(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 2 608 717 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
11.05.2016 Bulletin 2016/19

(21) Application number: **11819507.2**

(22) Date of filing: **24.08.2011**

(51) Int Cl.:
A61B 5/12 *(2006.01)* ***A61B 5/00*** *(2006.01)*

(86) International application number:
PCT/IB2011/053715

(87) International publication number:
WO 2012/025892 (01.03.2012 Gazette 2012/09)

(54) APPARATUS FOR DIAGNOSING OBSTRUCTIVE SLEEP APNEA

VORRICHTUNG ZUR DIAGNOSE VON OBSTRUKTIVER SCHLAFAPNOE

APPAREIL POUR DIAGNOSTIQUER UNE APNÉE OBSTRUCTIVE DU SOMMEIL

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **26.08.2010 US 377105 P**

(43) Date of publication of application:
03.07.2013 Bulletin 2013/27

(73) Proprietors:
- **Ben Gurion University of The Negev Research and Development Authority**
  84105 Beer Sheva (IL)
- **Mor Research Applications Ltd.**
  69710 Tel Aviv (IL)

(72) Inventors:
- **ZIGEL, Yaniv**
  84965 Omer (IL)
- **TARASIUK, Ariel**
  85025 Meitar (IL)
- **BEN ISRAEL, Nir**
  62097 Tel Aviv (IL)

(74) Representative: **Hocking, Adrian Niall et al**
Albright IP Limited
County House
Bayshill Road
Cheltenham, Glos. GL50 3BA (GB)

(56) References cited:
WO-A1-2010/066008
US-A1- 2002 099 033
US-A1- 2005 043 645
US-A1- 2007 287 896
US-A1- 2008 243 014

- **XU L ET AL: "The optimization of perceptually-based features for speaker identification", 19890523; 19890523 - 19890526, 23 May 1989 (1989-05-23), pages 520-523, XP010083114,**
- **UDANTHA R ABEYRATNE ET AL: "Pitch jump probability measures for the analysis of snoring sounds in apnea; Snore sounds in OSA", PHYSIOLOGICAL MEASUREMENT, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, GB, vol. 26, no. 5, 1 October 2005 (2005-10-01), pages 779-798, XP020092229, ISSN: 0967-3334, DOI: 10.1088/0967-3334/26/5/016**
- **ZIGEL Y ET AL: "Analysis of speech signals among obstructive sleep apnea patients", ELECTRICAL AND ELECTRONICS ENGINEERS IN ISRAEL, 2008. IEEEI 2008. IEEE 25TH CONVENTION OF, IEEE, PISCATAWAY, NJ, USA, 3 December 2008 (2008-12-03), pages 760-764, XP031399513, ISBN: 978-1-4244-2481-8**

EP 2 608 717 B1

Description

TECHNICAL FIELD

[0001] Embodiments of the invention relate to detecting sleep apnea.

BACKGROUND

[0002] Obstructive sleep apnea (OSA) is a common disorder characterized by repetitive collapse or narrowing of the upper airway passages during sleep that impairs ventilation and disrupts sleep. Factors that contribute to upper airway collapse include reduced upper-airway dilator muscle activity during sleep, specific upper-airway anatomical features, decreased end-expiratory lung volume, ventilatory control instability, and sleep-state instability. A collapse or narrowing of the airway passages during sleep may result in total or near total cessation of breathing or a partial reduction of ventilation.

[0003] Total or near total cessation of breathing that lasts at least ten seconds is referred to as "apnea", and typically results in neurological arousal of the person from sleep that initiates activity to reopen the upper airway passages and reestablish breathing. A partial obstruction of the airway passages can lead to a partial reduction of normal airflow during breathing by at least 50% for at least ten seconds, and is accompanied by oxygen desaturation of blood by at least 4%, and/or arousal from sleep is referred to as "hypopnea". In a vast majority of cases OSA is accompanied by snoring, which is caused by vibration of soft tissue in the upper airway passages.

