33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

Normal non-regular snores as a tool for screening SAHS severity

J.Mesquita, *Student Member IEEE*, J.A.Fiz, *Member IEEE,* J.Solà-Soler, J.Morera, and R.Jané, *Member IEEE*

***Abstract*—Snoring is one of the earliest and most consistent sign of upper airway obstruction leading to Sleep Apnea-Hypopnea Syndrome (SAHS). Several studies on *post-apneic* snores, snores that are emitted immediately after an apnea, have already proven that this type of snoring is most distinct from that of normal snoring. However, *post-apneic* snores are more unlikely and sometimes even inexistent in simple snorers and mild SAHS subjects. In this work we address that issue by proposing the study of *normal non-regular* snores. They correspond to successive snores that are separated by normal breathing cycles. The results obtained establish the feasibility of acoustic parameters of *normal non-regular* snores as a promising tool for a prompt screening of SAHS severity.**

I. INTRODUCTION

SLEEP APNEA-HYPOPNEA SYNDROME (SAHS) is a serious sleep disorder with high community prevalence and snoring is one of its earliest and most consistent symptom. Snoring assumes particular characteristics, besides being a sign of pathology it can also be a trigger or a causative factor [1]-[3]. Consequently, due to its pathological importance, snoring has been recurrently analyzed and measured on the frequency and time domain by means of acoustic analysis techniques [4]-[6].

In our previous study [7] we introduced the concept of *regular snores* as the ones produced in consecutive breathing cycles. We proved that the time interval between regular snores has distinct distribution for subjects with different levels of SAHS severity.

In this work we assess the potential of *non-regular snores* features on screening SAHS subjects. According to our method, two successive snores are *non-regular snores* if they are separated by normal breathing cycles and/or apneas. Perez-Padilla et al [8] and Fiz et al [9] studied the snores emitted at the end of apneas: *post-apneic snores*. They found that the spectrum of this first snoring immediately after an apnea was most distinct from that of all other snoring episodes. Recently, Xu et al [10] found differences, for some frequency and spectral parameters, between first snores after upper and lower soft palate level obstructive sleep apneas.

Patients with severe SAHS produce greater number apnea events during the night than mild SAHS subjects and simple snorers. Consequently, the latter may sometimes present very few or even inexistent *post-apneic* snore episodes. In this work we address this issue by analyzing separately both groups that constitute *all non-regular snores*: *post-apneic snores* and *normal non-regular snores* [1]. We will investigate the information enclosed in both groups for a set of 34 subjects. And, more specifically, we will examine the possibility of *normal non-regular* snores carrying information about SAHS severity that up until now was only found in *post-apneic* snores.

II. MATERIALS AND METHODS

A. *Snoring Sound Signal acquisition*

Snoring sound signals were recorded while full-night polysomnography was being performed on the sleep disorders laboratory of the *Hospital Universitari Germans Trias i Pujol* in Badalona, Spain. Snoring sound was acquired with a unidirectional electric condenser microphone encapsulated and placed over the trachea at the level of the cricoid cartilage using an elastic band. A prototype of a single-channel device (Snoryzer Uno; Sibel SA, Barcelona, Spain) was used to acquire and record respiratory sounds during sleep. The signal was amplified and filtered using second order Butterworth analog band-pass filter between 70 and 2000Hz and then digitized with a sampling frequency of 5000Hz and a 12-bit analog/digital converter [11].

B. *Snoring and apnea detection*

Snoring and apnea episodes were identified by a proficiently trained and validated automatic detector and analyzer, developed by our group for the prototype of a single-channel device that was used to record snoring sound signals (DLL Snore Analyzer v9.52) [11],[12]. The automatic detector also identifies post-apneic snores.

C. *Subjects Database*

Our database consisted of respiratory sound signals from 34 subjects (8 females and 26 males with age range of 37-72 years and Apnea-Hypopnea Index (AHI) range of 3.2-109.9h^{-1}) whose anthropometric data is described in Table I.

