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Monitoring and Analysis of Cardio Respiratory and Snoring Signals by using an Accelerometer

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Abstract— **In this paper we present a system based on a sensor of acceleration for acquisition and monitoring of diverse physiological signals, by extracting respiratory, cardiac and snoring components inside the main source. Digital signal processing techniques used frequently in Biomedical Engineering have been used.**

The acceleration produced by the cardiac signals, the respiratory movements and the vibrations generated by the snores are detected with help of an accelerometer placed on the skin of the subject in not invasive way.

The presented device allows the monitoring of several biomedical parameters: heart rate (HR), heart rate variability (HRV), Sympathetic, parasympathetic and baroreflex activity, respiratory rhythms and their variations (bradypnea – tachypnea), snoring and abdominal-thoracic efforts.

A simple and effective method and device [1] is provided for helping to the diagnosis of Sleep Apnea-Hypopnea Syndrome (SAHS) and other breathing disorders.

I. INTRODUCTION

Disordered breathing during sleep is widely underdiagnosed. Among the diverse groups established by the International Classification of Sleep Disorders (ICSD), the sleep apnea-hypopnea syndrome (SAHS) is included in the first group "Intrinsic Sleep Disorders". SAHS causes a not repairer dream and important daytime repercussions such as sleepiness and psychiatric and cardiorespiratory secondary disorders [2][3].

Nowadays diagnosis of SAHS is not easy. On the one hand Primary Care Doctors have problems in sending patients to Pneumology Services for a deeper study, diagnosis and treatment. All this process usually takes a long time and requires complex diagnostic studies with a high cost.

Overnight full-channel polysomnography (PSG) remains the "gold standard" for the diagnosis of sleep apnea. PSG is a comprehensive recording of the biophysiological changes that occur during sleep, by monitoring many body functions including brain (EEG), eye movements (EOG), muscle activity or skeletal muscle activation (EMG), heart rhythm (ECG), and breathing function or respiratory effort during sleep. For thus, many sensors need to be attached to the patient and a manual screening of recorded data by a specialist is required for the diagnosis of the disorder [4].

PSG requires in most of cases staying a full night in a Sleep Unit, being attended by a specialist and anyway it does that an important number of cases with apnea remain underdiagnosed. This problem drives to the increasing interest to find alternative approximations to the diagnosis, as the portable methods.

This paper presents a new method, portable, simply and effective for helping to the diagnosis of SAHS and other cardiorespiratory disorders. It also provides information of the cardiac, respiratory and snoring activity of the subject.

II. PORTABLE METHODS AND STATE OF THE ART

The employment of alternative methods to the PSG to evaluate patients with suspicious of sleep apnea has been a motive of multiple reviews in the literature [5][6][7]. In most of these reviews, portable monitoring systems classified by the American Sleep Disorders Association are based on multiple sensors for monitoring and recording relevant physiological signals and parameters as blood oxygen saturation and/or airflow. However the employment of these systems is not extended because of the multiple obstacles they present

A. Portable devices for respiratory and cardiac activity

Nasal and oral airflow can be measured in portable systems by using thermocouple. This allows the clinician/researcher to measure rate of respiration or help to diagnose apneas but they are not effective in the detection of hypopneas. Pressure transducers for detecting changes of pressure determined by the inspiration and expiration are also employed. They are a better alternative system for the diagnosis of respiratory events because they provide a quantitative airflow signal without a nasal mask like in case of pneumotacography [8][9][10].

John G. Sotos et al [11] use microphones or sensors of

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acceleration to evaluate aspects related to breathing while the patient remains awake or slept, without this information contributes relevant data related to SAHS. David Francois [12] proposes the employment of a microphone placed in the neck of the patient to detect the states of hypoventilation, establishing a not detailed correlation of these states with apnea and hypopnea indexes. Rymut et al [13] use a piezoelectric sensor placed on the neck to fix some respiratory conditions of the patient, being based on the recording of the acoustic vibrations over the throat. Schechter et al [14] employ an accelerometer in the neck of the patient for recording acoustic vibrations, which are compared with bosses of breathing, for the identification of some disorders.

