Analyzing non-respiratory movements of the chest: methods and devices

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ABSTRACT

Respiration is the main reason of the chest movements. However, there are also non-respiratory ones, resulting from e.g. snoring, wheezing, stridor, throat clearing or coughing. They may exist sporadically, however should be examined in case when their incidences increase. Detecting non-respiratory movements is very important, because many of them are symptoms of respiratory diseases such as asthma, chronic obstructive pulmonary disease (*COPD*) or lung cancer. Assessment of the presence of non-respiratory movements could be important element of effective diagnosis. It is also necessary to provide quantitative and objective results for intra-subject studies. Most of these events generate vibroacoustic signals that contain components of sound and vibrations. This work provides the review of the solutions and devices for monitoring of the non-respiratory movements, primarily considering the accuracy of the chest movements' detection and distinguishing.

Keywords: non-respiratory movements, cough monitoring, sleep apnea, biomedical system designing

1. INTRODUCTION

The chest movements might be caused by physiological respiration (related with changes in the volume of the chest during inspiration and expiration phases) or other non-respiratory reasons. Non-respiratory movements are the results of abnormal function of the respiratory system, including e.g. snoring, wheezing, stridor, throat clearing and cough. If these events exist sporadically, they are not dangerous for the subject, but when their incidences increase, it could be an evidence of disease.[1,2] Most of these events generate vibroacoustic signals that contain components of sound and vibrations, associated with the movements of the chest.[3]

There are two main purposes for detection of non-respiratory movements. First, many of them are symptoms of respiratory diseases such as asthma, chronic obstructive pulmonary disease (COPD), and lung cancer and could also correspond with sleep apnea and gastro esophageal reflux. Therefore, detection and appropriate assessment of the presence of non-respiratory movements are important element of effective diagnosis.[1,3–8] Second, it is important to monitor the course of drug therapies and compare the progression in terms of the quantitative results, rather than just subjective opinion of the patient.[2,4–6,9–11] Quantitative results are also necessary for intra-subject studies.[12,13] Currently, in the cough monitoring, very important is to assess cough comprehensively by the combinations of subjective and objective tools.[13]

Objective and automatic assessment of non-respiratory movements is the subject of many researches.[3] The main task is to design an ambulatory device.[10] For example, while monitoring sleep apnea patients usually need to be in the hospital overnight. It is very uncomfortable, costly and could adversely affect the accuracy of measurement results. Therefore, it is necessary to construct a device capable of patient monitoring in his natural environment. In addition, according to American College of Chest Physicians and European Respiratory Society, the device must be also current-efficient, easy to use, inexpensive and most of all reliable.[3,9,10,14]

However, designing of the device which could detect only "events", eliminate the artifacts from the signals, characterize the signals and "events" occurrences parameters and consume low power seems to be problematic

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task.[2,6,15] The presence of background noises, e.g. speech, laugh, sneeze, shout and ambient noise interferes with the important components of the signals and lower the accuracy level of detection and classification.[2,6,16] The key point of the correct analysis is the ability to automatically distinguish the correct "event" from the ubiquitous interferences.[17] This work reviews the solutions and devices on that topic.

2. METHODS

There are many concepts of the devices described in the literature and some of their common features can be distinguished. First of all, these devices are mainly multichannel. Due to the vibroacoustic properties of the signal, there are two, the most commonly used, sensors. They are a microphone for recording the sounds and an accelerometer to register the vibration signal from the movements of the chest.[2,3,10,16,18,19] Different configurations of these sensors were considered. Depending on the application, other additional sensors and modules were installed, for example ECG channel,[18,19] EMG channel,[1,20] esophageal pressure topography,[21] measurement of oxygen saturation (SpO_2) and heart activity (for sleep apnea).[2,15,18] In order to make a correct analysis it is necessary to ensure the proper synchronization of acquisition.

The gold standard in monitoring the non-respiratory movements is polysomnography (PSG) and video recordings (for example during monitoring the cough).[19,22] They are also used as a reference during testing new methods.[10,23,24]

Schematic diagram of the system for monitoring non-respiratory movements contains several basic elements. Input signal is recorded using a variety of sensors as separate channels. Due to the low amplitude of the recorded signals, they must be pre-amplified. An important element of the processing path is also filtering. Band-pass filters are commonly used. Analog signal is next converted into digital one.[2] The microprocessor is used to handle the conversion and transmission of digital signals to the memory card or wirelessly to the receiving station. Digital signals are then processed and analyzed offline. However, audio dataset needed to be processed and analyzed are large (in most cases, because of 24 h monitoring). Therefore, it is a difficult task for a one computer to perform analysis quickly. The researchers are working on the using of cloud computing system for analyzing big datasets in a short time.[24] The new trend in monitoring is also using a mobile platforms (even mobile phones). The recognition algorithm is then implemented on a mobile device.[25,26]

The non-respiratory movements are associated with the presence of the sound signal, thus microphones are commonly used.[2,3,6,12,20,27] Primarily, omni-directional electret condenser microphones, with the sensitivity at the level of $-40dB$, are implemented.[5,18,21,28] Various possibilities of sensor mounting were investigated. There are two strategies:

- The microphone is attached to the patient and adhered with the tape around the neck, on the trachea or on the surface of the chest[2,4]
- The microphone is positioned in a separate device, outside the patient, on a tripod in a radius of $1m$ or in the device that are set along the bed of the patient.[3,21]

In the literature recordings of both single microphone or a set of several sensors were assessed.[2,29]

