MICROCOMPUTERIZED RESPIRATORY SOUND RECORDER
A Low Cost Device

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Abstract: Auscultation of breathing sounds is a common practice since the antiquity. In 1819, Laënnec invented the stethoscope and published the first work on pulmonary disorders and their associated sounds. Since then, the auscultation was incorporated into medicine. The first electronic device to record and analyze physiological sounds was built in 1955, being followed by many other developments. In 2000, a task force of the European Respiratory Society established guidelines for computerized respiratory sound analysis (CORSA). Our work describes a low cost microcomputerized system, based on the CORSA guidelines, developed to acquire and record breathing sounds as well as respiratory flow waveforms. It consists of a four channel micro-controlled device that can simultaneously record sounds from three different sources and flow waveform. These signals are transmitted to a microcomputer running dedicated software that shows the waveforms on the screen and stores them into the hard disk. The developed device was tested in patients with heart failure, idiopathic pulmonary fibrosis, pneumonia and asthma. Examples of the registered signals and results of a qualitative assessment of the developed system are presented.

1 INTRODUCTION

In 1819, Laënnec developed a noninvasive diagnostic tool for the assessment of pulmonary diseases named stethoscope (Laënnec, 1819). Based on necropsies, he associated respiratory sounds auscultated on the thorax to pathologies, such as: edema, pneumonia, tuberculosis, bronchitis and emphysemas. However, lung sound auscultation carried out with the stethoscope is a subjective procedure, since it depends on the experience and hearing acuity of the examiner (Garcia, 2002). Besides, the human auditory system is not very sensitive to the frequency response of stethoscopes that attenuate components above 120Hz (Sovijärvi et al., 2000).

In 1955, the first electronic device to record and analyze biological sounds was developed (McKusic et al., 1955), being followed by other projects in the decades of 60 and 70 (Forgacs, 1969; Weiss and Carlson, 1972). In 1987, the International Lung Sounds Association proposed a common nomenclature that has been used internationally (Mikami et al., 1987). Computerized methods to record and analyze respiratory sounds may overcome many limitations of the auscultation. Nevertheless, the conclusive characterization of the sounds belonging to different respiratory disorders was being hampered by the fact that researchers were employing systems with different technical specifications for the sound acquisition. To circumvent that, the European community promoted the CORSA (Computerized Respiratory Sound Analysis) project that established guidelines for the investigation of lung sounds (Sovijärvi et al., 2000).

The adventitious respiratory sounds are classified in discontinuous or continuous (Sovijärvi et al., 2000). Pulmonary crackles are discontinuous, be-
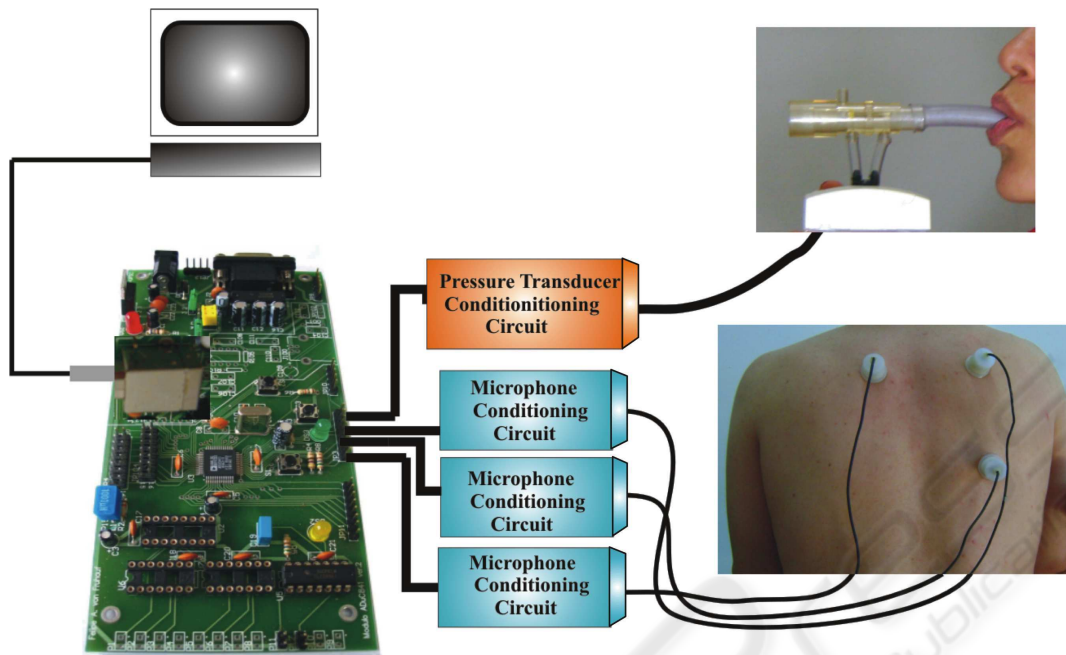
Figure 1: Microcomputerized system for acquisition of breathing sounds and flow waveforms. There are three channels to record sounds and one channel to register the flow signal.
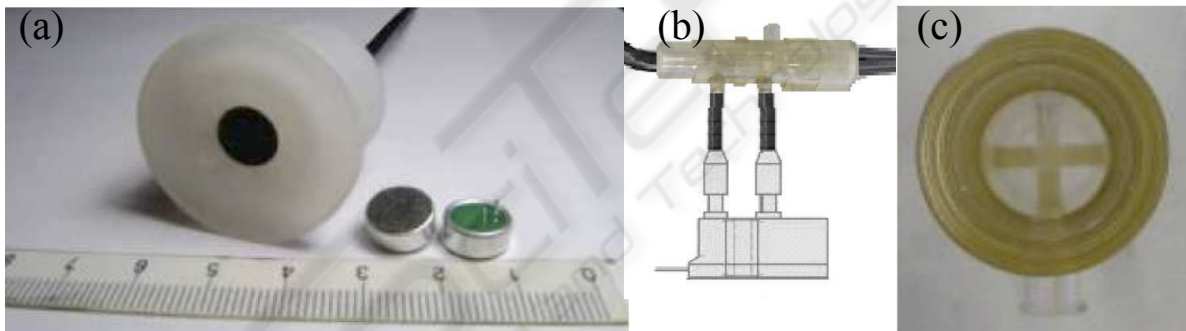

