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Audio-visual based recognition of auscultatory breath sounds using Fourier and wavelet analyses

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ABSTRACT— ***In the era of computer management on clinical data, it is essential to establish new technique to analyze auscultatory sounds that is capable to better understanding for both physicians and patient. In this paper, we describe about visual-based recognition technique of breath sounds using two spectrograms created by short term FFT and wavelet analyses. The changes of frequency, intensity and tone with time of breath sounds (twenty-one specimens) could be shown by two kinds of spectrograms. Thus, abnormal breath sounds could be simply detected by differences of those patterns. It would assist recognition of associated condition of disease. We expect to become a diagnostic support system in near future.***

Keywords— Breath Sound, Visualization, Image Analysis, STFFT and Wavelet

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1. INTRODUCTION

Since the invention of the stethoscope by René Laennec, auscultation became possible practical new method of bedside examination [1]. Auscultation is performed to examine the circulatory, respiratory and gastrointestinal systems. However, it is a subjective method that depends on quite clinical experience, good listening skills and auditory perception to differentiate sound patterns.

Breath sounds can be divided into two categories, normal and abnormal (adventitious) sounds, according to their acoustic characteristics as shown in table 1. Abnormal sounds are divided into continuous and discontinuous sounds depend on their duration. Continuous sounds are further subdivided into wheezes and rhonchus. Discontinuous sounds are similarly divided into fine crackle and coarse crackle. In other words, abnormal breathing sound is additional sounds that are heard over normal breath sounds. Thus, the main task is to recognize those abnormal sounds.

On the other hand, the shared bands between audible sounds and auscultatory sounds are very narrow and low pressure with negative decibel as seen in Fig. 1 (the tracheal and vesicular sounds plotted are that of Fig. 3 and Fig. 8 respectively). Therefore, there are difficulties to appreciate abnormal breath sounds even with the stethoscope because the sensitivity of the human ear in detecting lower frequency and pressure of sound is relatively poor. Therefore, it needs special attention to changes in frequency and sound pressure with time. One of solutions is to make sound visible.

Many newer imaging techniques for the evaluation of breath sounds have been tried. Kandaswamy et al. reported [2] on the classification of breath sounds using the artificial neural network with wavelet transform into six categories: normal, wheeze, crackle, squawk, stridor, or rhonchus. Styliani A. et al. reported [3, 4] on the nonlinear analysis method of wheezes using wavelet bicoherence, and described the nonlinearities of wheezes with time. And there are many reports on pattern recognition of wheeze class [5], an integrated automated system for crackles recognition [6], signal analysis using FFT [7] and wavelet [8]. However, most of them are reports about mathematical procedures. Thus it is essential to prepare visual-based evidence of auscultatory sound from practical viewpoint. Hence, we have proposed [9] a visual based recognition technique of the heart sounds using both short term fast FFT and wavelet analyses, and demonstrated the validation of the procedures.

In the present paper, we report on visual-based recognition technique of breath sounds using two kinds of spectrograms created by short term FFT and wavelet analyses. The feasibility assessment was performed using twenty-one breath sounds of the textbook with CD [10]. The results showed that abnormal breath sounds can be recognized by image pattern recognition.

Table 1: Classification of breath sounds and its acoustic characteristics

Normal sounds :	
i) tracheal breath sounds	iii) bronchovesicular breath sounds
ii) bronchial breath sounds	iv) vesicular breath sounds
Abnormal (adventitious) sounds :	
・continuous sound (longer than 0.25s)	
・wheeze (over 400 Hz, with a musical tone, low or high-pitched)	high / low frequency
・rhonchus (less 200 Hz)	low: dry whistlelike noise , resemble snoring
・discontinuous sound (less than 0.25s)	
・crackle	
fine crackle (≈1000 Hz)	high frequency : crepitation
coarse crackle (<500 Hz)	low frequency : bubbling rale
・other (miscellaneous sound)	
pleural friction rub	low : sound like walking on fresh snow

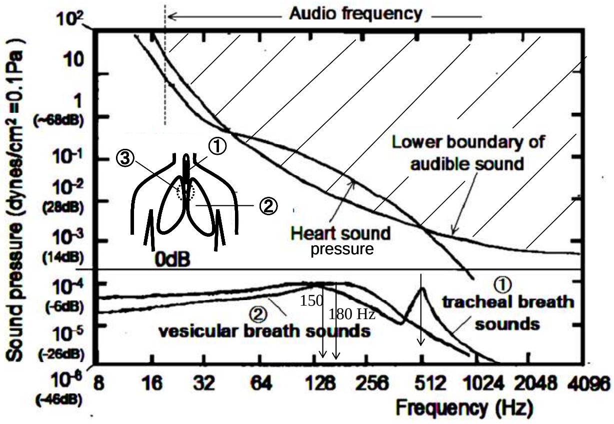

Figure1: A graph showing frequency bands of audible and breath sounds; note very low sound pressure with negative decibel. The curves (1 and 2) were plotted by referring the literature [10].

2. METHOD AND SPECIMENS

The organs of the respiratory system consist of the airway (nose, pharynx, larynx, trachea, and bronchial tube) and the lungs. With breathing, air flows in and out of the respiratory tree. It produces complicated variation of air velocity that induces laminar and/or turbulent flows and vibrations in the airway walls by location. Furthermore diseased respiratory tissue, mucus, or pus can produce abnormal sounds such as rales (rhonchus) and a whistling sound (wheezing). As a result, it appears changes in frequency, intensity (soft, loud), and continuous (wheeze) or discontinuous (crackle) sounds. In this report, two techniques were used to show spectrogram: short-term Fast Fourier transform with a Gaussian window and continuous wavelet transform (CWT) with a complex Morlet function. Those are powerful tools to analyze time-frequency characteristics, which is the same technique applied to the heart sounds [9].

