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# DIAGNOSTICS OF RESPIRATORY DISEASES BASED ON VIRTUAL INSTRUMENTATION

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***Abstract:*** *Since the stethoscope was found, acoustic analysis was used for diagnostics of patients with pulmonary diseases. This method is characteristic with high level of subjectivity and results of auscultation vary between specialists. Last 10 years we can see significant development of signal digitization and its processing, what is the main engine of auscultation objectivity. Modern medical methods are characterized by influence of electronics to conventional and subjective diagnostics. In this article we propose integration of virtual instrumentation based on LabVIEW to respirology. Designed LabVIEW instruments can be applied each phase of implementation: sound acquisition, signal filtering and processing, representation and results visualization. Flexible LabVIEW instruments can replace many specialized and expensive tools and detectors.*
***Keywords:*** *wheezing, LabVIEW, respirology, acoustic analysis*

## INTRODUCTION

*Since the stethoscope was found, acoustic analysis was used for diagnostics of patients with pulmonary diseases. This method is characteristic with high level of subjectivity and results of auscultation vary between specialists. Last 10 years we can see significant development of signal digitization and its processing, what is the main engine of auscultation objectivity.*

*With increasing quality of life and the age of mankind comes demand for monitoring of patient health. Automatic and continuous monitoring of respiration of patients with respiratory pathologies is crucial for correct diagnosis and therapy. Notably sensitive group of patients are children. Early control of disease can fully or partially improve the quality of their life.*

*The expression wheezing is a general name for group of artifacts covering sounds in normal respiration with duration from 80 to 250 ms and frequency range 100 – 2000 Hz. Wheezing is continual sound caused by air oscillation in the place of stenotic airways. Frequency of oscillation depends on thickness and elasticity of relevant airways segment, also from local air flow. Wheezing partially correlating with the level of obstruction in respiratory tract. Polyphonic wheezing is hearable like compound of variable tones. This type of wheezing is present in expiration in the place of small airways. In the case of strong obstruction the air flow is minimal and wheezing absents.*

*Wheezing diagnostic importance is in early beginning of therapy in clinical units such as asthma bronchiale. Nowadays, big accent is put for detecting wheezing in the place of small airways, which are critical for asthma; single and accessible detector of this type of wheezing is missing in clinical praxis. Wheezing monitoring helps us to control therapy success.*

## ACTUAL METHODS USED IN MODERN RESPIROLOGY DIAGNOSTICS

*The most common clinical diagnostic methods for wheezing and pathology sounds contain physical methods (auscultation), CLSA – Computerized Lung Sound Analysis (electronic auscultation method), functional lung diagnostics (for obstructs in bronchus and bronchial hyperreactivity), oscillometric method for detection of obstructions in small airways and flexible bronchoscopy (or bronchoalveolar lavage) for patients with persistent wheezing durative 6 weeks or longer and resistive for bronchodilatation therapy.*

*Intersection of medicine and technical branches increased objectivity and automation of basic diagnostic methods. The simplest method for pathological artifacts detection is calculation of PSD (Power Spectral Density) as an application of Fast Fourier Transformation (FFT) for random sequence of finite duration. Acoustic record of breathing is sequentially divided into windows with width of tenths of milliseconds (e.g. 100 ms). Then power spectrum of each finite sub-sequence is characterized with dominant frequency and frequency band (Figure 1).*

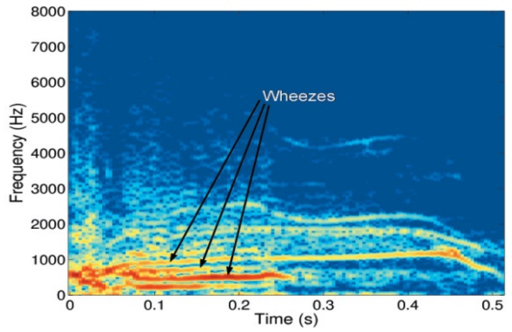


***Figure 1**. Power spectrogram for half-second recording of breathing sounds with pathological segments in range to 1 kHz*

*Methods for automatic detections of pathological artifacts could be divided into two basic categories [1] - [9].*

*First category contains methods based on harmonic analysis (FFT) and its basic applications. These methods use evaluation of amplitudes in computed spectrograms or CSAs (CSA = Compressedd Spectral Array). Methods are often completed with empirical decision and thresholding of amplitude, frequency, duration and number of pathological statuses. Advantage of these methods is in their relative simplicity, fastness and suitability to answer the question of presence of pathological segments in recording and their basic parameters.*