Figure 2: (a) Microphones and acoustic coupler manufactured in nylon; (b) Connections of the pressure transducer to the pneumotacograph (PT); (c) View of the PT resistance that provides pressure drop proportional to the flow velocity.

ing described as short, explosive and transient sound waves, characterized by a rapid initial pressure deflection, called a spike, followed by a short duration ringing and are usually associated with recruitment of obstructed airways (Alencar et al., 2001; Hantos et al., 2004). They occur in heart failure, fibrosis, pneumonia and others. The wheezes and rhonchi are continuous adventitious sounds and are caused by narrowed upper airways and secretion in bronchial airways, respectively. Wheezes are periodic, containing a single tone (monophonic) or many related harmonic tones (polyphonic).

This work presents a low cost system to record breathing sounds that was developed according to the CORSA recommendations. It also records flow wave-

form simultaneously.

To assess the developed system, sounds and flow waveforms were recorded from patients with heart failure, fibrosis alveolitis, pneumonia and asthma. The quality of the recorded sounds was analyzed by specialists. The recorded waveforms as well as the results of the qualitative assessment of the developed system are presented.

2 MATERIALS AND METHODS

Figure 1 depicts the block diagram of the developed system. It consists of a conditioning module (microphones, pressure sensor, amplifiers and filters), a con-
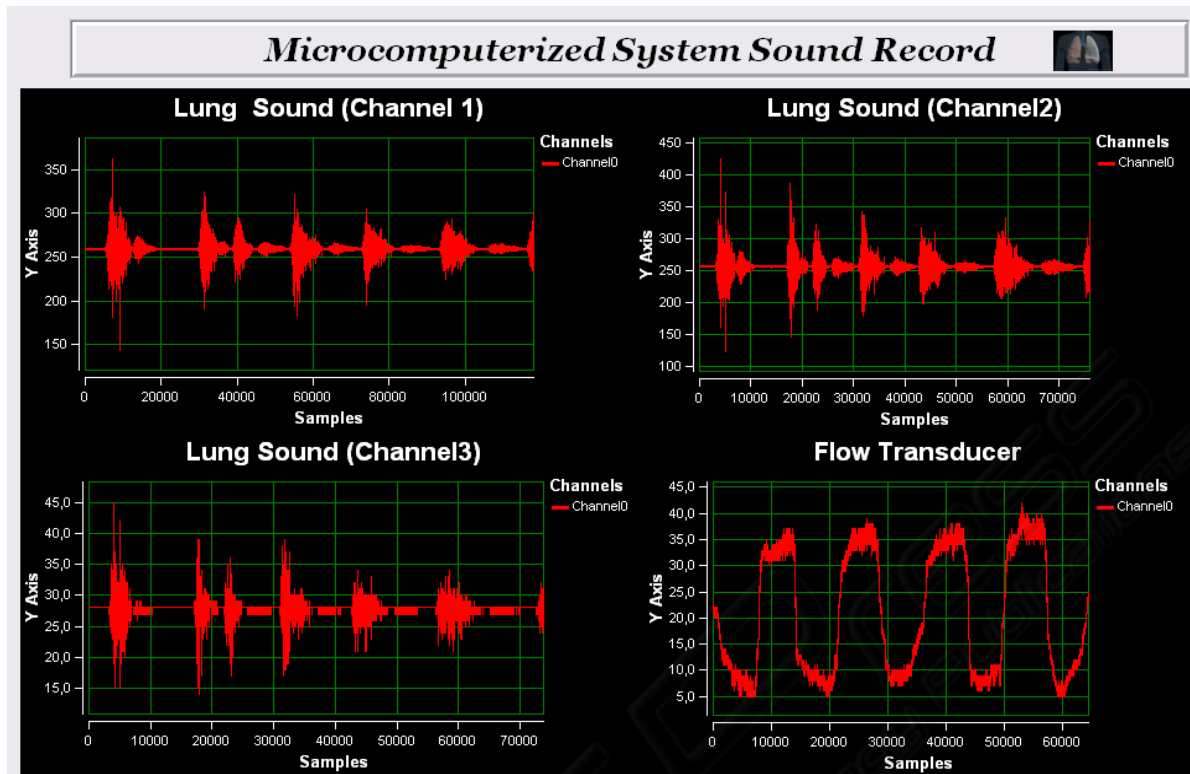
Figure 3: Screen of the software showing four acquired waveforms. On the top, left to right, lung sounds of the channels 1 and 2, respectively. On the bottom left, lung sound of the channel 3. On the bottom right, the flow waveform.

trol module (microcontroller and communication interface) and software for Windows® OS. The next subsections describe each module of the developed system.

2.1 Conditioning Module

The breathing sounds are acquired on the thorax using 3 electret microphones (MD9745APA-1 – Knowles Acoustics) that are housed by acoustic couplers manufactured in nylon (Fig. 2) according to the dimensions recommended by previous studies (Kraman et al., 1995). This microphone model has small dimensions (9.7 × 4.5 mm), low weight (about 1g), a flat frequency response from 100 to 3000 Hz, signal to noise ratio of 55 dB, output impedance of 2.2 kΩ, and sensitivity of 9 mV/Pa.