2.1 Visualization of breath sounds by applying short-time Fourier transform and wavelet analyses

STFFT (Short-Term Fast Fourier Transform) Analysis

The Fourier transform is computed as a fixed-length window slides along the time axis, resulting in a two-dimensional representation of the signal. Thus, it has a fixed resolution; the width of the windowing function relates to how long the signal is represented by spectrum. A wide window gives good frequency resolution but poor time resolution, while a narrow window gives good time resolution but poor frequency resolution. To analyze overall trend with time of oscillating phenomenon, this is better technique. The analysis condition of breath sounds is shown in Table 2: in case of the heart sound [9] was also shown.

CWT (Continuous Wavelet Transform) Analysis

To analyze the specific frequency of breath sounds in detail, we applied CWT analysis. In general, wavelet transformation has the ability to simultaneously clarify the spectral and temporal information within the signal [11]. This method overcomes the basic shortcoming of Fourier analysis, which is that the Fourier spectrum contains only globally averaged information, which leads to location-specific features in the signal being lost. If the scale parameter of the mother wavelet function is constant, it gives the same analysis window width for all frequencies. For analyzing breath sounds, a small window width is needed in with wide bands. Then, the complex Morlet function [11, 12] and a scaling parameter are applied. The relationship between the frequency (F) and the center frequency (F_c) is given by

$$F=\Delta F_c / a_n, \qquad \text{--- (1)}$$

where Δ is the sampling frequency, F_c is the center frequency, and the scaling parameter a_n is given by a numerical sequence,

$$a_n = a_1+kn(n - 1), \qquad \text{--- (2)}$$

where k is arbitrary constant and n is time of scaling. The value allows detail analysis at higher frequency bands than for integer values of a_n. Figure 2 shows the relation between frequency and the scale a_n (a_1 =5, k= 0.0014 and n=100) for the breath sounds.

Table 2: Calculation conditions of STFFT and wavelet analyses for breath sounds

	Breath sound	Heart sound [9]
Mother wavelet	Complex Morlet wavelets	Complex Morlet wavelets
Sampling frequency, Δ Hz	10000	5000
Time of scaling, an : a_1=5	5 - 144 (n=1 - 100)	5 - 150 (n=1 - 121)
Arbitrary constant, k	0.014	0.01
Analyzed frequency, Hz	70 - 2000	33~1000

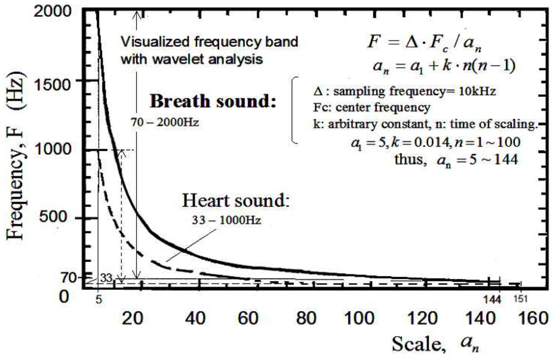

Figure 2: The relationship between frequency (F) and scale a_n in Eq. 1: a =5, k = 0.014 and n_1=100.

2.2 Specimens

Normal breath sounds are classified as tracheal, bronchial, bronchovesicular, and vesicular sounds depending on location of auscultation. While there are many types of diseases of the respiratory system such as pneumonia, pulmonary edema (PE), pleuritis sicca, bronchial asthma (BA) and so on. Therefore, breath sounds induced by disease are complicated. To demonstrate the audio-visual based recognition technique proposed here, twenty-one specimens were quoted from the compact disc (CD) of the textbook [10] as shown in the table 3 and 4: the diagnosed result and its comment were partly quoted in the discussion. In the report, two categories were divided as follows:

A: tracheal and bronchoalveolar breath sounds, five specimens of ① and ③

① tracheal breath sounds
② vesicular breath sounds
③ bronchoalveolar breath sounds

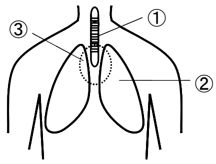

Table 3: Tracheal and bronchoalveolar breath sounds quoted from the CD [10].

No	Associated conditions	Remarks
1	Normal tracheal breath sounds	Fig. 3
2	Normal bronchovesicular breath sounds	Fig. 4
3	Bronchial stenosis, low-frequency continuous sounds	Fig. 5
4	Bronchial asthma, low-frequency continuous sounds	Fig. 6
5	Bronchial asthma, low-frequency continuous sounds (sputum retention)	Fig. 7

B: vesicular breath sounds, sixteen specimens of ② vesicular breath sounds

Table 4: Vesicular breath sounds quoted from the CD [10].

No	**Associated conditions**	**Remarks**
1	Normal vesicular breath sounds	Fig. 8
2	Mild pulmonary fibrosis, fine discontinuous sounds	Fig. 9
3	Pulmonary fibrosis, fine discontinuous sounds	Fig. 10
4	Hypersensitivity pneumonitis, fine discontinuous sounds (recorded during slow breath)	Fig. 11
5	Chronic articular rheumatism, fine discontinuous sounds	Fig. 12
6	Early stage heart failure (recorded during deep breathing), fine discontinuous sounds	Fig. 13
7	Bronchiectasis (secretions in the airway), coarse discontinuous sounds	Fig. 14
8	Bronchiectasis, coarse discontinuous sounds	Fig. 15
9	Mild pneumonia, coarse discontinuous sounds	Fig. 16
10	Lobar pneumonia, coarse discontinuous sounds	Fig. 17
11	Acute pulmonary edema, coarse discontinuous sounds	Fig. 18
12	Bronchial asthma, high tone continuous sounds	Fig. 19
13	Bronchial stenosis, high tone continuous sounds, wheezes monophonic	Fig. 20
14	Sinobronchial (SB) syndrome, discontinuous and continuous sounds	Fig. 21
15	Bronchiectasis (BE) with squawk	Fig. 22
16	Pleuritis sicca and dry pleurisy, pleural rub sounds (snowball crepitation)	Fig. 23

3. RESULTS AND DISCUSSION

A: tracheal and bronchoalveolar breath sounds

1) Normal tracheal breath sounds

Figure 3 shows normal breath sounds of a healthy person: a) waveform of sound, b) spectrogram by STFFT, and c) spectrogram by wavelet transform. In the present report, the STFFT image shows whole frequency-time spectrogram, and wavelet shows spectrogram of 70~250Hz as a visible pattern and it is on the nonlinear scale.