ECG is used for the recording of the cardiac signal. Though a typical ECG would use twelve electrodes, only two or three are used for a polysomnogram. They can either be placed under the collar bone on each side of the chest, or one under the collar bone and the other above the waist on either side of the body. It's often needed to clean the area by shaving or gathering the hair. Sometimes the cardiac signal is monitored by using a pulseoximeter.

Neil Townsend and Stephen Collins [15] describe a system for the presentation of the heart and respiratory rate based on the spectral analysis of the signal from one o more accelerometers. This system provides only these two parameters using monoaxial and/or biaxial sensors, and by using FFT or Autoregressive (AR) methods. This information is very limited especially if it's orientated to the diagnosis of SAHS, because of spectral analysis just provides average values in a wide signal interval.

Sierra, Gilberto et all [16] describe a method and device for the not invasive monitoring of the respiratory and cardiac rate and the apnea, by means of a sensor that detects the sounds and biological vibrations proceeding from the throat. This method and all those based exclusively in the recording of sounds [17] present the disadvantage of the application in patients not snorers who can present obstructive and/or central apneas. On the other hand, the heart rate obtained by mean of tracheal sounds is subject to multiple artifacts due to the used algorithms in the band of 20-200HZ.

B. *Portable snore-recording solutions*

In PSG test, snores are registered by a small usually piezoelectric microphone placed in the pretracheal area. Campos et al [18] propose a system including the hardware necessary for the analysis of tracheal snores by means of a high sensibility microphone. This information is not enough for an efficient diagnosis of diseases related to sleep apnea.

C. *The proposed method and device*

The system presented in this study [1] allows the constant monitoring of the respiratory signal and in consequence the detection of events as the cessation or resumption of thoracic movements, and the change of their intensity, typical in the patients with sleep apnea.

Besides it allows obtaining heart rate and hear rate variability and a high. These parameters together to respiratory activity supposes a great help for the diagnosis of these disorders.

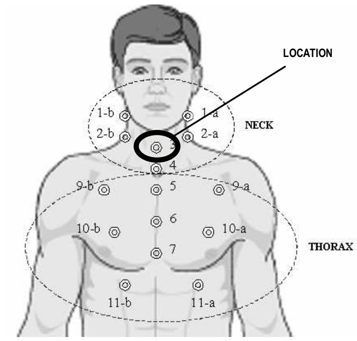

Fig. 1. Locations for the accelerometer

In addition to the information detailed previously, the system provides a further parameter: snoring activity, which allows discriminating possible events of SAHS from those that with certainty are not.

III. MATERIALS AND PROCEDURES

A. *Equipments and patients*

We considered for our study subjects referred to the Sleep Unit from "Hospital Universitario Puerta del Mar" of Cadiz (Spain), because of symptoms of SAHS for a PSG test. Individual consent for the study was obtained.

All of them were studied during a full or split night by mean of a supervised sleep study, using a SleepLab Polysomnographic System (Jaeger).

Together to the PSG related sensors, further information was recorded by using the following equipments (figure 1):

1. One piezoelectric accelerometer with integrated electronics (TEDS), model Endevco 752A12.
2. One polarized capacitive microphone, mode Bruel and Kjaer 41888A021. Microphone was used the acquisition of snore signals and its later correlation with the information from the accelerometer.
3. A Laptop and a unit of portable acquisition of information Brüel and Kjaer, model Pulse Front-End 3560 and its software for managing acquisition and recording of microphone and accelerometer signals.

A sampling rate for both sensors of 8192 Hz was fixed.

B. *Accelerometer location*

Obtaining the best position for the accelerometer is a basic item for the recording of valuable information for the help to the diagnosis of sleep apnea and other respiratory disorders. In a previous study to determine the ideal position of the acceleration sensor in order to maximize the average levels of power of the signal in the different bands of frequency (heart, breathing and snore), fifteen positions were analyzed. They were around neck and thorax as can be seen in figure 1. Finally it was chosen to locate the device between the thyroid cartilage and the superior third of the breastbone.

C. Signal Processing

MathWorks MATLAB® Software was used for digital signal processing and graphical representation.

The vibrations coming from the movement of the cardiac muscle, the respiratory movements originated by the respiratory activity of the subject, and the acoustic vibrations and sibilances originated by the snores, turn into an electrical signal as the output of the sensor of acceleration. This electrical signal is transmitted to a processing circuitry which amplifies the signal, filters it and converts it into a digital signal by sampling.