Manuscript received April 14, 2011. This work was supported in part by Ministerio de Ciencia e Innovación from Spanish Government under grants TEC2007-68076-C02-01 and TEC2010-21703-C03-01

J.Mesquita, J.Solà-Soler and R.Jané, are with Dept. ESAII, Universitat Politècnica de Catalunya (UPC), Institut de Bioenginyeria de Catalunya (IBEC) and CIBER de Bioengenieria, Biomateriales y Nanomedicina (CIBER-BBN) Baldiri Reixac, 4, Torre I, 9 floor, 08028, Barcelona, Spain (jmgil@ibec.pcb.ub.es; jordi.sola@upc.edu;raimon.jane@upc.edu)

J.Morera is with Hospital Universitari Germans Trias i Pujol, Badalona (HUGTP), Spain (josepmorera.germanstrias@gencat.net)

J.A.Fiz, is with HUGTP, IBEC and CIBER-BBN, Spain (jafiz@msn.com)

978-1-4244-4122-8/11/$26.00 ©2011 IEEE

TABLE I

CHARACTERISTICS OF THE DATABASE

	Age	BMI	NSnores	AHI	Number
m±sd	50±10	28.5±3.9	2190±937	37.6±30.1	34 (8 F; 26 M)

BMI = Body Mass Index in kg/m^2, NSnores= total number of snores, AHI = Apnea-Hypoapnea Index in h^{-1}, F = female, M=male, m±sd = mean ± standard deviation

D. Non-regular snore classification

In our previous study [7] we focused on the time difference between the instant of the onset of a snore and the ending instant of its preceding one. In this paper we are uniquely interested in detecting *non-regular* snores and the time difference between the onset of a snore and the onset of its preceding one.

Let *TI* be the time interval between successive snores:

$$TI(i) = S_{onset}(i) - S_{onset}(i-1) \qquad (1)$$
$$i = 1,\ldots,NSn$$

where $S_{onset}(i)$ is the onset of the detected *i*th snore *S(i)* and *NSn* is the total number of snores detected by the method cited section II.B. In order to select *regular* and *non-regular* snores we apply the previously proposed moving threshold $TH_{adaptive}(i)$ to *TI* [7]:

$$TH_{adaptive}(i) = \begin{cases} \theta, & i < 10 \\ A + B & ,otherwise \end{cases}$$

$$A = (1-\delta)\frac{\sum_{10}^{i} TI(i-1)\,\mathrm{H}[TH_{adaptive}(i-1) - TI(i-1)]}{\sum_{10}^{i} \mathrm{H}[TH_{adaptive}(i-1) - TI(i-1)] - 1} \qquad (2)$$

$$B = \delta\,\frac{\sum_{10}^{i} TI(i-1)\,\mathrm{H}[TH_{adaptive}(i-1) - TI(i)] + TI(i)}{\sum_{10}^{i} \mathrm{H}[TH_{adaptive}(i-1) - TI(i)]}$$

The threshold is initialized with θ=10. Bearing in mind the *TI* definition in (1), the significance assigned to the *i*th *TI* for computing the adaptive threshold $TH_{adaptive}(i)$ at the *i*th snore is δ=0.5. H[β] is the Heaviside step function, whose value is 0 for β<0 and 1 for β>=0.

Non-regular snores are defined as the ones for which $TI(i) > TH_{adaptive}(i)$. After selecting *all non-regular snores* (*GANR*) we divided them into 2 subgroups:

GP: group of snores that are produced immediately after an apnea episode, i.e. post-apneic non-regular snores;

GN: group of snores that are separated by normal breathing cycles, i.e. normal non-regular snores.

A short segment of a snoring signal is shown in Fig.1 where *S(1)* is the snore produced forthwith after the apnea event: *post-apneic* snore. All *S(2)*- *S(7)* snores are *regular* snores because they are produced in consecutive breathing cycles. Given that *S(7)* and *S(8)* are separated by normal breathing cycles, then *S(8)* is a *normal non-regular* snore.