*Second category of methods is based on extraction of high level features of analyzed sub-sequences. These features are elements of feature vectors. Harmonic analysis is also input for these methods, but in the role of additive tool for feature extraction. Feature vectors are the key components for classification process which is sophisticated mean for diagnosis support. Training of classification algorithm or neural network requests wide statistical group of patients (wide group of recordings with and without pathologies) for creating fine (accurate) classification classes. Classification is modern and developing task in signal processing which brings detailed segmentation of analyzed signal. Basic methods can be as follows:*

- *a. MFCC – Mel-Frequency Cepstral Coefficients;*
- *b. LPC – Linear Prediction Coefficients;*
- *c. AR Model;*
- *d. Multivariable AR model;*
- *e. SVM – Support Vector Machine;*
- *f. GMM – Gaussian Mixture Models;*
- *g. SVD – Singular Value Decomposition – for feature vector reduction*
- *h. PCA – Principal Component Analysis – for feature vector reduction.*

*An interesting research work comes from R. J. Riel and his team from Brazil [10], where wheezing is detected by conversion of spectrogram obtained by Fourier analysis to the image. Wheezing in the spectrogram is shown as horizontal system of frequency peaks in the range up to 1 kHz. These peaks are selected by image thresholding, which are next converted to the spectrum after shape analysis and thus wheezing selected during this step is classified in multilayer perceptron (Figure 2). The accuracy of this method ranges from 92 to 94%. Accuracy depends on the occurrence of distracting sounds and noise at specific frequencies. Record length for analysis was tentatively set for at least 5 seconds (while breathing cycle has a standard length of 2 seconds). The authors acknowledge the possibility of optimization algorithms for use in real-time.*

*Present methodics for detecting pathologies in breathing sounds is based on 24-hour recording (similar to "holter" monitoring), its transmission to computer and offline digital processing. Development of DSPs (Digital Signal Processors) and their peripherals makes possibility to do this analysis as real-time and complete whole detection system with "threat sense" module for acute status mainly for pediatric patients.*

*From medical point of view, it is necessary to specify suitable group of investigated patients. Optimal statistical group in the process of designing of biomedical application plays key role for setting up the parameters of algorithms, mainly for developing problematics of signal identification and classification.*

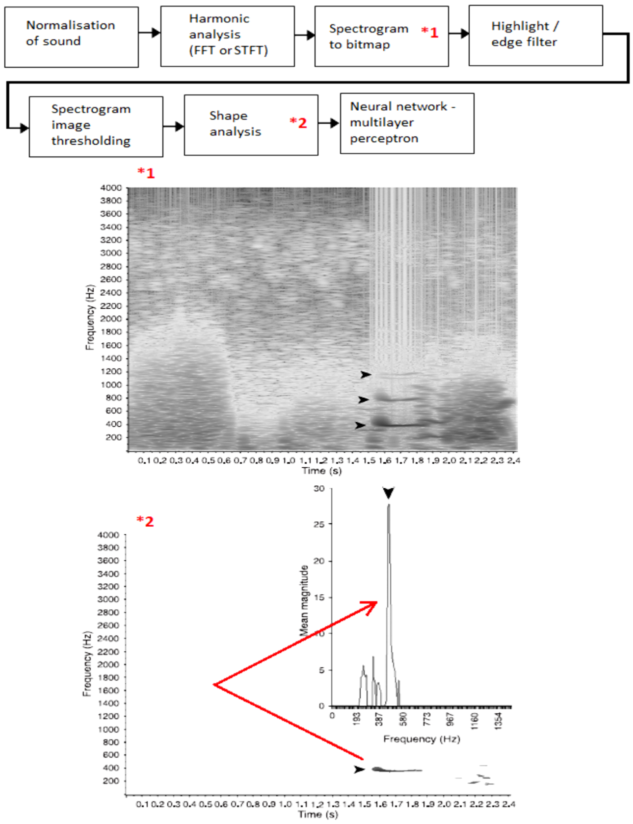


***Figure 2**. Principle of detection and classification of wheezing with respiratory spectrogram conversion sounds and neural network*

## *VIRTUAL INSTRUMENTATION MODULES*

*Currently, there are several types of automatic detectors for wheezing and other sound phenomena. The algorithm is, of course, know-how of particular manufacturer. Websites inform that general tool is classic FFT or short-time (STFT) Fourier analysis, where its sensitivity is around 91% and a specificity of 89%. Audio recording is done via contact piezoelectric sensors or pressure-sensitive switches, which application can be problem in young pediatric patients. Random movement can cause the occurrence of intrusive sound elements, which must be recognized, selected and removed. From this perspective, non-contact recording using a sensitive microphone eliminates some discomfort senses of patient (child).*

*Literature overview for last decade brings information about range of sampling frequencies used for audio recordings from units of kHz (4, 5, 8 kHz) to 22 kHz. Selection of microphone with upper cut-off frequency for example 40 kHz can answer the question, if the signals contain potential high frequency artifacts. Condenser microphones satisfy this condition. [11]*