[0004] OSA is associated with an increased risk of cardiovascular disease, stroke, high blood pressure, arrhythmia and diabetes. Sleep fragmentation resulting from obstructive events can also increase a person's risk of being involved in an accident, such as a driving accident as a result of excessive daytime sleepiness and fatigue. Once diagnosed, a number of different therapies are available for treating OSA. The therapies include behavioral modification training, use of masks for introducing a flow of pressurized air into the throat to prevent collapse of tissue in the upper airway passages, and surgery to modify anatomical features of the airway passages that are responsible for OSA.

[0005] Diagnosis of OSA and determination of OSA severity are typically made with reference to an index referred to as an apnea-hypopnea index (AHI). The index is simply a count of the number of apnea and hypopnea events that a person exhibits per hour of sleep. An AHI index that is less than about 10 e/hr (events per hour) is usually considered clinically insignificant. An AHI index between about 10 e/hr and about 30 e/hr is considered to indicate a moderate case of OSA, and an AHI index greater than about 30, is considered to indicate a severe case of OSA.

[0006] Whereas the AHI index appears simple and straightforward, determining an AHI value for a patient generally involves performing a sleep study, referred to as polysomnography, (PSG) study. PSG is a relatively complicated and expensive procedure carried out in a sleep laboratory during the patient's overnight stay in the laboratory. PSG typically involves attaching a variety of sensors to the patient's body to track changes that occur in a battery of physiological activities and functions such as brain activity, eye motion, skeletal muscle activation, and heart rhythm during sleep. The waiting period for PSG has been reported to be a few weeks to more than a year in the United States.

[0007] Document WO 2010/066008 A1 discloses an apparatus for diagnosis OSA comprising a microphone. The apparatus records snore sounds and determines a set of mel-frequency cepstral coefficients of the snore sounds. Document "The optimization of perceptually-based features for speaker identification" by L. Xu et al., pp. 520-523 in Proc. IEEE Conf. Acoustics, Speech and Signal (ICASSP), 1999, discloses the calculation of the variance of mel-frequency cepstral coefficients for speech recognition.

SUMMARY

[0008] An aspect of the present disclosure relates to providing a non-invasive method of diagnosing presence of obstructive sleep apnea (OSA) in a person by determining an index, hereinafter an "apnea diagnosing index" (ADI), for the person responsive to detection and processing of snoring sounds made by the person during sleep. A value for ADI is determined as a function of a plurality of, optionally five, features F1, F2, F3, F4, and F5 that characterize snoring sounds and provides an indication of OSA that correlates with indications of OSA provided by the well-known apnea-hypopnea index (AHI). Optionally, the function is a linear function.

[0009] An aspect of the present disclosure relates to providing at least one new feature that may be used to distinguish snoring sounds that are indicative of presence and/or severity of OSA and to provide a value for ADI. In an embodiment of the invention the at least one new feature comprises "mel-cepstability", which provides a measure of variance of mel-frequency cepstrum coefficients (MFCC) of snoring sounds exhibited during a sleep period. Optionally, the at least one new feature comprises an average of variances in energy of groups of snores sounded during the sleep period. In an illustrative embodiment, the at least one feature comprises a number of groups of snores sounded during the sleep period for which variance in group energy is greater than a predetermined threshold.

[0010] An aspect of the present disclosure relates to providing a method of classifying severity of OSA responsive to values of the ADI. In an illustrative embodiment, the ADI provides an indication as to severity of OSA exhibited by a patient. Optionally, the ADI provides a classification of snoring sounds as not indicative of OSA, indicative of mild OSA, or indicative of severe OSA.

[0011] The invention relates to providing apparatus, hereinafter referred to as an "ADITESTER", which is relatively easily and conveniently used, optionally in a home environment, to diagnose OSA.

[0012] There is therefore provided in accordance with the present invention an apparatus for diagnosing OSA according to claim 1. Preferred embodiments are defined in the dependent claims.

DETAILED DESCRIPTION

[0013] In the following detailed description an ADITESTER in accordance with an embodiment of the invention, is schematically shown in Fig. 1 and its components and operation are discussed with reference to the figure. The ADITESTER is shown being used to determine a value for ADI and therefrom a diagnosis for the presence and severity of OSA for a person responsive to snoring sounds that the person makes during sleep. Details of the operation of the ADITESTER in generating a feature set that characterizes the person's snoring sounds and determining an OSA diagnosis for the person in accordance with an embodiment of the invention are discussed with reference to a flow diagram shown in Fig. 2.