At first glance, it might seem an abnormal breath sound. However, the result indicates the existence of carotid pulse (70~150Hz with interval of ≈0.9 second) because the stethoscope was put at the trachea where is near cervical artery. Repeated images of the carotid pulse were formed of slim and vertically long shape as seen in the Fig 3 (c). The carotid pulse was shown by symbol “CP” and arrow in the figure. Therefore, by ignoring the carotid pulse wave, it can be understood that normal tracheal breath sounds is clear and soft sound like air is being blown through a pipe.

In brief, it would be a strong tool that both of STFFT and wavelet analyses are useful for identifying unrecognized sound(s).

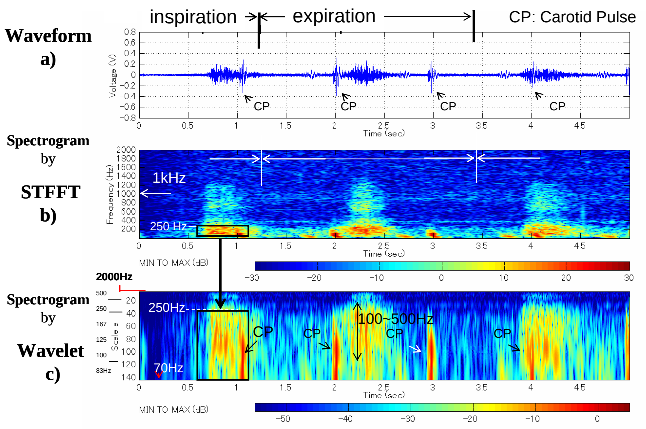

Figure 3: Normal tracheal breath sounds

2) Normal bronchovesicular breath sounds

Figure 4 shows normal breath sounds at the posterior chest between the scapulae and in the center part of the anterior chest. The time of between during inspiration and expiration is nearly equal. And it has middle intensity and low frequency about 200Hz. Now, we give an eye to slim and vertically long shaped spectrogram in the Fig. 4 (c), then periodic the heart sound (HS) can be found; symbol “HS” and arrows are shown in Fig. 4 (a). By applying the both STFFT and wavelet methods, It helps to have a short path through for recognizing a plurality of sound sources.

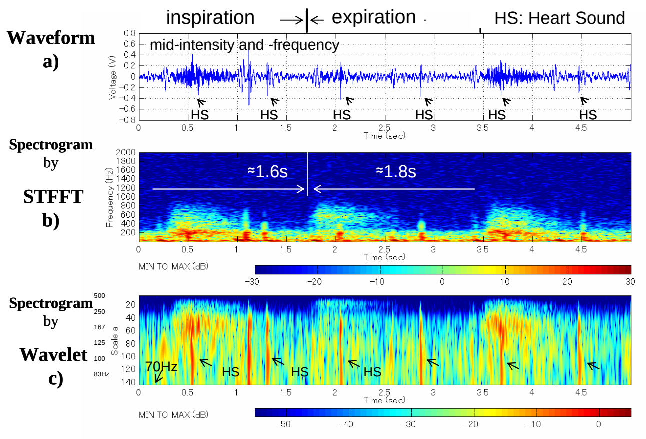

Figure 4: Normal bronchovesicular breath sounds

3) Bronchial stenosis, low-frequency continuous stenos

Figure 5 shows sound of a bronchial stenosis patient. The stenosis is a disease that causes a variety of failure in cavity some of the bronchial becomes narrower than usual. It is known that sounds are continuous monophonic rhonchus [10]. Therefore, the wavelet image shows unique shape and long expiration time with frequency of about 200 Hz as shown in Fig. 5 c).

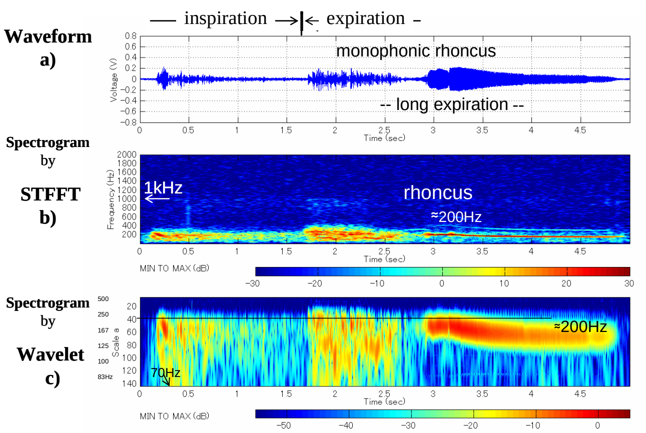

Figure 5: Bronchial stenosis, low-frequency continuous sounds

4) Bronchial asthma, low-frequency continuous sound

Figure 6 shows sound of a bronchial asthma patient. A symptom of the disease is that bronchi become narrower, shortness of breath and wheezy sound from the small bronchial tubes when breathing. The result shows moderate polyphonic rhonchus during the phase of inspiration and low intensity rhonchus during the phase of expiration. And the wavelet image shows typical rhonchus by obvious distribution map of the disease. It is obvious that difference between STFFT and wavelet images. Thus, the importance of utilizing the both figures is clear.

5) Bronchial asthma, low-frequency continuous (sputum retention)

Figure 7 shows sound of a bronchial asthma with sputum retention patient. The result of the sound shows polyphonic and intense rhonchus of 70~200 Hz. The wavelet image shows clear variations of frequency during the phrase of inspiration and expiration. It is easy to understand than the STFFT image.