*Higher sampling rates put higher requirements on DAC / ADC converters, memory devices of DSPs and time for analysis (computing power). But higher sampling frequencies can make final analysis more accurate. Fast Fourier Transformation (FFT) and its derivatives (e.g. cepstral analysis, power spectrograms or feature extraction for classification process) are basic operations with raw signal. Relevant* *literature specify optimal block of data (input for analysis) as 20-100 ms: for sampling rates to 10 kHz the FFT is 256 – 1024 point; for higher sampling frequencies the FFT is 2048 or 4096 point. But this fact is not problem for hardware implementations of FFT in modern DSPs. Hardware solution for harmonic analysis significantly decreases time consumption calculating time in the side of DSP core. We can also apply wide palette of lowpass or noise killing filters, which create basis of implemented tools for each good DSP [12] -[17].*

*LabVIEW Development system from National Instruments Company is complex environment for designing applications in many fields of interest. In our work we have successfully started implementation of LabVIEW virtual instruments and relevant hardware peripherals in a place of Sleep Laboratory in Clinic of Children and Adolescents in Faculty hospital in Martin (Slovakia). LabVIEW toolboxes Sound and Vibrations and Signal Express are suitable to cover the basic needs for creating efficient tools in modern respirology. On the other side, LabVIEW virtual instruments can replace many specialized and expensive devices.*

*Implementation and use of LabVIEW in our work can be divided into following phases: sound acquisition with NI DAQ means, sound processing and representation (diagnostic support).*

## ***ANALYSIS OF SOUND RECORDINGS***

*Condenser microphones are suitable for wide range of measurement applications. Their advantages are the highest sensitivity from all types of microphones and high level of fidelity. Each condenser microphone contains two thin metallic plates which create classical condenser. Supplying circuit generates electric potential in the condenser. On of these plates is solid electrode and the second is movable (in the function of acoustic membrane). Mutual movement of electrodes generates capacity changes and output voltage. Membrane thickness is several micrometers and is covered with precious metal (gold) – similar technology is used for transistors. Capacity is converted to output voltage thank to soft power supply or preamplifier with very high input impedance. The first microphones were constructed with tubes.*

*It is necessary to have distance between membrane and preamplifier very small. Membrane diameter is usually 1 inch (2.54 cm). Diameter of membrane implies upper cut-off frequency of microphone. Merchants often distribute microphone sets with several membranes of various diameters and sensitivities. With special membrane insert we can significantly influence directional characteristics of microphone.*

*Preamplifier is a important part of each microphone set. It adjust level of acquired signal to the acceptable one for purposes of digital processing. Preamplifiers also contain several noise-killing filters or corrections.*

*In experimental measurement in sound acquisition phase we used following components (Figure 3): preamplifier and microphone set Robotron 00 017, measurement I/O card NI PCI – 6229 with BNC – 2120 terminal, PC with LabVIEW toolbox Sound and Vibration.*

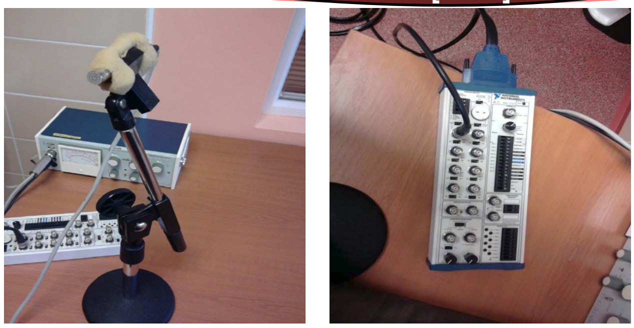

***Figure 3.*** *Components for sound acquisition*

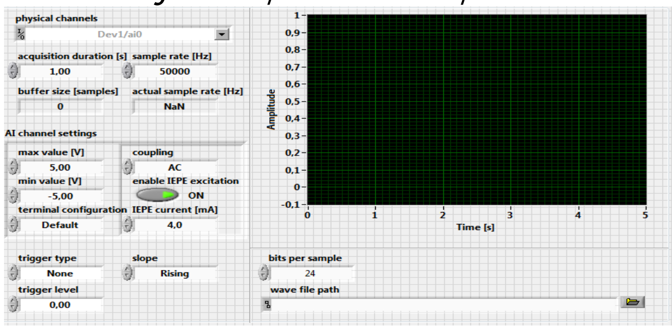


***Figure 4.*** *Sound recording LabVIEW module*

*Microphone was placed over patient's bed in Sleep Laboratory room and signal was transmitted to computer via cable to control room. In LabVIEW sound recording module user can define basic parameters for wave file: bits per sample, coupling, voltage range, acquisition duration, sampling rate and many other parameters (Figure 4).*