[0014] Fig. 1 schematically shows an ADITESTER 20 operating to determine possible presence and severity of OSA in a person 100 sleeping, optionally, in a bedroom 102 of his own house. ADITESTER 20 comprises a microphone 22, optionally placed on a night table 104 near person 100 and a computer system 24. Microphone 22 registers sounds made by the person during sleep and sounds that are not made by the person that reaches the microphone. Sounds that are made by the person comprise for example, snoring sounds, breathing, coughing and voice sounds, and sounds that are produced by motion of the person, such as bed creaking and blanket rustling sounds. Sounds that are not made by the person may comprise street sounds and sounds originating in other rooms of the person's house that reach the bedroom and sounds made by appliances, such as a whirring sound made by an overhead fan 106 in bedroom 102. Sounds not made by the person may also include sounds made by another person (not shown) in the bedroom. For convenience of presentation, sounds that are registered by microphone 22 that are not respiratory sounds (snoring and breathing sounds) made by person 100 are referred to as background sounds. Microphone 22 transmits the sounds that it registers as a "sleep sound signal" schematically represented by a waveform 23, to computer system 24.

[0015] Computer system 24 processes the sleep sound signal to identify snoring sounds therein and provide a value for ADI for the person responsive to the snoring sounds. The computer system is optionally configured having computer executable instruction sets referred to as a snore detector 25, a feature extractor 26, and an ADI/OSA modeler 27 and optionally comprises a memory 28 in which it stores sleep sound signal 23 that the computer system receives from microphone 22. Snore detector 25 processes the sleep sound signal stored in the memory to identify snoring sounds therein. Feature extractor 26 processes snoring sounds identified by snore detector 25 to determine features, in accordance with an embodiment of the invention, that characterize the snoring sounds and may be used to determine a value for ADI for person 100. ADI/OSA modeler 27 uses the features provided by the feature extractor to determine a value for ADI and therefrom a diagnosis as to presence and severity of OSA for person 100.

[0016] Computer system 24 may comprise a smart phone PC, a laptop, and/or a work book located in the home of person 100 that stores and executes the instruction sets defining snore detector 25, feature extractor 26, and ADI/OSA modeler 27. However, computer system 24 is not limited to being housed in a single computer, or a computer located in a same room with person 100. Computer system 24 may be a distributed system having components and executable instruction sets located in different servers, and may be partially or completely based on access to servers via the internet, that is partially or completely "cloud based". For example, memory 28 may be located close to microphone 22 and directly coupled to the microphone to receive and store sleep sound signal 23. Snore detector 25, extractor 26 and ADI/OSA modeler may be connected to memory 28 and each other by the internet and reside and function in different internet servers.

[0017] Aspects and functioning of ADITESTER 20, snore detector 25, feature extractor 26, and ADI/OSI modeler 27 in determining if person 100 suffers from OSA, and if so a severity of the OSA, are discussed below with reference to a flow diagram 200 shown in Fig. 2A.

[0018] In a block 202 ADITESTER 20 is turned on and microphone 22 is registering sounds made in or reaching room 102 and transmitting analog electronic signals that form sleep sound signal 23 to computer system 24. The computer system converts sound signal 23 from an analog signal to a digital signal and optionally stores the digital sleep sound signal in memory 28. Hereinafter, unless otherwise specified, reference to sleep sound signal 23 is assumed to reference the digital form of the sleep sound signal. Sleep sound signal 23 includes background sounds, such as background sounds noted above, and respiratory sounds made by person 100 during a period in which the person is asleep. A sleep period, for which an associated sleep sound signal 23 is acquired, may have different durations, and may of course have

duration of a nominal full night's sleep of 6-8 hours. The sleep sound signal may include electromagnetic interference from power lines and appliances in a neighborhood of ADITESTER 20.

[0019] In a block 204, snore detector 25 processes sleep sound signal 23 to distinguish and identify snoring sounds in the sound signal. Any of various methods and algorithms may be used by the snore detector to identify snoring sounds. In an illustrative embodiment, snore detector 25 first filters sleep sound signal 23 to remove readily identifiable interference, such as electromagnetic interference generated at frequencies of alternating currents in power lines and appliance transformers, from sleep sound signal 23.

