Evaluation of Breathing Dynamics Using the Correlation of Acoustic and ECG Signals

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Abstract

This research was aimed at finding a correlation between acoustic signals and heart activity parameters representing sleep disorders. The measurement of breathing through simultaneously acquired acoustic and ECG signals is used to quantify the respiratory obstruction during sleep. It is believed that the dynamic characteristics of this noninvasive technique allows for an inexpensive and accurate analysis of these events. ECG recordings from a number of subjects were used to collect electrocardiogram-derived respiratory (EDR) and heart rate variability (HRV) information. The respiratory signal was calculated using two methods: acoustic analysis and EDR. Comparison of the results indicates that both methods are equivalent in the assessment of breathing during sleep. The information collected by simultaneous recordings of acoustic effects and the ECG signal are partially overlapping, giving the opportunity to improve accuracy and partially complementing, allowing for extension of the sleep analysis aspect. Proposed data collection scheme is more convenient and can be performed in ambulatory conditions.

1. Introduction

Respiratory monitoring during sleep has important clinical applications because of its potential to detect repetitive apneas in patients with sleep apnea. Simultaneous bioacoustic and electrocardiographic monitoring has importance in diagnosing abnormal breathing. There has been a growing interest in using breath sounds for the diagnosis of OSA (Obstructive Sleep Apnea) with ECG analysis at the same time. It gives opportunity to find high prevalence of OSA syndrome, for example: repetitive obstructive apneas accompanied by symptoms of excessive daytime tiredness, disturbed sleep or neurocognitive impairment, which affect approximately 4% of men and 2% of women. It is believed that sleep apnea constitutes a major public health burden, that's why it is so important. One of the most common sleep disorders that affect's people of all ages is snoring, leading to obstructive sleep apnea. These pathological sound symptoms could be a sign of a cardiovascular disease. Correct interpretation of obtained data is very important to diagnose dangerous symptoms.

2. Methods: data acquisition

Respiratory signal analysis was performed using two described methods: acoustic analysis and ECG signal. Comparison of the breath signal calculated using both methods indicates their equivalence in the assessment of breath or disturbance during sleep.

2.1. Acoustic signal acquisition

There are advances in techniques for signal analysis and performing sound measurements. This allowed acoustic analysis of respiratory sounds to become significant to diagnosis of respiratory disorders. Respiratory sound analysis is used to identify pathological respiratory sounds, for example: snoring, wheezes and apnea [1, 2]. Sound analysis recorded during sleep can be also used to identify the type of obstruction it is and locate the place from which it arises [3].

Sounds occurring during the night are produced in the vocal tract, similarly to speech. Thanks to that analogy, existing techniques for speech analysis have been applied to evaluate snoring sounds. Snoring sounds were precisely and easily detected with the use of a condenser microphone. The microphone was hung in front of the patient's mouth at a distance of about 5cm. Full-night breathing sounds were recorded and sent through the analogue-digital converter directly to the computer system and subsequent analysis was performed (Figure 1). The recordings were scanned to identify periods of regular breathing.

Acoustic analysis of sounds commenced with auditory analysis, where different types of sounds can be observed e.g. snoring, wheezing, stopped breathing etc. Snoring and other sounds have been analyzed in the frequency and time domain and were defined with a set of quantitative sound parameters. Visual analysis of images of acoustic signal of standard and pathological sound was comprised of observing and comparing the shape of the individual time variations, spectra and the degree of deformation.

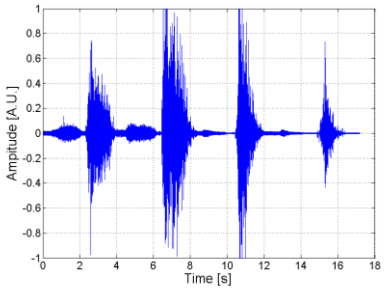

Figure 1. Screenshot of a 18 s recording of breathing sounds from one subject during sleep, AU: arbitrary units

Based on the time variation of the signals (Figure 2), two- and three-dimensional dynamic spectra were prepared (Figure 3), giving the possibility to evaluate the signal's degree of distortion. Visual analysis began with timed series observations, as they represent the original image of a pathological condition.

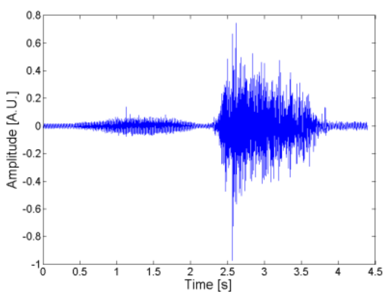

Figure 2. Single breath (inspiration and expiration) in the time domain

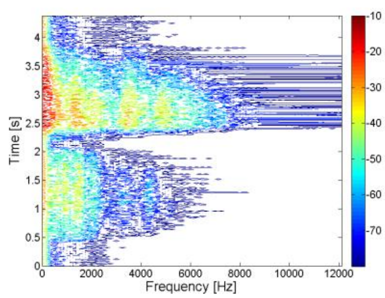

Figure 3. Single breath (inspiration and expiration) in the time-frequency domain

Breaths were sampled from 8 subjects with a mean number of 10 breaths per subject. The selection of breaths for further analysis was made by the investigator regardless of the patient's sleep stage. The real-time stamp of each breath was registered allowing identification. The investigator listened to these samples again to divide each breath into its inspiratory, expiratory and interbreath phases and labeled type of breath: normal, with snoring sound or wheezing. Each phase was defined manually and subsequently analyzed. A normal breathing cycle is composed of two main phases - inspiration and expiration. The acoustic analysis indicates that characteristics of inspiration and expiration could vary significantly for the same subject.