E. Parameters and Features

Several snore parameters from the 3 groups of snores, GANR, GP and GN were calculated. In time domain, the parameters studied were the Mean and Maximum Sound Intensity. In frequency domain, the snore parameters calculated were Peak, Mean, Center and Maximum Frequency and parameters that describe the shape of spectrum like the Standard Deviation, Symmetry coefficient and Spectral Flatness [13]. Mean, standard deviation and 75th percentile of the most significant parameters are included in this study, with p-value (Mann-Whitney *U* test) obtained to assess the independence of the populations with AHI cut-points of 5, 15 and 30 h^{-1}.

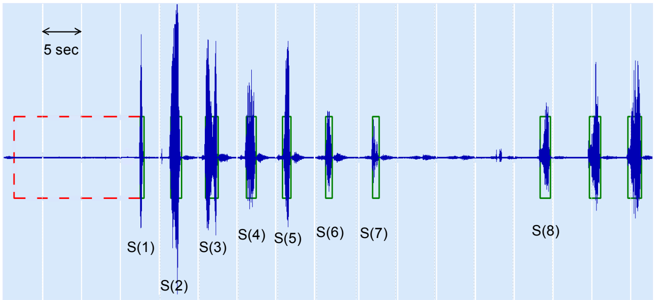

Fig. 1 Excerpt of a snoring sound signal. The dashed line box corresponds to an apnea episode and the solid line boxes correspond to snore episodes. *S(1)* is a *post-apneic non-regular* snore. All *S(2) - S(7)* snores are *regular* snores. *S(8)* is a *normal non-regular* snore.

III. RESULTS

After applying $TH_{adaptive}$ to the snore sequences of our set of 34 subjects we were able to select *non-regular* snores (GANR). Henceforth, for each subject GANR snores were divided in two subgroups: *post-apneic* snores, GP, and *normal non-regular* snores, GN. Table II summarizes the number of snores analyzed in each group for the set of 34 subjects. Since for our mild to moderate subjects (AHI range: 3.2-12.1h^{-1}) we had very few and in some cases inexistent *post-apneic* snores, we built two subsets of subjects. The SUBSET17 comprises 17 moderate to severe SAHS subjects that present both GP and GN groups of snores (Table III) and SUBSET11 is composed of 11 mild to

TABLE II

SET – 34 SUBJECTS (AHI RANGE: 3.2-109.9 h^{-1})

	Total NS	NS per subject
GANR	21204	624 ± 253
GN	20400	600 ± 240
GP	804	24 ± 35

TABLE III

SUBSET – 17 SUBJECTS (AHI RANGE: 15.1-109.9h^{-1})

	Total NS	NS per subject
GANR	12712	748 ± 225
GN	11930	702 ± 220
GP	782	46 ± 38

TABLE IV

SUBSET – 11 SUBJECTS (AHI RANGE: 3.2-12.1h^{-1})

	Total NS	NS per subject
GANR	5177	471 ± 208
GN	5170	470 ± 207
GP	7	0.6 ± 1.2

GANR: group of all *non-regular* snores. GN: group of *normal non-regular* snores. GP: group of *post-apneic non-regular* snores. Total NS: total number of snores in each group. NS per subject: mean ± standard deviation of the number snores for each subject moderate subjects that almost uniquely produce *normal non-regular* snores (Table IV).

For the whole set of 34 subjects we studied the acoustic parameters for GANR and GN (Table V and Table VI, respectively). Results obtained for the frequency domain parameters (Peak frequency, Mean frequency, etc) were not significant either for GANR or for GN.