[0020] Thereafter, snore detector 25 processes the filtered sleep sound signal 23 to identify portions, hereinafter referred to as "audio events", of the filtered sleep sound signal 23 having energy and duration that indicate that the audio events are candidates for being "snore signals", which represent snoring sounds made by person 100. In an illustrative embodiment, for a portion of sleep sound signal 23 to be considered an audio event, the portion may be required to exhibit energy greater than a determined threshold energy E_{th} and have a duration "τ_d" greater than a minimum duration τ_{dmin} and less than a maximum duration τ_{dmax}.

[0021] To determine a value for E_{th} the sleep sound signal is segmented into consecutive, optionally partially overlapping sound frames having duration equal to about 30 ms (milliseconds). An energy for each sound frame is optionally, determined to be equal to a sum of squared amplitudes of sleep sound signal 23 in the frame, or an average of the squared amplitudes in the frame.

[0022] In an illustrative embodiment, a value for E_{th} is determined for each of a plurality of relatively long "windows" of time into which sleep sound signal 23 is divided responsive to lower and upper bound energies E_L and E_U respectively determined for sleep sound signal 23. A time window may have duration equal to hundreds or thousands of times that of the sound frames into which sleep signal 23 is segmented. Optionally E_L and E_U are determined from a frequency distribution of frames in the sleep sound signal as a function of frame energy. In an illustrative embodiment, E_L is an energy greater than an energy at which the distribution is maximum and for which the distribution falls to a fraction of the maximum. Optionally, the fraction is equal to about 0.10. Optionally, E_U is a multiple of E_L determined to provide a reasonable upper limit to a value determined for Et_h.

[0023] For a given time window, a candidate threshold energy "CE_{th}" for threshold energy E_{th} of the window is determined from a frequency distribution of frames in the window as a function of frame energy. Optionally, CE_{th} is an energy equal to a factor times an energy greater than an energy at which the frequency distribution is maximum, and for which the distribution falls to a fraction of its maximum. Optionally, the factor is equal to about 1.3. Optionally, the fraction is equal to about 0.10.

[0024] In an illustrative embodiment, the threshold energy E_{th} for the given time window is set equal to E_L if $CEt_h < E_L$; is set equal to E_U if $CEt_h > E_U$; and is set equal to CEt_h if $E_L \leq CE_{th} \leq E_U$.

[0025] A portion of sleep sound signal 23 in a given time window is determined to be an audio event in accordance with an illustrative embodiment if the portion comprises a plurality of consecutive sound frames: that have cumulative duration τ_d satisfying the constraint $\tau_{dmin} \leq \tau_d \leq \tau_{dmax}$; that have a peak energy "Ep" greater than E_{th}; and for which none of the frames have energy less than a threshold energy "E_r". In an embodiment of the invention, E_r is equal to $0.5(E_{th} + E_{Wm})$, where E_{Wm} is a minimum energy exhibited by frames in the given window. Optionally, τ_{dmin}, is equal to about 0.2 s (seconds) and τ_{dmax} is equal to about 2.5 s.

[0026] For each audio event that is determined to be a candidate snore signal, snore detector 25 generates a feature set and uses a Gaussian mixture model (GMM) classifier to determine responsive to the feature set, if the candidate snore signal is to be classified as a snore signal.

[0027] In an illustrative embodiment, the feature set that snore detector 25 generates for a snore signal candidate comprises a set of "n" linear predictor coefficients (LPC), and the candidate's pitch density; average pitch value; total energy; duration, and rise time. Optionally, n is equal to 12. In an illustrative embodiment, the GMM classifier comprises two Gaussian density models, one having order n_S for snore signal candidates that represent snoring sounds and one having order n_B for snore signal candidates that represent background sounds. Optionally, n_S and n_B are equal to 3 and 11, respectively. A set of GMM parameters that define the GMM classifier are optionally determined as a GMM parameter set that maximizes a likelihood of the feature sets for the models. The feature sets acquired for each of a plurality of training snore signal candidates that are known to represent a snoring sound or a background sound.