2.1.1 Flow Transducer

To sample the flow waveform, the volunteer breaths through an acrylic tube containing a pneumotacograph (PT). The pressure drop across the pneumotacograph resistance is proportional to the flow velocity (Doeblin, 1990). The transducer (DC030NDC4 – Honeywell) measures the differential pressure

through the obstacle in a range of ±76.2 cmH$_2$O. It has a sensitivity of 52.36 mV/cmH$_2$O, generating a voltage output of 2.25 ± 2.0 V. Figure 2 shows how the transducer inputs are connected to the PT apertures as well as the flow resistor. The pressure drop is negative for inspiratory flow and positive for expiratory flow.

Electrical signals generated by the microphones have low amplitude, requiring amplification and filtering (anti-aliasing) before being sampled. The signal generated by each microphone is applied to a preamplifier with a gain of 2 that also accomplishes impedance matching to the next circuit stage (Sedra and Smith, 2004). The amplified signal has its bandwidth limited from 60 to 2500Hz by two second order Butterworth filters in cascade. The high pass filter attenuates the low frequency sounds produced by the heart that may saturate the circuit, distorting the sampled signal. The low pass one attenuates sounds that are above the expected frequency content of the crackles. These respiratory sounds have the highest frequency components that may achieve up to 2000 Hz (Sovijärvi et al., 2000). The filtered signal is further amplified to 600 times by the inherent filters gains and by software programmable gain amplifier (IC AD526 – Analog Devices).

The output voltage signal of the pressure trans-

ducer is filtered by a second order Butterworth low pass filter with a cut-off frequency of 40Hz. The signal amplitude is adjusted to the maximum value of the acquisition module (0 to 2.5V), considering the maximum expected flow range (-70 to +70ℓ/min). For that, it is amplified and summed to a dc offset to achieve positive values. The obtained resolution is 17.9mV(ℓ/min)$^{-1}$.