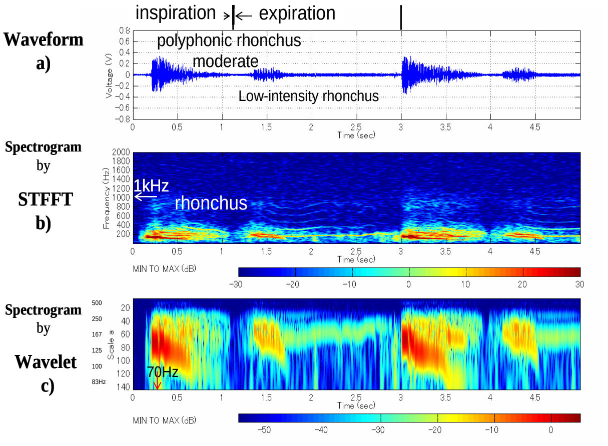

Figure 6: Bronchial asthma, low-frequency continuous sounds

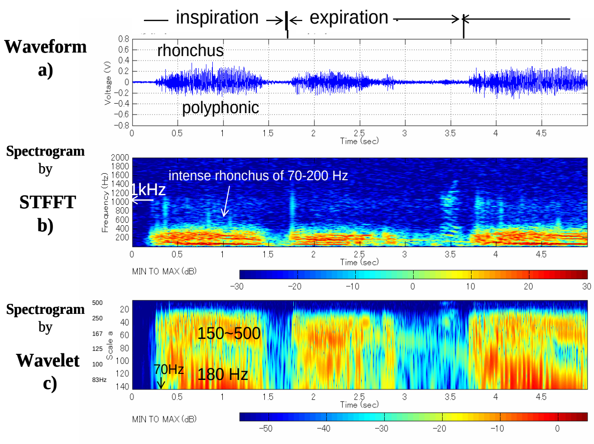

Figure 7: Bronchial asthma, low-frequency continuous sounds (sputum retention)

B: vesicular breath sounds

1) Normal vesicular breath sounds

Figure 8 shows a normal breath sounds. The sound shows low-pitched quality with high intensity about 180 Hz during the phase of inspiration and shows softer sound during the phase of expiration. In Fig. 1, the frequency differences between this vesicular breath sound and the bronchial sound (Fig.3) are shown; the peak frequency of two sounds is about 180 Hz (monophonic sound) and 100~500Hz (fluctuating sound) respectively. The normal vesicular breath is soft and whisper sounds than others.

2) Mild pulmonary fibrosis, fine discontinuous sounds

Figure 9 shows sound of a mild pulmonary fibrosis patient. Sign and symptom of the disease are rapid respiration (tachypnea) with respiratory cycle of about 1.6s and discontinuous sounds. It is observed intense fine crackles during latter half of the inspiration and then coarse crackles during the phase of expiration. The characteristic shape of crackle sounds is slim and vertically long shape that frequency range is about 1000 Hz and moderate 600~1800 Hz as seen in the STFFT and wavelet images; color distribution shows intensity of the sound. Thus, it will be easy to differentiate fine crackle or other sounds from viewpoint of the frequency range and its repeat variation.

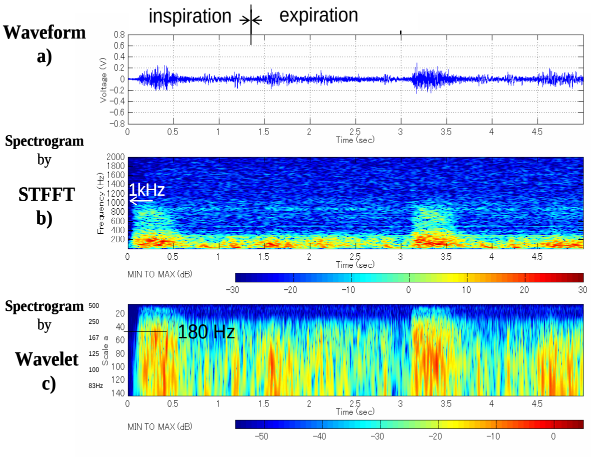

Figure 8: Normal vesicular breath sounds

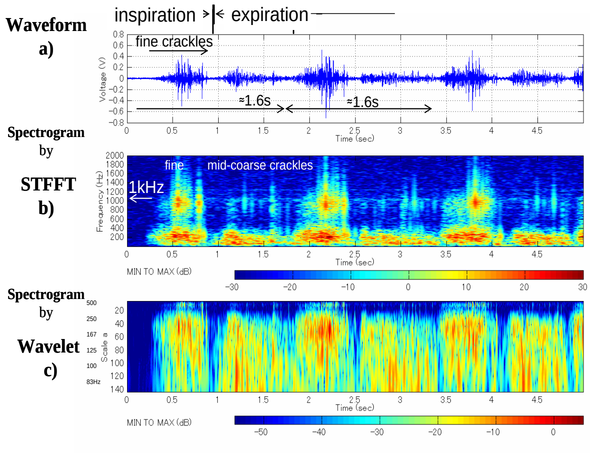

Figure 9: Mild pulmonary fibrosis, fine discontinuous sounds

3) Pulmonary fibrosis, fine discontinuous sounds

Figure 10 shows sound of a pulmonary fibrosis patient. Sign is rapid respiration due to difficult breathing; respiratory cycle of about 1.7s. It is observed intense fine crackle with about 1k Hz during the phase of inspiration and no crackle during the phase of expiration.

4) Hypersensitivity pneumonitis, fine discontinuous sounds (sound recorded during slow breath)

Figure 11 shows the sound recorded during slow breathing of a hypersensitivity pneumonitis patient. It is known that the disease most often occurs in people who work or live in places with high levels of dust. Many fine crackles (crepitant rale) with moderate intensity during the phase of inspiration and discontinuous soft sounds during the phase of expiration can be clearly seen in the STFFT and wavelet images.