For all *non-regular* snores, GANR, (Table V) we observed that *Imax* and *Imean* (maximum and minimum sound intensity) were significantly higher for more severe SAHS patients in all 3 AHI cut-points considered (5, 15 and 30h^{-1}). Mean, standard deviation and 75th percentile of different spectral parameters that consider frequency energy distribution obtained significant results. Among them, *Std*

TABLE V

FEATURES FOR **SET OF 34 SUBJECTS** ***GANR (all non-regular snores)***

		Imax			***Imean***			***Std Dev***			***CSymm***		
		M	SD	pC75	M	SD	pC75	M	SD	pC75	M	SD	pC75
S AHI	**<5**	55.24 ± 3.1	8.48 ± 1.7	61.09 ± 4.7	44.73 ± 2.9	7.63 ± 1.5	49.30 ± 3.6	183.64 ± 36.6	59.07 ± 18.7	228.83 ± 38.9	213.92 ± 49.8	67.91 ± 13.2	257.76 ± 56.8
	>=5	61.87 ± 5.2	10.40 ± 2.4	70.36 ± 7.2	50.93 ±4.5	9.39 ±2.21	58.12 ± 6.8	198.92 ± 40.3	55.80 ± 13	233.25 ± 45.3	260.45 ± 47.63	76.98 ± 17.9	313.86 ± 59.47
p_5		**0.0150***	0.1148	**0.0174***	**0.0201***	0.1148	**0.0231***	0.3778	0.8099	0.6496	0.1148	0.3227	0.1030
S AHI	**<15**	59.49 ± 5.7	9.04 ± 1.6	66.18 ±6.1	47.90 ±5.1	7.97 ± 1.8	53.35 ± 7	178.61 ±42.1	51.00 ±16.9	209.89 ±48.7	214.56 ±50.4	73.00 ±19.7	257.13 ± 62.4
	>=15	61.86 ±5.2	10.73 ± 2.5	70.74 ± 7.8	51.30 ± 4.3	9.76 ± 2.2	58.86 ± 6.5	205.97 ±36.1	58.66 ±11	243.65 ±38.2	274.31 ± 36.3	77.30 ± 16.6	331.24 ± 44.5
p _15		0.1053	**0.0272***	0.0713	0.0510	**0.0299***	**0.0359***	0.0713	0.1053	**0.0299***	**0.0041***	0.5559	**0.0029***
S AHI	**<30**	59.18 ± 5.5	9.15 ± 1.7	66.12 ± 6.3	48.30 ± 5	8.23 ± 2	54.01 ± 7.1	182.63 ± 37.8	53.56 ± 16.3	217.21 ± 45.2	226.90 ± 49.4	74.95 ± 16.9	274.31 ± 61.3
	>=30	62.79 ±4.8	11.10 ± 2.5	72.07 ± 7.5	51.89 ± 3.9	10.03 ± 2.1	59.80 ± 6	210.00 ± 37.7	58.51 ± 10.2	246.52 ± 39.3	279.94 ±34.7	76.76 ± 18.5	336.55 ± 44.8
p _30		**0.0338***	**0.0068***	**0.0165***	**0.0218***	**0.0181***	**0.0199***	**0.0401***	0.2771	**0.0401***	**0.0040***	0.8495	**0.0040***