For example, one of the causes of OSA is narrowing of the upper airway, which could present itself in one phase of the breathing cycle only. In such a case, it is possible to observe changes in the acoustic characteristics. Because of that, treating the two phases similarly should be avoided. To draw conclusions about the dynamics of the airway, the cyclic sound of breath necessitates dividing into phases: inspiration and expiration. A summary of the average values for 10 breaths (inspiration and expiration) for each subject is shown in table 1. The set of values was calculated for inspiration and expiration for each breath using acoustic analysis performed in Matlab.

Table 1. Selected acoustic parameters for inspiration and expiration

No.		type of breath	M0	M1	M2	F2	F3	F4
1	IN	normal	1810	66	5599	875	2499	3248
	EX		914	54	4057	1387	2198	2786
	IN/EX		1.98	1.23	1.38	0.63	1.14	1.17
2	IN	normal	2260	63	5040	124	1874	2374
	EX		1062	56	4359	2136	2873	1624
	IN/EX		2.13	1.13	1.16	0.58	0.65	1.46
3	IN	snoring sound	1452	62	4795	750	1249	2249
	EX		973	59	4755	2124	3498	3873
	IN/EX		1.49	1.05	1.01	0.35	0.59	0.64
4	IN	snoring sound	1413	59	4703	625	1249	2124
	EX		1085	57	4040	900	1724	3411
	IN/EX		1.30	1.04	1.16	0.69	0.72	0.62
5	IN	light snoring/ apnea	1321	65	5438	750	1499	1999
	EX		850	52	3882	812	1436	2062
	IN/EX		1.55	1.24	1.40	0.92	1.04	0.97
6	IN	light snoring/ wheezing	159	66	5362	750	1874	2624
	EX		1338	57	4095	750	1787	2736
	IN/EX		1.19	1.15	1.31	1.00	1.05	0.96
7	IN	snoring sound	1350	62	5143	875	1499	1999
	EX		1079	59	4706	1586	2349	3136
	IN/EX		1.25	1.05	1.09	0.55	0.74	0.64
8	IN	normal	1945	65	5478	750	1749	1874
	EX		1159	44	3541	673	1323	1767
	IN/EX		1.68	1.46	1.55	1.11	1.13	1.06

IN – inspiration, EX-expiration

Calculated parameters which form a vector of features of the abnormal sound were quantitatively compared with normal sound, which allowed drawing conclusions from the available data. The most important parameters were moments M0-M2 and formants (F2-F4). The medically relevant parameter is M0: in the inspiration phase for snoring subjects, this parameter is lower compared to normal breath for the same phase of breathing cycle. Also the ratio of inspiration to expiration is lower than 1.5. Parameter F3 for subject with disturbance during night is lower for the inspiration phase. Also F4 parameter is different for each group of sleepers, ratio IN/EX for normal breath is more than 1, for the light snorer it is around 1 and for snorer it is between 0.62-0.64.

2.2. ECG signal acquisition

The ECG recordings were used to acquire electrocardiogram-derived respiratory (EDR) and the pattern of heart rate variability (HRV) in the time domain. During the breathing cycle, the ECG from the chest surface is disturbed by the position change of heart electrode and impedance changes associated with inhalation and exhalation. These changes are recorded as a slow oscillation frequency in QRS amplitudes corresponding to the breathing cycle. This phenomenon is referred to as the EDR from the ECG. Amplitude method exploits the fact that the movements of the chest during respiration cause changes in the amplitude of the measured ECG signal. During inhalation, electrodes placed on the chest recede from the heart, thus decreasing the amplitude of the recorded signal. During exhalation the chest drops, therefore the distance between the heart and the electrodes is reduced and the amplitude of the measured signal increases. Method of intervals relies on getting a signal on the basis of respiratory intervals between successive heartbeats, represented by the QRS complex. This is possible due to physiological phenomenon of respiratory arrhythmia heart rate. During inhalation heart rate speeds up, so the spacing between successive QRS decreases. During exhalation the opposite is true. The method of inverse intervals, has the above described physiological and physical basis, where the respiratory curve is plotted based on the inverse of the spacing. EDR signal is calculated within the detected QRS area, based on RS amplitude, measured as the difference between the minimum of the S and maximum of the R waves:

$$amp(i) = R_{amp}(i) - S_{amp}(i),\ i=1, 2, \ldots, n \qquad (1)$$

From R-R intervals of ECG (the time intervals between heart beats of ECG), EDR signal can be extracted, which can show physiologically events related to sleep apnea (Figure 4). At the beginning of an apnea event, vagus activity increases, causing the heart to slow down (bradycardia), followed by an increase in heart rate (tachycardia). Apart from the information of HRV pattern, ECG-derived respiration can be another good pattern of activity of the heart. This effect can be seen as a slow modulation of the ECG amplitude, with frequency equal to that of the breathing cycle. Features based on EDR might be useful for detection of sleep apnea. The comparison of features of HRV and the EDR signal can give the best classification of results for sleep apnea detection and other disturbance during sleep.