At this point, three different stages of processing were used, one for each component into the accelerometer signal.

1) Heart signal processing

The original accelerometer signal was previously downsampled to 256Hz in order to possibly the comparison with the ECG signal recorded from polysomnographic test. This sampling rate can be enough and even improved by cubic interpolation methods for getting a 1ms resolution [19]. A first stage of Band Pass filtering was then used in cutoff frequencies of [0.5Hz, 30Hz]. The frequencies were chosen for removing non heart related information. A second filtering stage was applied to eliminate baseline component in the bandwidth of cardiac signals (respiratory movements, artefacts, etc…). A Band Pass FFT filter was used to extract baseline component. The upper cutoff frequency was $f_u=0.67/f_s$, where f_s was the sampling rate.

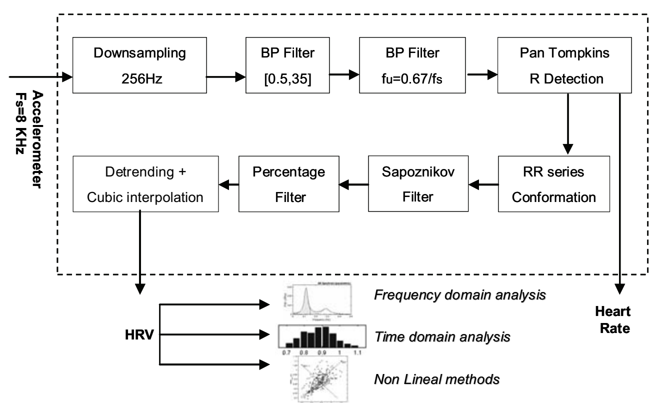

Fig. 2. Heart signal processing

A variant of Pan Tompkins' algorithm with Backward Search [20] was then applied to the previous resulting signal for the detection of R points. Ectopics beats and other anomalies in the RR series were removed using Sapoznikov's method [21] and the heart rate variability signal (HRV) was then obtained. RR interval time series usually includes a disturbing low frequency baseline trend component so a detrending filter using smoothness priors method [22] was used to remove these components. Finally a cubic interpolation was realized to get a 4 Hz HRV signal making possible a later frequency analysis of the resultant series. From this point, all the commonly used time and frequency domain parameters and the nonlinear methods as Poincare plot can be calculated.

2) Respiratory signal processing

Respiratory signal in PSG is often sampled at 8 Hz. Then for extraction of respiratory component a downsampling was firstly applied. The downsampled signal was low pass filtered. LP cutoff frequency was f_u=0.68Hz, normalized by the sampling rate. This processing allowed obtaining the correlated to respiratory signal without needing of windowing. For the calculation of the breathing rate, Power Spectral Density of respiratory component was evaluated. The rate is obtained of direct form from its maximal value.

3) Snore signal processing

Finally, component corresponding to the snore could be extracted from the electrical original signal coming from the sensor of acceleration by applying a band pass filtering with cutoff frequencies around vocal frequencies.

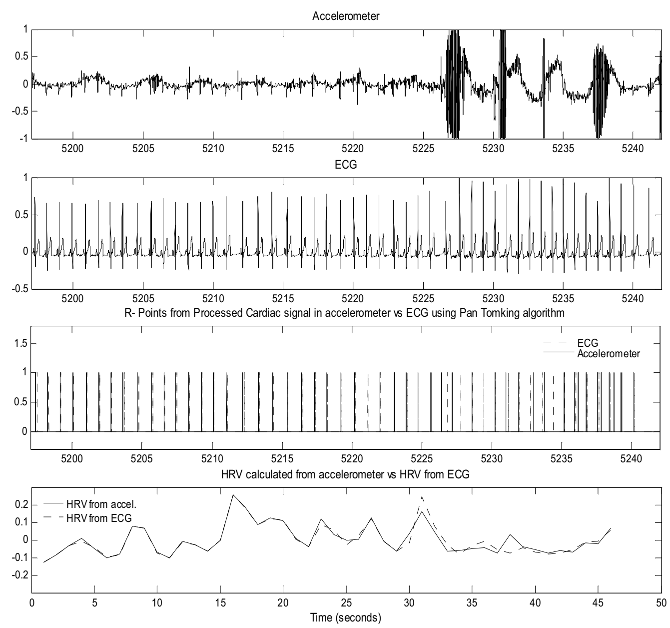

Fig. 3. ECG vs. Accelerometer

IV. RESULTS

Equipments and method for acquiring and processing the accelerometer signal been exposed. With the processing detailed in figure 2, it was possible to extract the heart rate and the heart rate variability signal (HRV), as can be appreciated in figure 3, where results using a common ECG and the proposed sensor are compared.