TABLE VI

FEATURES FOR **SET OF 34 SUBJECTS** ***GN (normal non-regular snores)***

		Imax			***Imean***			***Std Dev***			***CSymm***		
		M	SD	pC75	M	SD	pC75	M	SD	pC75	M	SD	pC75
S AHI	**<5**	55.25 ± 3.1	8.48 ± 1.7	61.09 ± 4.7	44.73 ± 2.9	7.64 ± 1.5	49.30 ± 3.6	183.63 ± 36.6	59.10 ± 18.7	228.86 ± 39	213.90 ± 49.7	67.93 ± 13.2	257.82 ± 56.9
	>=5	61.67 ± 5.1	10.39 ± 2.4	70.10±7	50.76 ± 4.4	9.37 ± 2.2	57.85 ±6.7	198.17 ± 40.1	55.97 ± 13.3	232.89 ± 45.3	258.74 ± 46.5	76.85 ± 18	311.80 ± 58.2
p_5		**0.0150***	0.1148	**0.0174***	**0.0201***	0.1277	**0.0265***	0.3778	0.7688	0.6885	0.1277	0.3227	0.1030
S AHI	**<15**	59.48 ± 5.6	9.03 ± 1.6	66.19 ± 6.1	47.90 ± 5	7.98 ± 1.8	53.35 ± 7	178.56 ± 42	50.93 ± 17	209.9 ± 46.7	214.46 ± 50.3	72.96 ± 19.7	257.01 ±62.1
	>=15	61.60 ± 5.1	10.70 ± 2.5	70.41 ± 7.6	51.08 ± 4.2	9.73 ± 2.2	58.51 ± 6.4	205.01 ± 36	58.92 ± 11.4	243.19 ± 38.3	272.12 ± 35.3	77.16 ± 16.7	328.61 ± 43.4
p_15		0.1053	**0.0272***	0.0836	0.0510	**0.0429***	**0.0429***	0.0713	0.1134	**0.0328***	**0.0058***	0.5559	**0.0032***
S AHI	**<30**	59.13± 5.4	9.14 ± 1.7	66.04 ± 6.3	48.24 ± 5	8.21 ± 2	53.90 ± 7	182.49 ± 37.7	53.44 ± 16.5	217.07 ± 45.2	226.57 ±49.1	74.74 ± 16.9	273.79 ± 60.8
	>=30	62.51 ± 4.8	11.07 ± 2.5	71.71 ± 7.4	51.66 ± 3.9	10.01± 2.1	59.45 ± 5.9	208.87 ± 37.8	58.91 ± 10.5	246.06 ± 39.4	277.37 ± 33.8	76.74 ± 18.6	333.59±43.6
p_30		**0.0368***	**0.0083***	**0.0218***	**0.0238***	**0.0181***	**0.0218***	**0.0401***	0.2621	**0.0435***	**0.0061***	0.8225	**0.0061***

Values are mean ± standard deviation. M: mean. SD: standard deviation. pC75: 75th percentile. S AHI: Subjects with AHI above or under the cut-points 5, 15 and 30h^{-1}. * significance obtained using Mann-Whitney *U* test. p_X <0.05 was considered statistically significant.

