirogram) of the sound of puerile breathing of an infant

Figure 9 shows an acoustic sonogram of the same puerile sound of an infant's breathing, obtained using WaveView-MWA software. There is a high frequency-time resolution of lung sounds in a given frequency range. In the low-frequency region of 45-120 Hz, synchronously with breathing, a repeating structure of heart tones is visible.

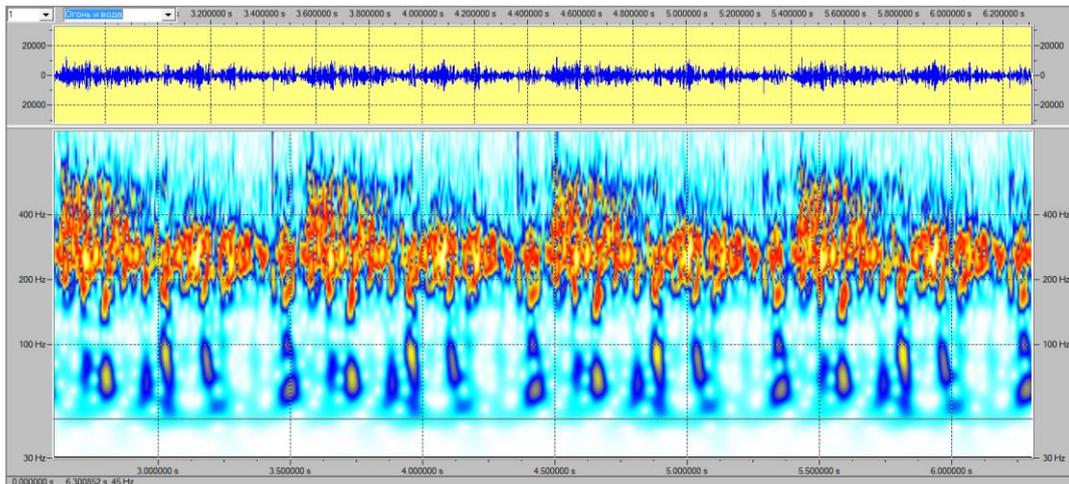


Fig. 9. Acoustic sonogram of the sound of puerile breathing of an infant

From the analysis of phonospirograms (Figures 1, 2, 8) and acoustic sonograms (Figures 7, 9) of pulmonary sounds, it follows that acoustic sonograms or wavelet sonograms have an increased frequency-time resolution compared with Fourier spectrograms. When processing 40 recordings of textbooks [24, 25], it was shown that acoustic phonograms make it possible to obtain a "thin" time-frequency structure of sounds and respiratory noises of the lungs, inaccessible to spectrograms. Acoustic sonograms, in addition, provide visual objective information of low-frequency sound components of the lungs, inaudible during auscultation and not displayed on Fourier spectrograms. A necessary condition for the construction of acoustic sonograms of high frequency-time resolution is the fulfillment of the requirements for the accurate registration of the studied sounds [26]. The received acoustic sonograms are issued in the form of supplements to the textbooks "Auscultation of the lungs" of the Far Eastern State Medical University (DSMU) of the Ministry of Health of the Russian Federation and the website "Medical Books and Atlases".

### 3. Conclusion

The developed software tools for multi-level wavelet analysis WaveView-MWA allow obtaining time-frequency descriptions - acoustic sonograms of sounds and respiratory noises of

the lungs with a resolution significantly exceeding the Fourier spectrograms of computer phonospirographic complexes. Acoustic sonograms provide visual, objective and complete information, which, with a remote doctor's consultation, allows you to assess the condition of patients' lungs at home and detect signs of pneumonia in time with coronavirus infection, as well as other diseases.

The proposed technology of visualization of pulmonary sounds confirmed its high efficiency in processing recordings of domestic textbooks "Auscultation of the lungs" and the international database on respiratory sounds ICBHI 2017.

The approbation of the developed technology of visualization of lung sounds in practice, when diagnosing the detection of obstructive sleep apnea syndrome (OSA) in patients, was carried out in the department of somnology of the FSBI NMIC of Otorhinolaryngology of the FMBA of Russia [27]. It allows you to perform a survey with minimal costs, to identify the primary signs of OSA both in a hospital and at home.

It may be of interest to developers of telemedicine systems for remote monitoring of the health status of patients undergoing outpatient treatment with signs of a new coronavirus infection COVID-19, whose condition allows them to be monitored at home.

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