Figure 4 shows signals for an obstructive apnea event for a patient with SAHS and how respiratory component has a high correlation with the airflow and effort signals acquired with a thermistor and the belts used at Hospital.

Figure 5 shows the accelerometer and microphone signals recorded for a patient. The intervals of snores are identified at the output of filtering stage. These intervals can help to identify segments of interest for a more specific analysis.

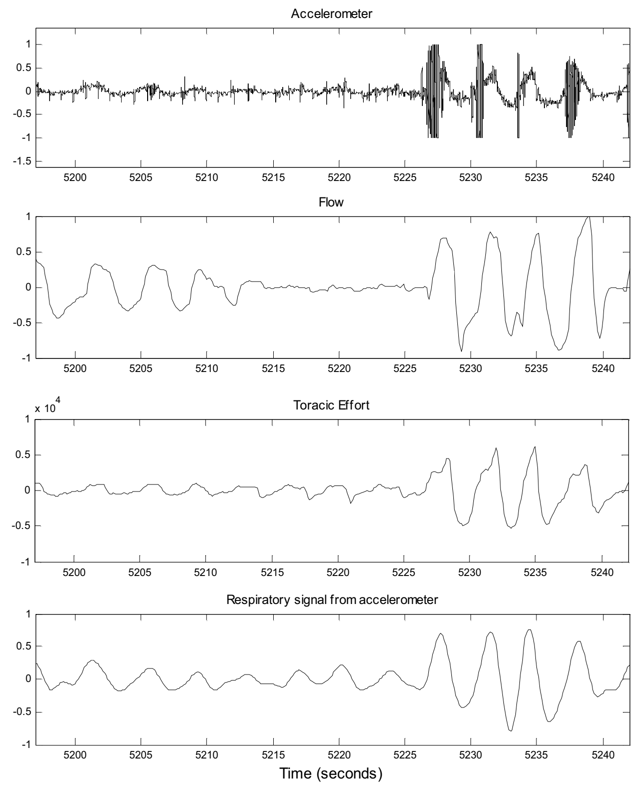

Fig. 4. Airfkw, thoracic effort and respiratory signal from accelerometer during an obstructive apnea event.

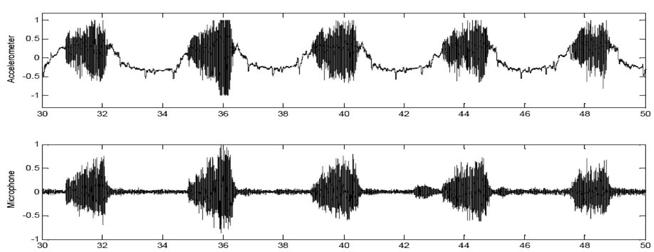

Fig. 5. Accelerometer vs. Snores in Microphone

V. CONCLUSION

The presented system provides fundamentally information of the different cardiorespiratory variables useful for the diagnosis of the different types of respiratory abnormal phenomena during the sleep or in position of decubitus (apneas, hypopneas and respiratory efforts, heart disorders and respiratory rates), by recording scalar temporary one-dimensional series of these physiological variables, and processing them by means of digital signal processing techniques for presenting several parameters. Heart rate, heart rate variability (HRV) and thus sympathetic and parasympathetic activity, bradypneas, tachypneas, and snores could be calculated. Just a sensor of acceleration is used, with home application possibility by substitution of the electrodes used for cardiac tests, the belts used for the acquisition of the efforts and the microphone used for the recording of the snores.

REFERENCES

[1] JL Rojas, A Leon, LF Crespo, DS Morillo, and N Gross, "Sistema para la determinación y monitorización de los índices de desaturaciones y tasa respiratoria instantánea", Patent P200602577, October 2006.

