Computerized Lung Sounds Analysis using LabVIEW™

Omar ALGhamdi, M.D., MS
Medical Informatics

omar@osalghamdi.com
Table of contents

1. Introduction.
2. Methods of respiratory sounds analysis.
   2.1. Signal acquisition.
   2.2. Analogue pre-filtering and storage.
   2.3. Digitization protocols.
   2.4. Signal processing.
   2.5. Display.
3. Categories of Lung sounds.
4. Clinical applications.
   4.2. Telemonitoring.
   4.3. Education.
5. Lung sounds analysis using LabVIEW™.
   5.1. Data acquisition.
   5.2. Description of the Virtual Instrument (VI).
6. Acknowledgements
7. References.

1. Introduction

Despite two centuries of experience of pulmonary auscultation since the invention of the stethoscope by Laënnec in 1821, the physical basis of the acoustic phenomena of human respiratory system has not been precisely elucidated (Korenbaum, Kulakov, & Tagiltsev, 1998).

Chest auscultation is an important part of clinical patient assessment. The skills required to interpret the auscultatory findings are traditionally learned by listening to lung sounds of many patients (Kompis & Russi, 1997). However, traditional auscultation with a stethoscope doesn't meet the requirements for a diagnostic test due, primarily, to limitations of human ear auditory system. The ears are sensitive to deterministic sounds in the time or frequency domains, but are substantially less accurate in identifying, analyzing and classifying noise. Another reason for human deficiency in the auscultatory analysis of lung sounds is their low signal-to-noise ratio “Thoracic lung sounds have relatively low amplitude compared with background noise of heart and muscle sounds”. Because of the subjectivity, and the qualitative nature of breath sounds, many physician no longer rely on auscultation as a diagnostic tool (Gavriely, Nissan, Rubin, & Cugell, 1995).

Most of the modern stethoscopes remain simply a conduit for sounds conduction between the body surface and the ears with an inherent feature in their design that amplifies sounds below 112 Hz and attenuates higher frequencies (Pasterkamp, Kraman, & Wodicka, 1997). Even with the evolution of the electronic stethoscopes that provide higher amplification and selective different ranges of frequencies, the factors of limitation of the human ear and the subjectivity of interpretation remain as major obstacles in lung sound analysis.

Over the past 30 years, computerized methods for the recording and analysis of
respiratory sounds have overcome many limitation of simple auscultation. Respiratory acoustic analysis can now quantify changes in lung sounds, make permanent records of measurements made and produce graphical representations that help with the diagnosis and management of patients suffering from chest disease.

In their research paper, Earis and al.(Earis & Cheetham, 2000a, 2000b) found that there are marked similarities in the basic methodology of respiratory sounds analysis in the main world centers. However, there are many variations in the details of sound capture and analysis techniques between researchers, which make comparison of results between different centers difficult.

The European Union BIOMED 1 program has financed a project entitled Computerized Respiratory Sound Analysis (CORSA). The main objective was to develop guidelines for research and clinical practice in the field of respiratory sound analysis. (Sovijarvi, Vanderschoot, & Earis, 2000) .

2. Methods of respiratory sounds analysis

2.1. Signal acquisition

Upper airways sounds such as snoring and cough are often captured by microphones used in free field at a set distance from patient mouth. Adventitious and breath sounds originating from the lower airways are usually captured from the chest wall using two types of microphone: 1) electret air coupled microphone and 2) contact sensor (accelerometer).

2.2. Analogue pre-filtering and storage

The filter application to the captured sounds signals varies from center to center according to established practice, available technology, and the particular application. Most researchers employ a high-pass filter with a cut-off frequency in the range of 30-150 Hz to eliminate the noise of heart, muscles, and other low frequency sounds. A low-pass filter is always used for the lower airway sounds with a cut-off frequency in the range of 1600-3000 Hz. Until 1990, signals were stored on analogue magnetic recording tape, now a day’s direct digitization and acquisition by a computer is the common practice.

2.3. Digitization protocols

Analogue-to-digital converters with 12, 14, or 16 bits per sample are used. A wide range of sampling rate is in common use, ranging from 4 KHz to 22.05 KHz.