Registration of the chest movement is not only based on a sound signal, but also on the vibration. For this purpose, the accelerometers and the piezoelectric sensors are commonly used.[3,5,7,30,31] The models of sensitivity range: $\pm 1.7g/\pm 5g/\pm 8g$, both uniaxial and triaxial,[2] were tested. Accelerometers are placed on the surface of the patient's body, usually between the cartilage of the thyroid and the highest position of the sternum[3,18] and adhered with the tape.[26]

Low amplitude of the signals requires their amplification. The gain of $100-200$ is achieved using a differential operational amplifiers.[2,8] The amplified signal is then band-pass filtered with the frequency range of vocal.[12,20,30,32] Eliminating low frequency components is mainly added due to the need to remove signals from contracting muscles and heart murmurs.[8,12,31]

AD conversion is performed by different types and families of microcontrollers (STM, PIC, AD),[2,21,27] external DAQ module[1] or dedicated analyzer.[5] The sample rate varies from $2kHz$ to even $44.1kHz$, depending on the application and analysis strategy.[5,14,24]

The raw data are analyzed in the dedicated software (e.g. LabView, Matlab).[1,5,8,12,14,18,26] The main objective of the automatic analysis is to extract and classification of “the events” resulting from the non-respiratory movements. It is necessary to determine useful (diagnostic and objective) parameters, such as the frequency and severity of “the events”. In order to shorten the analysis time and improve its results, ”the events” should be initially extracted from recordings of silence. Various types of processing in the time, frequency and time-frequency domain, are applied. Classification has to clearly define the frequency of “events” and assign them to the relevant characteristics of similarity classes.[3,12,21,33]

The first processing step is time-domain analysis, in which an important element is the detection and measurement of peak amplitudes.[21,34] Correlation analysis leads to extract those pre-classified signal episodes that are come from sources being outside the patient.[3,5] Spectral analysis (*FFT* or *STFT*) is the most widely used method to distinguish the cough events from other sounds of the patient and recognize specific wheezing.[3,5,8,17,20,35,36] The wavelet analysis is also used.[8,32]

Two classification techniques are mainly used:

- Statistical models, e.g. Hidden Markov Models (*HMM*), which aims to create unique models for each class (“events”) of signals.[2,6,16,17,28]
- Artificial neural networks and especially probabilistic neural networks (*PNN*).[2,23,28] It is a network made up of at least three layers: input, radial and output. Interpretation of the output values of the network is treating them as probabilities of belonging to classes. *PNN* method has been used in a number of created systems.[2,14,23,28]

3. RESULTS

Several systems were presented as the result of research on methods and devices for automatic analysis of non-respiratory movements of the chest. The examples are:

- Snoring detector,[21] which embodiment includes a microphone connected to the PIC microcontroller, which coordinates the processing and signal transmission. Microphone was placed on the front of the housing unit, and recorded signals within a radius of 1 m from the patient.[21]
- Wheeze detector,[8,31] with bone conductive microphone. Sound signals could be displayed on the screen of palmtop, which was used for their recording.[31] Wheeze detector was also used in E-health asthma controlling system.[8]
- Cough detector (made by MES in Cracow) with recording equipment mounted at the sternum supported by a belt around the chest[4,9]
- Cough detector (Leicester Cough Monitor) consists of a microphone suspended around the neck of the patient. The signal is recorded in an electronic device mounted on the belt.[6,16]

Designed and tested monitoring systems were validated in relation to the reference methods (video recording). Reliability test was based primarily on the appointment of the parameters of sensitivity and specificity. The following Table 1 presents a comparison of the effectiveness of a number of selected systems.

4. CONCLUSIONS

Subjective assessments of cough, snore and other sounds generated by the non-respiratory movements are not effective enough for the diagnostics of respiratory diseases. According to the European Respiratory Society, in the field of monitoring the cough, none of the subjective methods obtained the status of the gold standard. In turn, in research on sleep apnea, patients need to stay in hospital and need to be connected to a number of various sensors, thus the test conditions differ significantly from the natural environment of the patient. For these reasons, there is necessary to develop effective, objective methods and devices for automatic detection and analysis of vibroacoustic signals while monitoring of non-respiratory movements.

Table 1: Comparison of the reliability of selected systems

Author	**Device**	**Sensitivity**	**Specificity**
Yeh-Liang Hsu et al.[19]	Snoring detector	85% (lab), 70% (home)	–
Jane et al.[37]	Snoryzer-Uno	83%	100%
Hyo-Ki Lee et al.[16]	Snoring detector HMM	93.3%	–
Zhang et al.[35]	Wheeze detector	> 85%	–
Krajnik et al.[4]	MES Cracow	> 95%	> 99%
Grabowski et al.[5]	PULSE analyzer	> 80%	–
Drugman et al.[2]	Audio cough detector	94.39%	94.45%
Matos et al.[20]	Leicester Cough Monitor	98.4%	98.2%
Barry et al.[15]	Hull Automated Cough Counter	80%	96%

It seems that the most effective in this application are the combination of the microphone and accelerometer. However, the use of additional modules could enrich the obtained value, e.g. by measuring the correlation of vibroacoustic signals with *ECG*.

Available systems have a sensitivity ranging from 75% to 85% and specificity ranging from 90% to 95%. It is worth noting, however, that not all studies were carried out on a sufficiently large group of patients and sometimes no information was given concerning the registration condition (day or night).

Currently, the aim of research is to achieve better results in terms of accuracy and to find the best location of sensors for improvement of signal detection. The proposed device should be lightweight, portable and easy to use. Offline analysis should provide quantitative parameters in assessing the type of cough, snore or wheeze events, which turn out to be an important element of effective diagnosis and in the assessment of therapy.

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