[2] H. Peter, T. Podszus, and P. von Wichert, Sleep Related Disorders and Internal Diseases. New York: Springer-Verlag, 1987, pp. 101–107.

[3] American Sleep Disorders Association Task Force, "The Chicago criteria for measurements, efinitions, and severity of sleep related breathing disorders in adults," in Assoc. Professional Sleep Soc. Conf., New Orleans, LA, 1998.

[4] C.Guilleminault and M. Partinen, Obstructive Sleep Apnea Syndrome,Clinical Diagnosis & Treatment. New York: Raven, 1990.

[5] Ross SD, Allen IE, Harrison KJ, et al. Systematic review of the literature regarding the diagnosis of sleep apnea: evidence report/technology assessment No. 1. Rockville, MD: Agency for Health Care Policy and Research; February 1999; AHCPR Publication No. 99–002

[6] Flemons W, Littner M, Rowley J, et al. Home diagnosis of sleep apnea: a systematic review of the literature; an evidence review cosponsored by the American Academy of Sleep Medicine, the American College of Chest Physicians, and the American Thoracic Society. Chest 2003; 124:1543–1579.

[7] Nancy A. Collop. Portable Monitoring for Diagnosing Obstructive Sleep Apnea: Not Yet Ready for Primetime. Chest 2004;125;809-811

[8] Norman R, Ahmed M, Walsleben J, et al. Detection of respiratory events during NPSG: nasal cannula/pressure sensor versus thermistor. Sleep 1997; 20: 1175-1184.

[9] Montserrat J, Farre R, Ballester E, et al. Evaluation of nasal prongs for estimating nasal flow. Am J Respir Crit Care Med 1997; 155: 211-215.

[10] Hosselet J, Norman R, Ayappa I, et al. Detection of flow limitation with a nasal cannula/pressure transducer system. Am J Respir Crit Care Med 1998; 157: 1461-1467.

[11] John G. Sotos et al. System and method for assesing breathing. US Patent application publication 2006/0155205 A1, 2006.

[12] David Francois. Dispositif pour surveiller la respiration d'un patient. Institut national de la propieté industrielle - PARIS. Publication 2847796/ 02 14920, 2004.

[13] Rymut et al. Method and apparatus for monitoring respiration. US Patent application publication 2002/0072685 A1, 2002.

[14] Schechter et al. Graphical readout of laryngotracheal spectra and airway monitor. . US Patent. Patent number 5.058.600, 1991.

[15] Neil T, Stephen C. Respiration and heart rate monitor. International application published under the patent cooperation treaty (PCT). WO 03/005893 A2, 2003.

[16] Gilberto S, Victor L, et all. Non invasive monitoring of respiratory rate, heart rate and apnea. International application published under the patent cooperation treaty (PCT). WO 2005/096931 A1, 2005.

[17] Raimon Jané, Jordi Solá José A Fiz Josep Morera, Automatic detection of snoring signals: Validation with simple snorers and OSAS patienrs. Proc. 22th Ann. EMBS Internat. Confer. . Chicago, 2000; 3129-3131

[18] Campos et al. Procedure for analysis of snoring and apnea and apparatus to carry out this analysis. European Patent Application, EP 1 410 759 A1, 2004.

[19] Daskalov I.,Christov I. Improvement of resolution in measurement of electrocardiogram RR intervals by interpolation. Medical Engineering and Physics, Volume 19, Number 4, June 1997, pp. 375-379.

[20] Pan J, WJ Tompkins. A real time QRS detection algorithm. IEEE Trans. On Biomedical Engineering. 32:230-236, 1985.

[21] D. Sapoznikov, M. H. Luria, Y. Mahler y M.S. Gotsman. Methods of arrhythmia removal in heart rate variability analysis. En 13th Annual Int. Conf. of the IEEE-EMBS, volumen 13, páginas 668{669, Orlando, 1991. IEEE Society Press.

[22] M.P. Tarvainen, P.O. Ranta-aho, and P.A. Karjalainen. An advanced detrending method with application to HRV analysis. IEEE Trans Biomed Eng, 49(2):172–175, February 2001.