[0028] In a block 206 snore signals identified by snore detector 25 in sleep sound signal 23 acquired for person 100 are processed by feature extractor 26 to define a feature set for sleep sound signal 23 that may be used to provide a value for ADI and therefrom a diagnosis of OSA for the person, in accordance with an embodiment of the invention. Feature extractor 26 generates a feature set comprising five features, F1, F2, F3, F4, and F5, for sleep sound signal 23.

[0029] Feature F1, referred to as a "Mel-Cepstability" of sleep sound signal 23, is a function of mel-frequency cepstral coefficients (MFCC) determined from the log power spectra as functions of frequency measured in the mel-frequency scale of snore signals identified by snore detector 25 in sleep sound signal 23.

[0030] The mel scale is a perceptual scale of frequencies, measure in "mels", that maps frequency conventionally measured in Hz to a perceptual scale for which pairs of pitches having a same difference in mels are perceived by a

human as having a same difference in frequency, or pitch. A frequency of 1000 Hz has a value in mels equal to 1000. A frequency "f_{Hz}" in Hz has a frequency f_{mel} in mels defined by a formula:

$$1) \qquad f_{mel} = 2595\log 10(1+f_{Hz}/700).$$

[0031] Let an s-th snore signal of a total of "S" snore signals identified in sleep sound signal 23 acquired for person 100 have a time dependent amplitude represented by $A_s(t)$. Then a power spectrum $P(f_{Hz})$ of $A_s(t)$ as a function of frequency in Hz may be written:

$$2) \qquad P(f_{Hz}) = |\boldsymbol{F}\{A_S(t)\}|^2,$$

where $\boldsymbol{F}\{A_s(t)\}$ is a Fourier transform of $A_s(t)$. Filtering $P(f_{Hz})$ with a mel-frequency filterbank comprising K mel-frequency filters, provides a discrete mel-frequency power spectrum $P(k,f_{mel})$ for $A_s(t)$ having K values.

$$3) \qquad P(k,f_{mel}) = (\mathbf{MEL}_k|\boldsymbol{F}\{A_S(t)\}|^2), \; k = 1 \rightarrow K.$$

[0032] If

$$4) \qquad X_k(s) = \{\log(\mathbf{MEL}_k|\boldsymbol{F}\{A_S(t)\}|^2)\}, \; k = 1 \rightarrow K,$$

then a discrete cosine transform (DCT) of the $X_k(s)$ generates optionally K mel-frequency cepstral coefficients $c_i(s)$ for $A_s(t)$, where

$$5) \qquad c_i(s) = \sum_{k=1}^{k=K} X_k(s)\cos[i(k-1/2)\,\pi/K], \; i = 1 \rightarrow K.$$

[0033] In accordance with the present invention, feature F1, that is Mel-Cepstability, is a sum of the variances of the MFCC $c_i(s)$ optionally normalized to an average energy "E" of the S snore signals in sleep sound signal 23 acquired for person 100. In symbols, F1 may be defined by an expression,

$$6) \qquad F1 = \text{MelCepstability} = \sum_{s=1}^{s=S}\sum_{i=1}^{i=K}[\,c_i(s) - \bar{c}_i(s)]^2/E.$$

In equation 6) $\bar{c}_1(s)$ is an average value for $c_i(s)$ over all S snore signals identified in sleep sound signal 23, and is defined by an expression,

$$7) \qquad \bar{c}_i(s) = \sum_{s=1}^{s=S} c_i(s), \quad i = 1 \rightarrow K.$$

If E(s) is the energy of the s-th snore signal then

$$8) \qquad E(s) = \sum_{k=1}^{k=K} X_k(s)^2 \,,$$

and the average snore energy E may be written

$$9) \qquad E = (1/S)\sum_{s=1}^{s=S} E(s).$$

[0034] Feature F2 is optionally equal to an average of variances in energy for groups of snore signals in sleep sound signal 23. A group of snore signals in accordance with a preferred embodiment of the invention comprises a sequence of snores in sleep sound signal 23 for which a time delay between an end of a snore in the group and a next subsequent snore in the group is less than or equal to a maximum time lapse "τ_g". Optionally, "τ_g is equal to one minute.