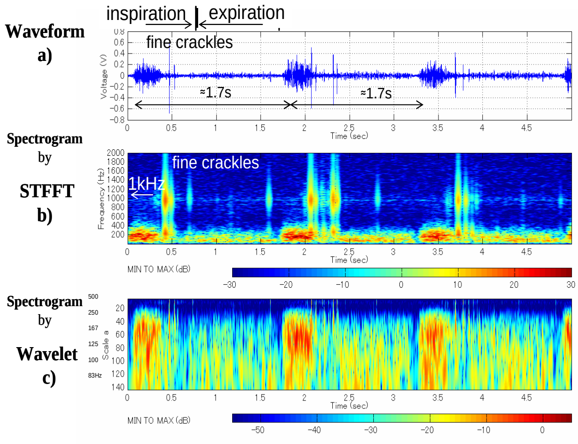

Figure10: Pulmonary fibrosis, fine discontinuous sounds

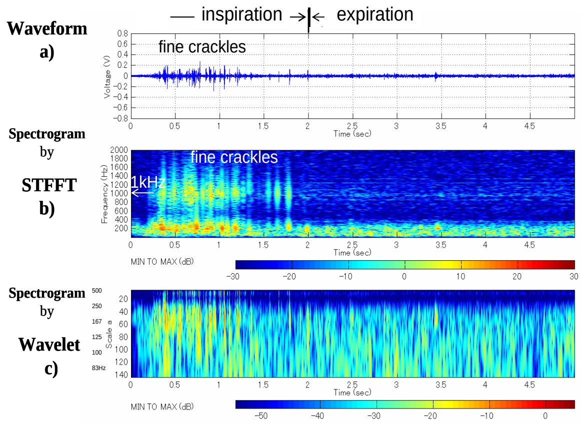

Figure11: Hypersensitivity pneumonitis, fine discontinuous sounds (recorded during slow breathing)

5) Chronic articular rheumatism, fine discontinuous sounds

Figure 12 shows sound of a chronic articular rheumatism patient. Very intense fine crackles during the phrase of inspiration and discontinuous soft sounds during the phase of expiration can be clearly seen in the figure.

6) Early stage heart failure (recorded during deep breathing), fine discontinuous sounds

Figure 13 shows sound of early stage heart failure (asked repeat deep breath). The sounds include fine crackle also with low-frequency during the phrase of inspiration. In case of fine crackle induced by elevated legs, there is a possibility of position-induced sound that suggest disease of potential heart failure and pulmonary congestion [13].

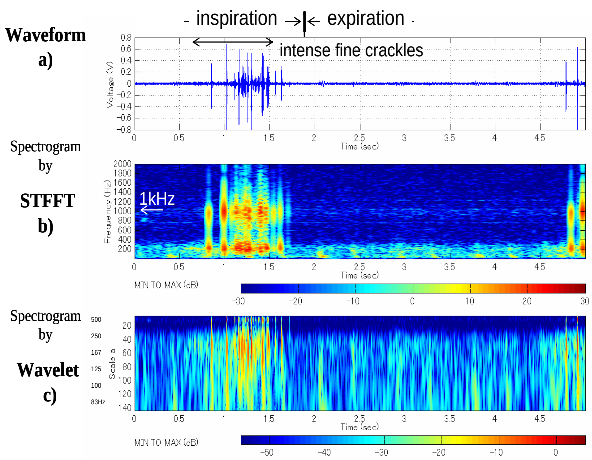

Figure12: Chronic articular rheumatism, fine discontinuous sounds

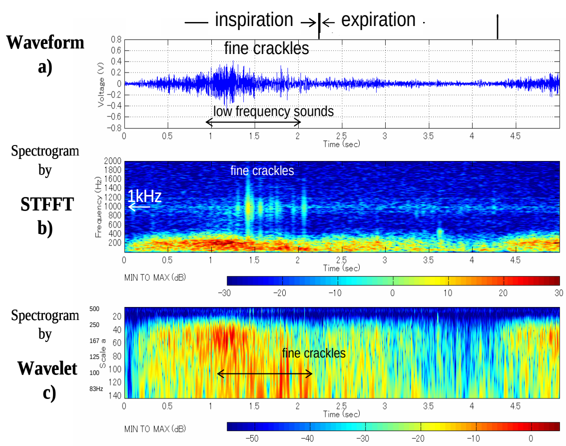

Figure 13: Early stage heart failure (recorded during deep breathing), fine discontinuous sounds

7) Bronchiectasis (secretions in the airway), coarse discontinuous sounds

Figure 14 shows sound of a bronchiectasis (secretions in the airway) patient. Many coarse crackles and then fewer crackles due to secretions remained in the airway are seen. Frequency of the coarse crackle is about 250 Hz.

8) Bronchiectasis, coarse discontinuous sounds

Figure 15 shows sound of a bronchiectasis patient. It can be seen that many coarse crackles and then fewer crackle during the phrase of inspiration and the phrase of expiration, respectively. The coarse crackles is bubbling sound due to bronchiectasis [10]. It can be seen discontinuous bubbling sound (coarse crackles) due to bronchiectasis in the figures.