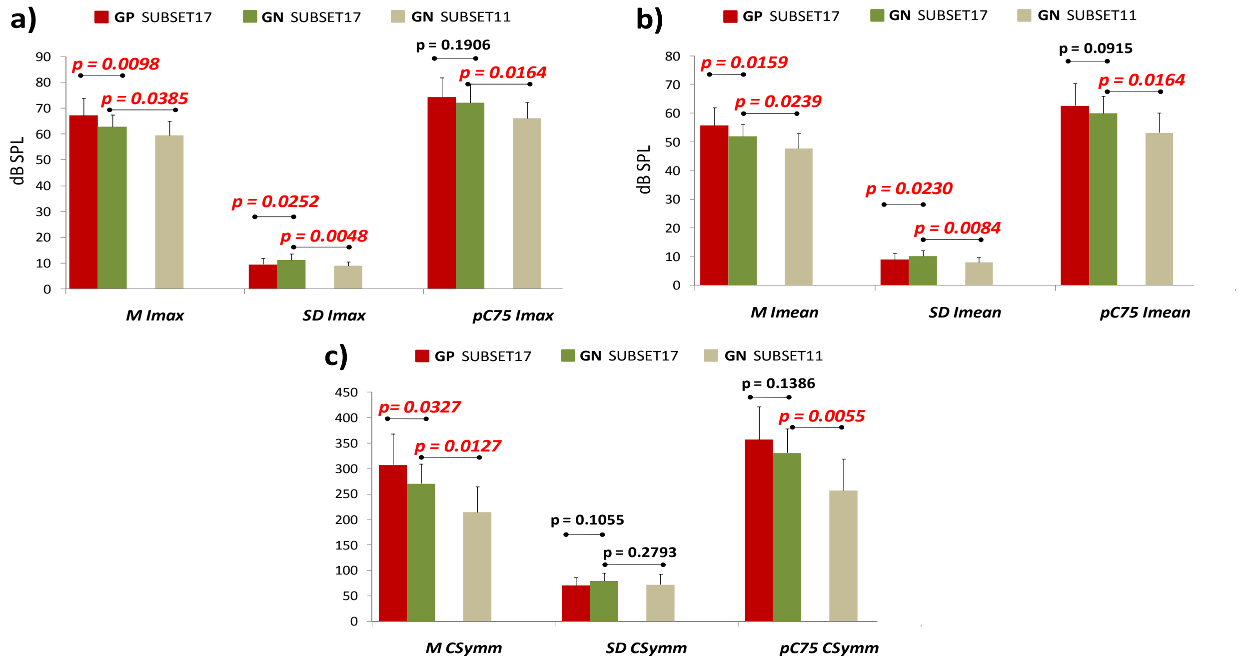

Fig 2 Bar graphs of the most significant parameters for groups of snores GP and GN from SUBSET17 and SUBSET11. Statistical significance between the groups GP and GN of SUBSET17 and between GN of both SUBSET17 and SUBSET11 is displayed. a) Maximum sound intensity features b) Mean sound intensity features c) Symmetry coefficient features.

Dev, measure of dispersion of the energy in frequency (second moment of the spectrum) and the symmetry coefficient (third moment of the spectrum) were significantly different ($p<0.05$) in patients with opposite levels of severity in AHI cut-points of 15 and $30h^{-1}$.

The same noteworthy results were obtained for *normal non-regular* snores, GN (Table VI). Statistical significance obtained for GN is less prominent when compared to GANR because *post-apneic non-regular* snores are excluded from this group but, nonetheless, the results showed that *normal non-regular* snores enclose notable information on the severity of SAHS subjects.

With SUBSET17 and SUBSET11 our goal was to study the effect of the presence/ absence of *post-apneic non-regular* snores on two sets of subjects with opposite levels of SAHS severity. The results for the most significant parameters are depicted using bar graphs in Fig. 2. Noticeable differences between the mean, standard deviation and pC75 values of all 3 parameters (*Imax*, *Imean*, *CSymm*) (Fig.2 a), b) and c)) of GP and GN of SUBSET17 are supported by p-values under 0.05, which confirms statistically significant differences.

Fairly remarkable results were obtained when comparing GN from both subsets: SUBSET17 and SUBSET11. We can observe that all GN features (mean, SD and pC75) of SUBSET17 have significantly higher value than GN features of SUBSET11 ($p<0.05$). This suggests that there are prominent differences between the acoustic characteristics of *normal non-regular* snores of mild (SUBSET11) and severe (SUBSET17) SAHS subjects. Therefore, *Imax*, *Imean* and *CSymm* parameters of *normal non-regular* snores prove to be key parameters for distinguishing mild from severe SAHS subjects.

IV. DISCUSSION AND CONCLUSION

In this work, a new method for a prompt screening of SAHS was proposed and validated in 34 snoring subjects. The method consists on studying parameters of *normal non-regular* snores. The time domain parameters include maximum and mean sound intensity. In the frequency domain, the parameters are Peak, Mean, Center and Maximum frequency and the ones used to describe the shape of the spectrum like the Standard Deviation of the spectrum, Symmetry coefficient and Spectral Flatness.

The novelty in this work is that it uses a group of snores that are present in all snoring subjects: *normal non-regular* snores. They consist of successive snores that are separated by normal breathing cycles, i.e., snores that are neither produced in consecutive breathing cycles (*regular* snores) nor emitted immediately after an apnea episode (*post-apneic non-regular* snores). Various studies have already proven the effectiveness of *post-apneic* snore characteristics on the purpose of distinguishing mild from severe SAHS patients. However, we quite often face the fact that for simple snorers and mild SAHS subjects there are very few or even inexistent *post-apneic* snores to carry on any feasible analysis. With this work we overcome this issue since we have proven that remarkable information about SAHS severity is enclosed in *normal non-regular* snores.

Moreover, we also found significant differences between the characteristics of *post-apneic non-regular* snores (GP) and *normal non-regular* snores (GN). This fact suggests that the comparison of these two types of snores may be a promising tool for stratifying a population composed of moderate to severe SAHS subjects. Finally, we observed that *normal non-regular* snore parameters of severe SAHS subjects have significantly higher values than those of mild SAHS subjects. Once again, this attests the fact that *normal non-regular* snores could be used for prompt screening of SAHS severity.