2.2 Control Module

The main IC of the control module is the ADuC841 microcontroller (Analog Devices), an optimized single-cycle 20 MHz 8052 core. It has a 12-bit analog to digital converter (ADC) fed by an 8-channel analog input multiplexer, four different memory blocks (62 kiB of flash for code, 4 kiB of flash for data, 256 bytes of general-purpose RAM and 2 kiB of internal XRAM), 3 timers, serial communication interfaces (UART, SPI, I2C) and 2 digital to analog converter (DAC) of 12 bits.

After being filtered and amplified, the three respiratory signals and the flow waveform are simultaneously sampled at 10 kSPS by a sample - and - hold (IC SMP04 - Analog Devices). The ADuC841 gets, one by one, the sampled voltage values and converts them to digital. It carries out the conversion in 8 μs with a voltage resolution of 0.61mV (1LSB=2.5 V/4096).

The digital samples are sent to the data-transfer device (IC FT245BM – Future Technology Devices Intl.) that establishes the USB communication with a notebook, transferring data at the rate of 1MiB/sec (Axelson, 2005).

2.3 PC Software

Software developed in C++ Builder establishes the communication between the computer and the control module. For that, USB driver made available by the FT245BM manufacturer is employed.

The received data contain multiplexed samples of each channel. The samples have a header with the number of the channel to which they belong.

The software demultiplexes the received data and shows them on the screen in real time. To achieve that, a scientific chart library for plotting multiple curves (Scope) is used (Scientific Plotting Library) since the native C++ Builder library is quite slow for real time applications. Each sampled waveform is stored into the hard disk in individual wave files. Figure 3 shows the screen of the developed software.

3 RESULTS

To assess the qualitative performance of the developed system, adventitious sounds were recorded from patients of a Medical School Hospital (Federal University of Santa Catarina) after the approval by its Research Ethics Committee (Process number:181/2007).

The patients were in a room without noise level control (infirmary). Based on the medical records, clinical signs, chest x-rays and lung function studies, the patients were diagnosed with the following pulmonary conditions: heart failure (2 men), idiopathic pulmonary fibrosis (3 men), pneumonia (2 men) and asthma (5 women).

Figures 3 and 4 show examples of sound curves as well as flow waveforms that were simultaneously recorded using the developed system.

The sounds collected from twelve patients (without any post-processing) were reproduced to seven respiratory sound specialists of the Therapeutic Laboratory in the Medical School of the University of São Paulo (LTFMUSP). The specialists filled up a questionnaire on the quality of the recorded sounds. 42 opinions were obtained (Table 1). Besides the sound quality, the questionnaire aimed to evaluate the need for further processing of the sounds to improve the diagnosis.

4 DISCUSSION

Figure 4a shows that crackles occurred during the inspiration and expiration for a fibrosis patient. Patient with heart failure had crackles only at the end of the inspiration (Figure 4b). It should be noted that this condition may generate crackles during expiration as well (Piirilä et al., 1991; Vyshedskiy et al., 2009). Figure 4c and d shows an expanded crackle waveform. The American Thoracic Society (ATS) uses time intervals of the expanded crackle waveforms (initial deflection width (IDW) and two-cycle duration (2CD)) to classify the crackles in two classes: fine, or high pitched crackles, and coarse, or low pitched crackles (American Thoracic Society, 1977). Figure 5a shows crackles and wheezes acquired from a patient with pneumonia. Figure 5b shows the expanded wheezes also known as squawks (Paciej et al., 2004).