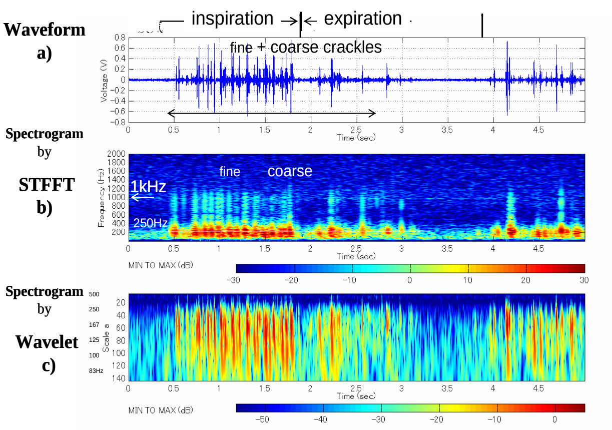

Figure14: Bronchiectasis (secretions in the airway), coarse discontinuous sounds

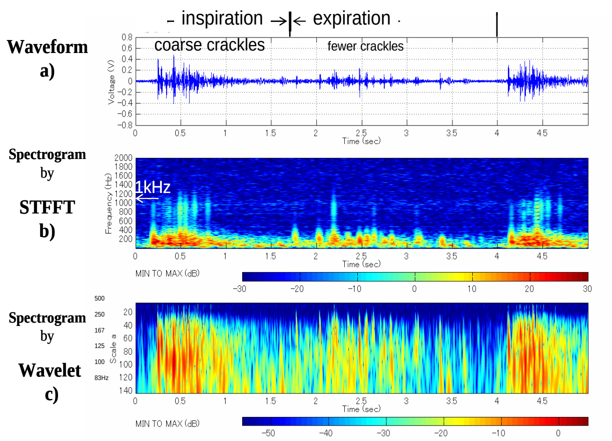

Figure 15: Bronchiectasis, coarse discontinuous sounds

9) Mild pneumonia, coarse discontinuous sounds

Figure 16 shows sound of a mild pneumonia patient. Some single crackle with mostly low and partly high frequencies can be seen due to mild pneumonia. There is no feature in the distribution of low-frequency sound as seen in the wavelet image.

10) Lobar pneumonia, coarse discontinuous sounds

Figure 17 shows sound of a lobar pneumonia patient. It can be seen that both intense fine and coarse crackles during the phase of inspiration and expiration. As seen in the figure, the visual based recognition technique is useful for in case of complicated sounds.

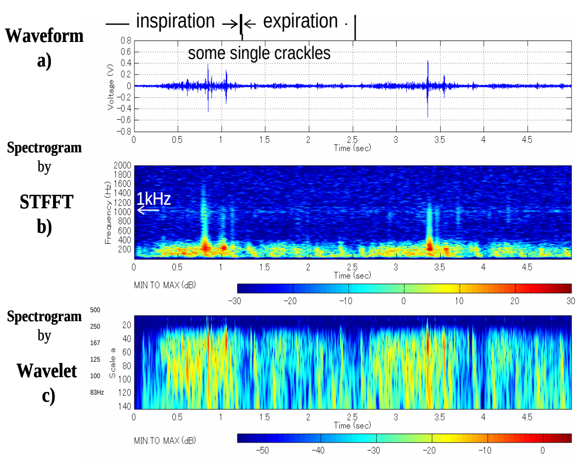

Figure 16: Mild pneumonia, coarse discontinuous sounds

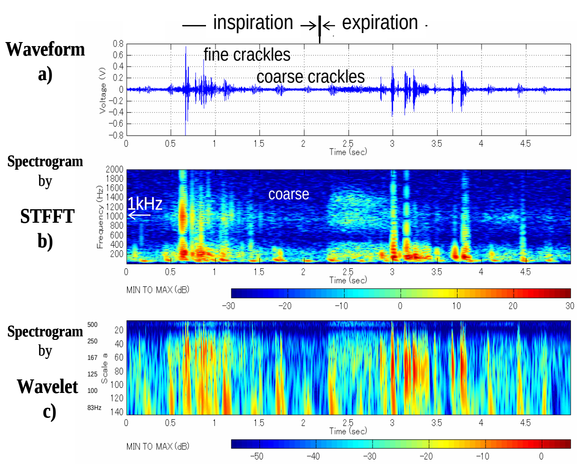

Figure17: Lobar pneumonia, coarse discontinuous sounds

11) Acute pulmonary edema, coarse discontinuous sounds

Figure 18 shows sound of an acute pulmonary edema patient. Typical intense coarse crackles can be seen during the phase of inspiration and expiration. The frequency distribution of coarse crackles can be seen in the wavelet image.

12) Bronchial asthma, high tone continuous sounds

Figure 19 shows sound of a bronchial asthma patient. High-pitched tone continuous and intensive sounds during last half of the phase of expiration are appeared. The frequency is about 380 Hz, near wheezing sound.

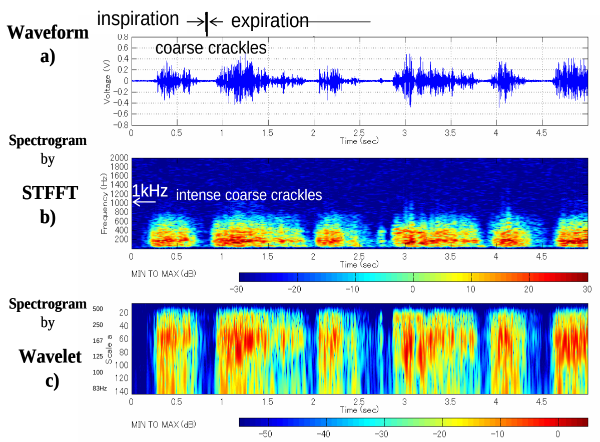

Figure 18: Acute pulmonary edema, coarse

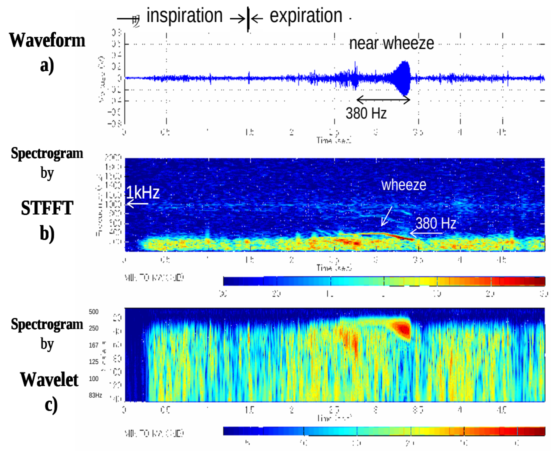

Figure 19: Bronchial asthma, high tone discontinuous

13) Bronchial stenosis, high tone continuous sounds, wheezes monophonic

Figure 20 shows sound of a bronchial stenosis patient including wheezes monophonic. It appears crackles and long-time monophonic continuous sounds (wheeze) about 800 Hz can be seen during the phase of expiration as seem in the STFFT image.