*LabVIEW I/O card NI PCI-6229 enables to acquire 16 independent sound (voltage) channels simultaneously, so we can obtain multiple data from one patient or breathing sound from multiple patients in one time. Sampling frequency can reach 250 kHz, but its value depends on microphone upper frequency (40 kHz in our case).*

## ***EXPERIMENTAL RESULTS***

*LabVIEW contains many tools for basic or advantage signal processing and statistics. After acquisition phase, recorded sound is converted to discrete vector. To evaluate LabVIEW possibilities for sound signal processing for respirological purposes we recorded sounds from three children patients with acute bronchitis and symptoms of wheezing. The sound was sampled with frequencies of 50 kHz and duration of each sample was 5 seconds (Figure 5).*

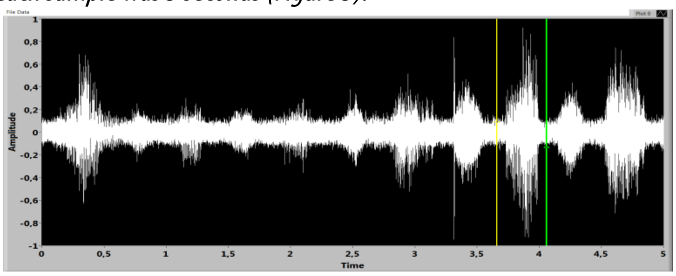


***Figure 5.*** *Sound waveform of patient with acute bronchitis and symptoms of wheezing*

*In designed LabVIEW module we can provide manual or automated segmentation of obtained signal and calculate basic parameters for selected segments: maximal or minimal value, mean value, correlation factors, FFT spectrum, PSD or cestrum. In Figure 6 we can see Fourier spectrum of selected region in waveform in Figure 5.*

*Spectrogram of entire sound file from Figure 5 is displayed in Figure 7 (interlaced windows with size of 2048 samples, representing 50 ms frames).*

*Calculation of statistical parameters and basic features in defined shifting window is a base for automatic segmentation or searching for simple breathing phases. Applying segmentation and feature extraction process for statistically significant group of patients enables to create references and templates for early detection of pathologies in breathing sound phenomena and enables to start relevant therapy. This fact significantly increases the possibilities of patients' quality of life.*

*Following some approaches from [10] it is very simple to convert spectrogram to bitmap (LabVIEW toolbox IMAQ) with function ArrayToColorImage. Some significant features visible in frequency domain can be obtained by advanced image algorithms: Color, geometrical or pattern matching and position of detected object can be transformed back to position in waveform.*

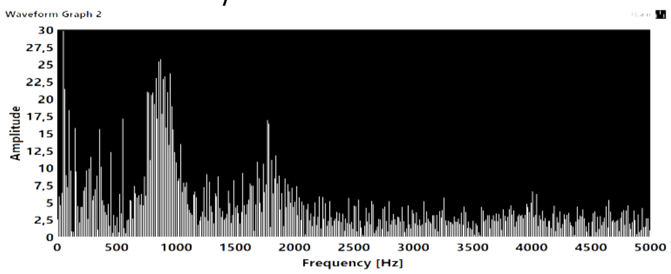


***Figure 6.*** *A part of FFT spectrum of selected segment from sound waveform limited to 5 kHz for detailed view*

## *CONCLUSIONS*

*From the first experiments we can see, that virtual instrumentation can be fully implemented to clinical environment. Expensive and specialized detectors can be replaced with universal I/O cards and sensors. LabVIEW contains many tools and algorithms for acquisition and processing of biological signal converted to discrete vectors. Extracted signal features from spatial or frequency domain are the key information for advanced methods of pathological sound phenomena classification. On the other side, universal I/O devices support multi-channel data logging or acquisition of combined signals (sounds, potentials, video signals, signals from chemical sensors, etc.) and virtual instrumentation becomes a strong "weapon" for increasing of life quality especially in children patients.*

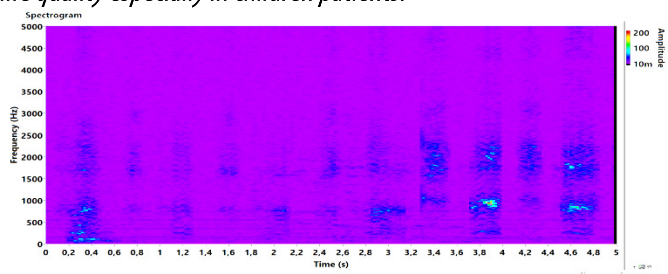


***Figure 7.*** *Spectrogram of entire 5 second sound recording limited to 5 kHz with significant wheezing activity in range to 2 kHz*

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