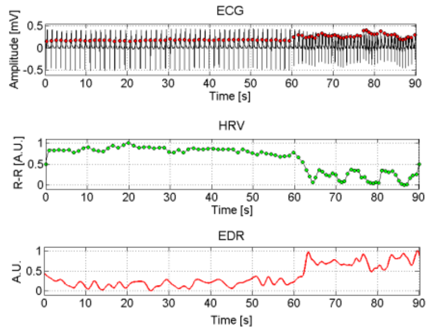

Figure 4. Stages to obtain EDR signal, breathe with apnea.

3. Correlation

In this paper, we described methods enabling sleep specialists to analyze, quantify and diagnose sleep disordered breathing based upon acoustic analysis (time and frequency-domain) and ECG analysis based on calculated EDR signal. This environment provides the means to import or read sleep data (ECG, wave) and displays them individually or collectively in a data window for interpretation. It also enables the sleep specialist to decide on the length of the data to be used in carrying out the analysis. Images exported from Matlab (Figure 5, 6, 7) show a 10 breath period for a snoring person during one stage of sleep in time, frequency domain and EDR signal.

From these images, the dynamic of the breathing cycle can be observed. For example, between 5 and 10 seconds of the recorded breathing cycle during inspiration we can see lower energy and the EDR signal is decreasing. The acoustic dynamics and EDR signal can be compared for every phase (inspiration or expiration), because these two methods are overlapping.

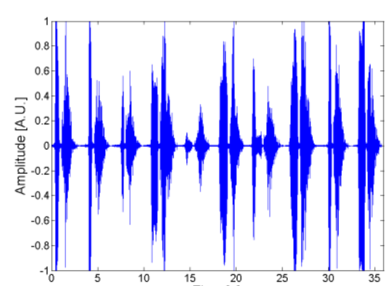

Figure 5. Time domain for 10 breath period for a snoring person

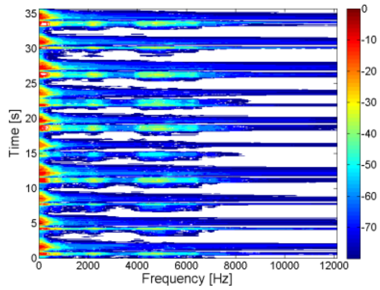

Figure 6. Frequency domain for 10 breath period for a snoring person

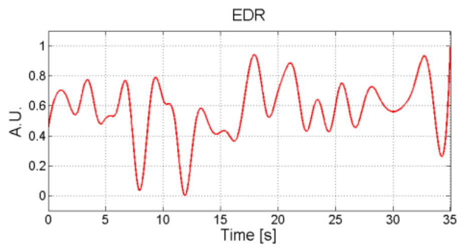

Figure 7. EDR signal for 10 breath period for a snoring person

Also it is possible to compare ECG with acoustic parameters (Table 2). Patients showing snoring symptoms exhibit lower value intensity [dB] in the expiration phase.

Table 2. Parameters comparison for two methods

Subject	10 breaths period [s]	type of breath	inspiration average power spectrum [dB]	exspiration average power spectrum [dB]	HRV
1	32	normal	30	20	53
2	34	normal	33	21	62
3	35	snoring	27	8	73
4	41	snoring	28	10	72
5	44	light snoring/apnea	26	8	75
6	33	light snoring/ wheezing	27	11	75
7	40	snoring	28	15	76
8	30	normal	30	21	62

4. Conclusion

In this research two methods for measuring the respiratory signal are presented. First method is electrocardiography (ECG) and second is acoustic analysis of respiratory sound. The measurement of breathing through simultaneously acquired acoustic and ECG signals is used to quantify the respiratory signal during sleep. The information recorded by synchronized recording of acoustic effects and the ECG signal partly overlaps, giving an opportunity to improve accuracy of measurement. Results indicate that the aspect of sleep analysis can be extended using this method.

Acoustic and EDR analysis techniques used in this work give information about cardiac activity, loudness and intensity of snoring sounds during sleep. A more precise analysis of the results led to the conclusion that the curved septum is a possible reason for obstruction of the upper airways. Close examination of snoring and other sound signals during various stages of sleep demonstrated that light snorers snored evenly throughout all of them. By the simultaneous measurement of the acoustic and cardiac signals, it is possible to identify life-threatening conditions associated with respiratory arrest. Snoring as a marker of abnormality can be only used in context of patient's medical history. The history and related diagnostic tests help to determine whether the patient has abnormalities or is just a healthy snorer without other disorders.

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