14) Sinobronchial (SB) syndrome, discontinuous and continuous sounds

Figure 21 shows sound of a sinobronchitis syndrome patient. It appears intense fine crackles and wheeze during the phase of inspiration, and fine, coarse crackles and polyphonic continuous during the phase of expiration. Spectrogram of wheeze is shown as typical stripe images in the STFFT and wavelet results.

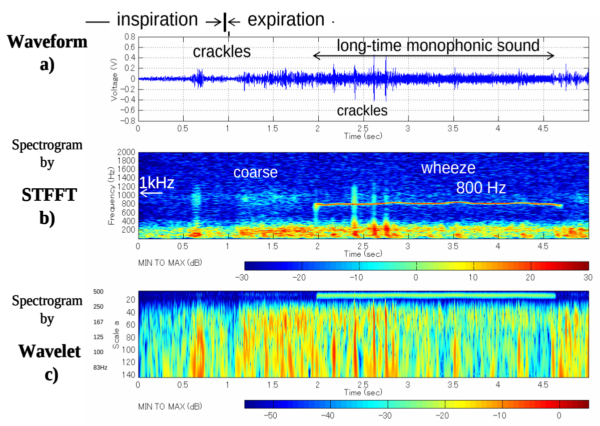

Figure 20: Bronchial stenosis, high tone continuous sounds, wheezes monophonic

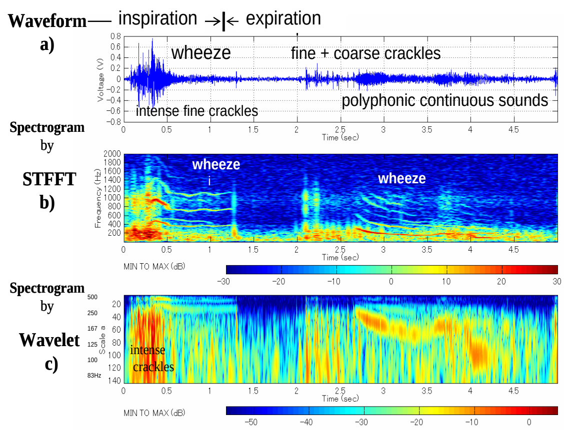

Figure 21: Sinobronchial (SB) syndrome, discontinuous and continuous sounds

15) Bronchiectasis (BE) with squawk

Figure 22 shows sound of a bronchiectatic patient. It appears monophonic or polyphonic squawk (wheeze) with both low and high frequency sounds after discontinuous coarse crackles [10]. The STFFT image allows recognition of these sorts of sounds clearly.

16) Pleuritis sicca and dry pleurisy, pleural rub sound (snowball crepitation)

Figure 23 shows sound of pleuritis sicca and dry pleurisy patient. It appears typical sound occurred by rubbing of the parietal pleura, intense crepitation (low and high frequencies) during inspiration and discontinuous sounds (about 250 Hz) during expiration. Associated conditions are pleuritis, pneumonia, and pulmonary embolism.

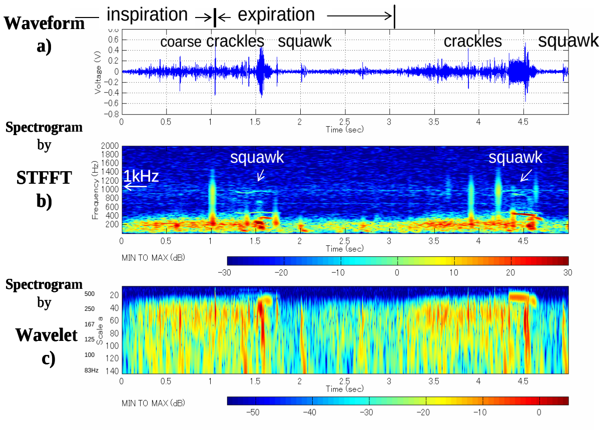

Figure 22: Bronchiectasis (BE) with squawk

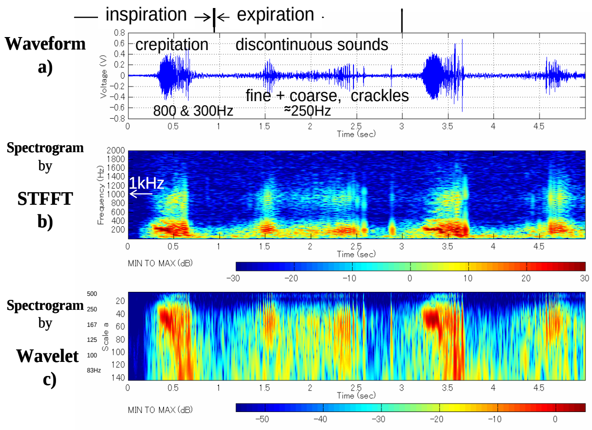

Figure 23: Pleuritis sicca and dry pleurisy, pleural rub sounds (snowball crepitation)

C: A characteristic classification of breath sounds

As seen in the figures mentioned above, auscultatory breath sounds are very complicated. Figure 24 shows the typical characteristic of abnormal sounds classified according to image pattern. It was selected from the viewpoint of acoustic properties shown in Table 1. These image patterns will become useful evidence for both physicians and patients. Therefore, we are able to classify different kinds of lung diseases by referring these patterns.