Figure 6 shows a short acoustic interval containing wheezes (and its sonogram) acquired from a patient with acute asthma. It is possible to see that the recorded sound has more than one tone, being named, therefore, polyphonic wheezes.
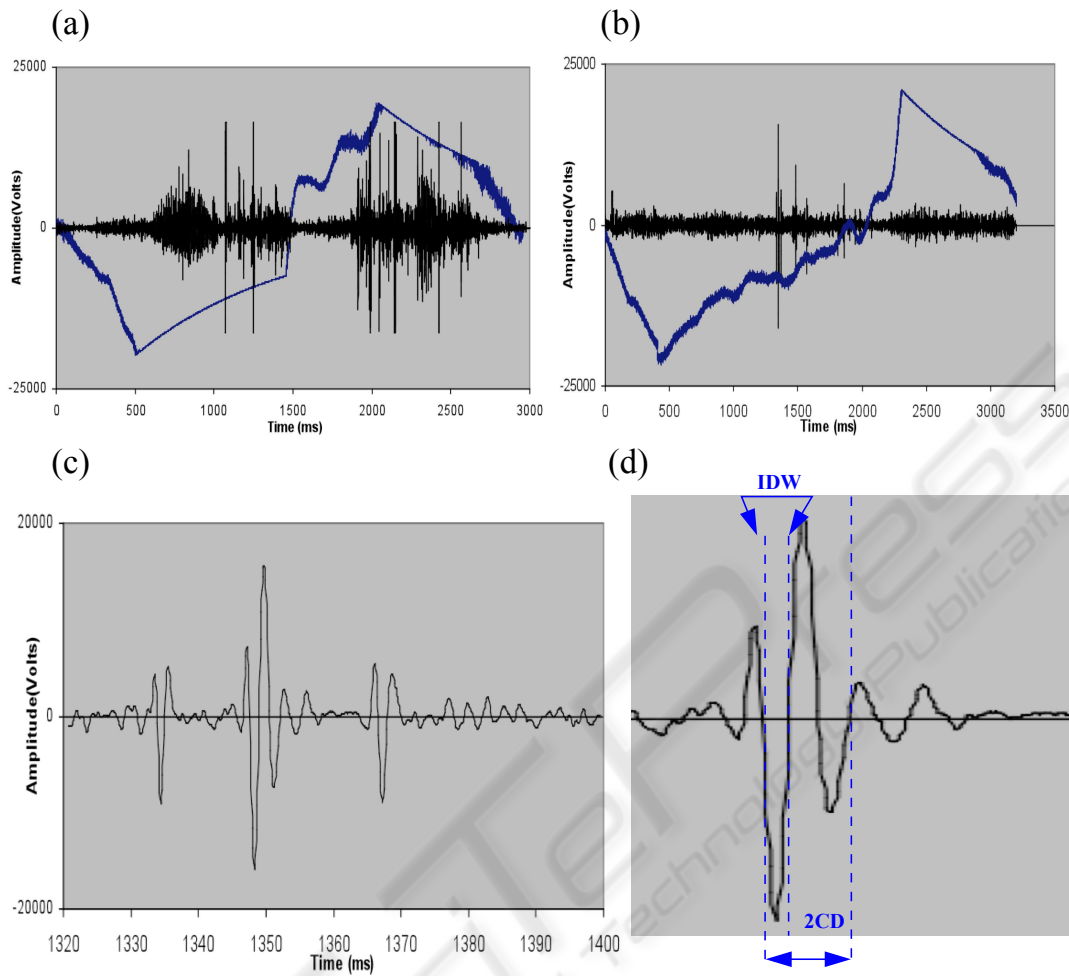
Figure 4: Crackles and flow waveforms recorded from patients with idiopathic pulmonary fibrosis (a) and heart failure (b). The sound and flow waveforms are shown by the black and blue lines, respectively. (c) Zooming of the crackles shown in (b). (d) The waveforms, initial deflection width (IDW) and two-cycle duration (2CD) waveforms of the strongest crackle shown in (b).

Table 1 summarizes the answers of the 42 questions posed to specialists on the quality of the sounds recorded with the developed system. The specialists heard background noise interference in nearly 15% of the recordings. They reported heart sounds superimposed to the adventitious sounds in about 27% of the recordings. The majority of the specialists considered that the noise level contained in the recordings was low enough to allow the sound classification.

In the infirmary, background noise is always present and it will be also heard when using a stethoscope. When the sound is recorded, digital signal processing techniques may be applied to reduce the interferences due to the background noise and due to the heart sounds.

5 CONCLUSIONS

Auscultation of breathing sounds using stethoscopes is a relevant medical practice. Nevertheless, it does not allow the information to be quantified, stored, reproduced, visualized or processed. Therefore, it is difficult for the specialists to exchange information and educate new professionals.

Breathing sounds acquired with microphones and recorded with eletronic devices contain information of a given patient lung condition that can be stored and does not depend on the specialist subjectivity.

The application of digital signal processing techniques to these signals may allow the development of quantitative methods to assist the diagnosis.

This work presented a low cost system that is able to acquire and store respiratory sounds and flow wave-

Table 1: Specialists answers about the respiratory sounds recorded with the developed system.