2.4. Signal Processing

The spectral analysis of respiratory sounds using the discrete Fourier transform (DFT) was universal. Many other algorithms were used by different research centers, a non exhaustive list would include:
- Short Time Fourier Transform (STFT).
- Zero-padding and overlapping of analysis segments technique.
- Periodogram (= Power spectrum) (simple, averaged, with Hanning window).
- Autoregressive analysis.
- Wavelets analysis.
- Pronys method.
- Neural networks.
- Higher order spectra.

2.5. Display

Usually the graphical representation of the results is custom written. Some of the common forms that were used are:
- Phonopneumogram (sound level/time display), with air flow.
- Time expanded waveform analysis (TEWA). (Earis & Cheetham, 2000a)
- Power spectra, averaged or not (also called Periodogram)
- Three dimensional Spectrogram (also called Sonogram) or Waterfall graph.

3. Categories of Respiratory Sounds

Lung Sound nomenclature has long suffered from imprecision and ambiguity. Until the last few decades, the name of lung sounds was derived from the originals given by Laennec and translated into English by Forbes. Table 1 summarizes the basic classification of lung sounds, their mechanism and basic acoustic features (Pasterkamp et al., 1997).

<table>
<thead>
<tr>
<th>Respiratory Sound</th>
<th>Mechanisms</th>
<th>Origin</th>
<th>Acoustic</th>
<th>Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic sounds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal lung sound</td>
<td>Turbulent flow vortices, unknown mechanisms</td>
<td>Central airways (expiration), lobar to segmental airway (inspiration)</td>
<td>Low-pass filtered noise (range &lt; 100 to &gt; 1,000 Hz)</td>
<td>Regional ventilation, airway caliber</td>
</tr>
<tr>
<td>Normal tracheal sound</td>
<td>Turbulent flow, flow impinging on airway walls</td>
<td>Pharynx, larynx, trachea, large airways</td>
<td>Noise with resonances (range &lt; 100 to &gt; 3,000 Hz)</td>
<td>Upper airway configuration</td>
</tr>
<tr>
<td>Adventitious sounds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wheeze</td>
<td>Airway wall flutter, vortex shedding</td>
<td>Central and lower airways</td>
<td>Sine wave (range ~ 100 to &gt; 1,000 Hz; duration, typically &gt; 80 ms)</td>
<td>Airway obstruction, flow limitation</td>
</tr>
<tr>
<td>Rhonchi</td>
<td>Rupture of fluid films, airway wall vibrations</td>
<td>Larger airways</td>
<td>Series of rapidly damped sinusoids (typically &lt; 500 Hz; duration &gt; 100 ms)</td>
<td>Secretions, abnormal airway collapsibility</td>
</tr>
<tr>
<td>Crackles</td>
<td>Airway wall stress-relaxation</td>
<td>Central and lower airways</td>
<td>Rapidly damped wave reflection (duration typically &lt; 20 ms)</td>
<td>Airway closure, secretions</td>
</tr>
</tbody>
</table>

* This table lists only the major categories of respiratory sounds and does not include other sound such as squawks, frictionals, grunting, snoring, or cough.

Table 1 courtesy of (Pasterkamp et al., 1997)
4. Clinical Applications

4.1. Clinical Diagnosis:

- *Diagnosis based on breath sounds*: acoustic mapping of the surface of the chest wall to non invasively measure regional ventilation and air flow obstruction within the lungs. This is of particular importance in the treatment of children and patients in the critical care setting. The measurement of intensity and spectral shape of sounds recorded at the trachea have been used as a noninvasive indication of airflow in sleep studies.

- *Diagnosis based on adventitious lung sounds*: Wheezes analysis can be used for long term monitoring of asthmatic patients, particularly at night to assess the severity of symptoms and efficacy of treatment. Crackles analysis can be used in for treatment and monitoring of patients with fibrosing alveolitis, asbestosis, heart failure, and Pneumonia.