REFERENCES

[1] D. Pevernagie, R. M. Aarts, and M. De Meyer, "The acoustics of snoring," *Sleep Medicine Reviews*, vol. 14, no. 2, pp. 131-144, Apr.2010.

[2] "American Academy of Sleep Medicine. ICSD - International classification of sleep disorders: Diagnostic and coding manual," 2nd ed. Westchester: American Academy of Sleep Medicine,2005.

[3] F. Dalmasso and R. Prota, "Snoring: Analysis, measurement, clinical implications and applications," *Eur Respir J*, vol. 9, no. 1, pp. 146-159, 1996.

[4] A. S. Karunajeewa, U. R. Abeyratne, and C. Hukins, "Multi-feature snore sound analysis in obstructive sleep apnea syndrome," *Physiol. Meas.*, vol. 32, no. 1, p. 83, 2010.

[5] M. Herzog, A. Schmidt, H. Bremert, B. Herzog, W. Hosemann, and H. Kaftan, "Analysed snoring sounds correlate to obstructive sleep disordered breathing," *Eur. Arch. Otorhinolaryngol.*, vol. 265, no. 1, pp. 105-113, Jan.2008.

[6] J. Solà-Soler, R. Jané, J. A. Fiz, and J. Morera, "Formant frequencies of normal breath sounds of snorers may indicate the risk of Obstructive Sleep Apnea Syndrome," in *Proc. IEEE Eng. Med. Soc. 30th Annu. Int. Conf.* ,Vancouver, BC, Canada, 2008, pp. 3500-3503.

[7] J. Mesquita, J. A. Fiz, J. Solà-Soler, J. Morera, and R. Jané, "Regular and non regular snore features as markers of SAHS," in *Proc. IEEE Eng. Med. Soc. 32nd Annu. Int. Conf.* , Buenos Aires, Argentina, 2010, pp. 6138-6141.

[8] J. R. Perez Padilla, E. Slawinski, L. M. DiFrancesco, R. R. Feige, J. E. Remmers, and W. A. Whitelaw, "Characteristics of the snoring noise in patients with and without occlusive sleep apnea," *Am. Rev. Respir. Dis.*, vol. 147, no. 3, pp. 635-644, 1993.

[9] J. A. Fiz, J. Abad, R. Jane, M. Riera, M. A. Mananas, P. Caminal, D. Rodenstein, and J. Morera, "Acoustic analysis of snoring sound in patients with simple snoring and obstructive sleep apnoea," *Eur Respir J*, vol. 9, no. 11, pp. 2365-2370, Nov.1996.

[10] H. Xu, W. Huang, L. Yu, and L. Chen, "Sound spectral analysis of snoring sound and site of obstruction in obstructive sleep apnea syndrome," *Acta Oto-Laryngologica*, vol. 130, pp. 1175-1179, 2010.

[11] J. A. Fiz, R. Jané, J. Solà-Soler, J. Abad, M. Á. García, and J. Morera, "Continuous analysis and monitoring of snores and their relationship to the apnea-hypopnea index," *The Laryngoscope*, vol. 120, no. 4, pp. 854-862, Apr.2010.

[12] R. Jané, J. A. Fiz, J. Rigau, J. F. Alonso, F. Sopena, J. Solà-Soler, I. Vilasseca, J. Abad, J. M. Montserrat, and J. Morera, "Sleep apnoea-hypopnea screening by snoring analysis using a single-channel device,", 36 ed The European Respiratory Society (ERS) annual congress, 2010.

[13] R. Jané, J. A. Fiz, J. Solà-Soler, S. Blanch, P. Artís, and J. Morera, "Automatic snoring signal analysis in sleep studies," in *Proc. IEEE Eng. Med. Soc. 25th Annu. Int. Conf.* , Cancun, Mexico, 2003, pp. 366-369.