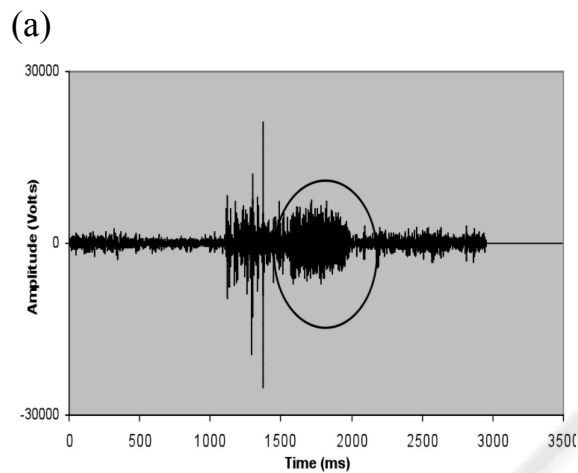|			No	Yes
Is there environmental noise in the respiratory sounds?			85.7%	14.3%
Is there heart sounds mixed with the respiratory sounds?			73.8%	26.2%
	Low	Acceptable	High	Unacceptable
Classify the level of the intrinsic system noise added to the respiratory sounds.	31%	47.5%	21.5%	0%

(a)

(b)
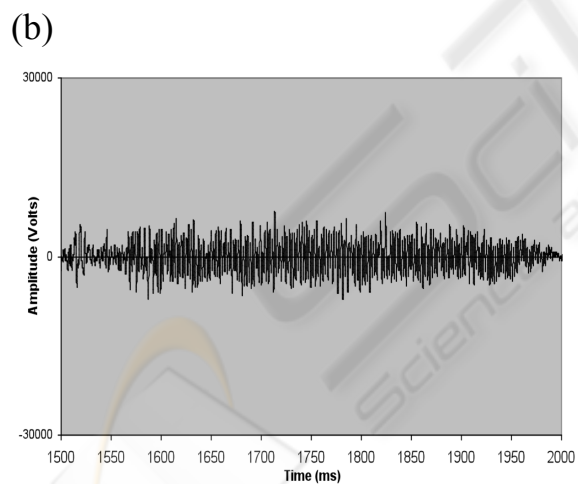
Figure 5: Crackles recorded from patient with pneumonia followed by wheezes (squawks - encircled region) (a) and the zoomed view of the squawks (b).

forms. The system presented a good performance. It was possible to record different respiratory sounds with a good quality (crackles, wheezes and others). The development of such low cost systems may allow the dissemination of computerized respiratory sound analyzes, contributing to a more objective diagnosis of pulmonary disorders in the clinical practice.
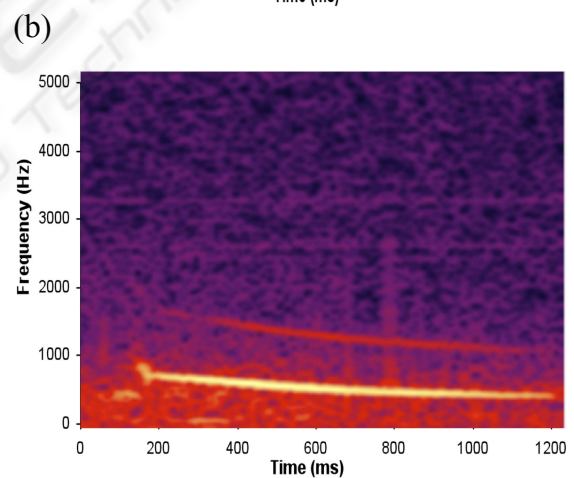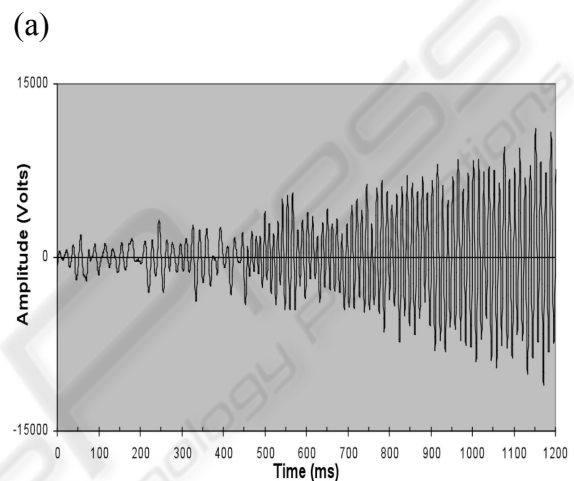
(a)

(b)

Figure 6: Wheezes from patient with acute asthma (a) and its sonogram using Hamming window (b).

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