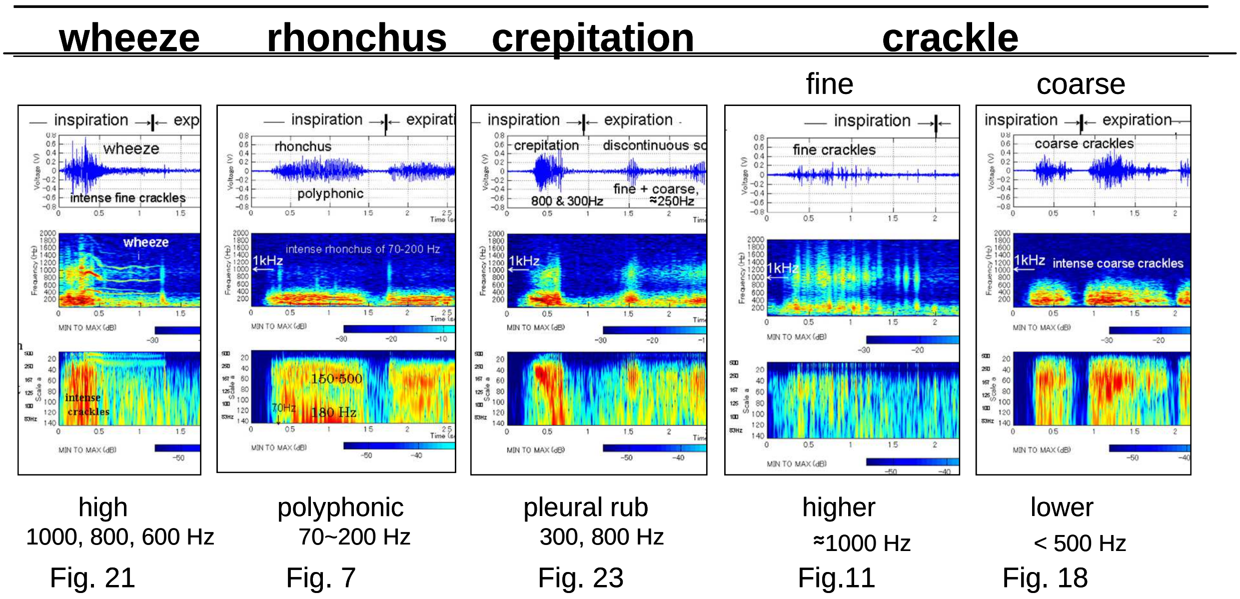

Figure 24: Typical characteristic classification of abnormal sounds as image pattern recognition

4. CONCLUEDING REMARKS

Since there are various difficulties associated with auscultation, we proposed an audio-visual based recognition method to assist in the evaluation of breath sounds. A feasibility assessment was performed using twenty-one breath sounds recorded in a CD of the textbook [10]. It is summarized as follows:

1) Two types of images created by Fourier and wavelet analyses give a strong tool to recognize causes of abnormal sounds. In the report, STFFT image showed global frequency band and wavelet image showed specific frequency of the sounds between 70~2000 Hz on a nonlinear scale. As visible image of the distribution, frequencies of 70~250 Hz are clearly shown. That is, we can focus on low frequency band depending upon the coefficients of Table 2.

2) Using the both spectrogram images of STFFT and wavelet, it assists to detect differences and classification of breath sounds such as wheeze, rhonchus, crepitation, crackle and so on.

3) It may be able to develop a detection system based on the image pattern recognition. It will assist to diagnose associated condition of disease.

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6. REFERENCES

[1] I.R. Hanna and M.E. Silverman, "A history of cardiac auscultation and some of its contributors," American J. of Cardiology, 90-3,pp. 259-267,2002.

[2] A. Kandaswamy, C. Sathish Kumar, Rm. Pl. Rm. Pl. Ramanathanc, S. Jayaraman, N. Malmurugan, "Neural classification of lung sounds using wavelet coefficients" Computers in Biology and Medicine 34,pp.523–537, 2004.

[3] Styliani A. Taplidou, Leontios J. Hadjileontiadis "Nonlinear analysis of wheezes using wavelet bicoherence", Computers in Biology and Medicine, Volume 37, pp.563-570, 2007..

[4] Styliani A. Taplidou, Leontios J. Hadjileontiadis "Wheeze detection based on time-frequency analysis of breath sounds" Computers in Biology and Medicine Volume 37, Issue 8, August, pp.1073–1083,2007.

[5] Mohammed Bahoura "Pattern recognition methods applied to respiratory sounds classification into normal and wheeze classes", Computers in Biology and Medicine, Volume 39, Issue 9, September, pp. 824–843,2009.

[6] Xiaoguang Lu, M. Bahoura, "An integrated automated system for crackles extraction and classification", Biomedical Signal Processing and Control, Volume 3, No.3, pp.244–254, 2008.

[7] Gwo-Ching Changa, Yung-Fa Laib, "Performance evaluation and enhancement of lung sound recognition system in two real noisy environments", Computer methods and programs in biomedicine, 97 (2010) pp.141-150.

[8] A. Marshalla,_, S. Boussakta, "Signal analysis of medical acoustic sounds with applications to chest medicine", Journal of the Franklin Institute,344, pp.230–242,2007.

[9] Fumio Nogata, Yasunai Yokota, Yoko Kawanura, Hiroyuki Morita, Yoshiyuki Uno, W. R. Walsh, "Audio-visual based recognition of auscultatory heart sounds with Fourier and wavelet analyses", Global Journal of Technology and Optimization,3, pp.43-48, 2012.

[10] Tsuneo Ishihara (supervising editor), "Pulmonary auscultation, Lung sounds on compact disc", Nankodo Co. Ltd., Tokyo (Japan), 1st. ed. (13), 1993.

[11] P.S. Addison, "Illustrated wavelet transform handbook introductory theory and applications in science, engineering, medicine and finance," Institute of Physics Publications ,2002.

[12] D. Kumar D, Carvalho P, Antunes M, et al. "Third heart sound detection using wavelet transform-simplicity filter," Conf. Proc. IEEE Eng. Med. Biol. Soc., 1277–1281, 2007.

[13] Mami Iida, Kohshi Gotoh, Yasuo Yagi, Sadao Ohshima, Yukio Ohsumi, Noritaka Yamamoto, Fumiko Deguchi, Senri Hirakawa" Study on the genesis of posturally induced crackles from hemodynamic data- in patients with ischemic heart disease having normal respiratory function", Volume 37(9) pp.1009-1014, 1989.