- *Diagnosis based on upper airway sounds*: Acoustic differences between post-apneic and simple snoring sounds have been identified electronically, and this may be useful in monitoring patients with sleep apnea syndrome.

4.2. Telemonitoring:

Remote monitoring of patients with sleep apnea and brittle asthma might be possible using simple sound acquisition equipment and a means of transmitting the data via fixed or mobile telephone, possibly via the Internet.

4.3. Education:

Digitization and analysis of lung sounds can be used in the education of medical students, and health care professionals. Remote teaching and learning, virtual universities, and continuing education via modern communication media such as the internet is another domain where such technology is applicable (Earis & Cheetham, 2000b).

5. Lung sounds analysis using LabVIEW™

5.1. Data acquisition:
The lung sounds used were downloaded from the R.A.L.E. ® website http://www.rale.ca. These sounds were already digitized in Wave format which gave us more time to concentrate on the analysis part of the project. The sounds were recorded using contact accelerometers. High-pass filter at 7.5 Hz to eliminate heart and muscle noise, and low-pass filter at 2.5 kHz to avoid aliasing were applied. Analogue-to-digital conversion made with 16 bits quantization. The sounds format was mono 16 bits, sampled at 11,025 Hz.
5.2. Description of the Virtual Instrument (VI):

The VI is composed of two main parts. The first part is, the Sound Input, either from a Wave file, from the file already used or from a signal created with one to three sine waves. The second part is the Sound Analysis, displaying the signal in time/magnitude, the power spectrum and finally the spectrogram after a STFT (Short Time Fourier Transform) processing.

The source of the signal is chosen, using a Listbox that controls a case. Active cursors allow to move along the time scale and analyze part of the signal. The first cursor is the "Zero", and the second is the "Duration". A property node was used for that, as the Get Waveform Subset.vi.

Sound input from Wave file:
The Snd Read Wave File.vi is used for this purpose. It is configured to prompt a file dialog window to get the desired sound file path. The sound is played by the Snd Play Wave File.vi. After the Unbundle by Name, the reciprocal of the sampling rate is transmitted for analysis use and the sound quality controls a Case, connecting to 8 or 16 bits.

Sound input from a sum of sine waves:
The Multitone Generator.vi, can generate one to three sine waves, combined to produce the signal to analyze. Frequency, Amplitude and Phase can be specified, and the Y component is extracted from the output by a Get Waveform Component.
The sound characteristics can also be adjusted, and are unbundled similar to the one described above.

**Power Spectrum of the entire signal:**
After passing through a Build Waveform that gets the reciprocal of the sampling rate (dt), the time (t0) and the signal itself, the data are passed to the *FFT Power Spectrum.vi*, controlled by a window selector. The Power Spectrum is finally displayed on a Waveform Graph.

**Power Spectrum of the signal between the cursors:**
The mechanism is the same as above, the initial time (t0) coming from the value given by the first active cursor (called Zero).

**Spectrogram:**
The STFT is used by the *STFT Spectrogram.vi*. Controls are the window type, the window length, and the time increment.

To correct the scales displayed, we used a Property Node extracting the Offset and Multiplier from the Spectrogram. On the X scale (time), the Offset was configured to
correspond to the Zero cursor and the Multiplier to the time increment. On the Y scale (frequency), the Offset was fixed to 0 and the Multiplier to (sampling rate/2) / ((Duration/2) +1), this scale being normally limited to (Window length/2)+1.

Write to Spreadsheet:
Finally, to allow a precise analysis and possible 3D waterfall display of the Spectrogram of a small portion of the signal, we used the Write to Spreadsheet File.vi. This VI writes the data to a spreadsheet (e.g. Excel), where different graphical displays can be obtained.

Images from the Front Panel:
The complete Front Panel:
sound displayed is wheezing from an 8 months old boy with bronchiolitis)
The Spectrogram:

- window selector
- window length
- time increment
6. Acknowledgements

I would like to Thank, Rick Lasslo, M.D. for his precious counsels at the beginning of this project, Keith R. Williams, Ph.D. for his indispensable help and valued contribution, and Wasyl Malyj, Ph.D. for his guidance and support.

7. References