[0035] Assume that sleep sound signal 23 comprises "G" snore signal groups, and a g-th group contains "S_g" snore signals. If the variation in snore signal energy in a given group g is varE(g), an average energy of snore signals in the group is $\overline{E}(g)$, and an s-th snore signal in the group has energy E(s, g), then

$$10) \quad \mathrm{varE(g)} = \sum_{s=sg}^{s=Sg}[\mathrm{E(s,g)} - \overline{\mathrm{E}}(\mathrm{g})]^2 / \mathrm{S_g},$$

and if an average of varE(g) is $\overline{\mathrm{varE(g)}}$, then

$$11) \quad \mathrm{F2} = \overline{\mathrm{varE(g)}} = (1/\mathrm{G}) \sum_{g=1}^{g=G} \mathrm{varE(g)}.$$

[0036] In a preferred of the invention, feature F3 is equal to a number of snore groups in sleep sound signal 23 whose variance, varE(g), in the group energy is greater than a threshold variance, "$\mathrm{varE(g)_{TH}}$." In symbols,

$$12) \quad \mathrm{F3} = \sum_{g=1}^{g=G} \boldsymbol{bool}\{\mathrm{varE(g)} > \mathrm{varE(g)_{TH}}\}/\mathrm{G}.$$

[0037] Feature F4 is a count N_Q of a number of silent periods, referred to a "quiet hiatuses", which are indicative of substantially total suspension of breathing in sleep sound signal 23 that are located between two audio events, whether or not at least one of the audio events is classified as a snore signal. In accordance with an embodiment of the invention, to be considered a silent period an absence of sound from person 100 is required to have duration "τ_Q" greater than a minimum duration "τ_{Qmin}" and less than a maximum duration equal to "τ_{Qmax}". In symbols, if $A(t)_S$ is the time dependent amplitude of sleep sound signal 23, the F4 count N_Q of quiet hiatuses may be defined by an expression:

$$13) \quad \mathrm{F4} = \mathrm{N_Q} = \sum_{s=1}^{s=S} \boldsymbol{bool}\{(\tau_{Qmin} < \tau_Q < \tau_{Qmax}) | \, \mathrm{A_S(t)} \leq \mathrm{A_{SB}}\}$$

In an illustrative embodiment, τ_{Qmin} is equal to about 10 seconds and τ_{Qmax} is equal to about 90 seconds. A_{SB} is substantially equal to a background noise level that may exist when person 100 is not making any respiratory sounds.

[0038] Feature F5 is optionally equal to a mean of the pitch density of all snore signals identified in sleep sound signal 23 acquired for person 100. In a preferred of the invention a pitch density for an s-th snore signal is determined by segmenting the snore signal into "F" frames having duration equal to 30 ms (milliseconds) and determining a maximum of an autocorrelation function for each frame. The pitch density PD(s) for the s-th snore signal is equal to a fraction of the frames in the snore signal for which a maximum of the autocorrelation function is greater than a threshold value "R". If the autocorrelation function of a given "f-th" frame in the s-th snore signal is represented by *Rii*(*s,f*) and a number of frames in the snore signal is equal to F, then,

$$14) \quad \mathrm{PD(s)} = \sum_{f=1}^{f=F} \boldsymbol{bool}\{\mathbf{Max}Rii(\mathrm{s,f}) > R\}/\mathrm{F},$$

and if an average of PD(s) over all snore sounds in sleep sound signal 23 **is** $\overline{\mathrm{PD}}$, then

$$15) \quad \mathrm{F5} = \overline{\mathrm{PD}} = \sum_{s=1}^{s=S} \mathrm{PD(s)}/\mathrm{S}.$$

[0039] In a block 208 ADI/OSA calculator 27 processes the features F1...F5 to generate a value for ADI. ADI is determined as a linear function of the features in accordance with an equation:

$$16) \quad \mathrm{ADI} = \alpha_o + \alpha_1\mathrm{F1} + \alpha_2\mathrm{F2} + \alpha_3\mathrm{F3} + \alpha_4\mathrm{F4} + \alpha_5\mathrm{F5}.$$

[0040] Optionally coefficients $\alpha_o \ldots \alpha_5$ are determined to provide a best fit to measurements of AHI acquired for a training group of persons that includes persons who do not exhibit OSA and persons who exhibit OSA characterized by different degrees of severity. Optionally values for AHI for the persons are determined from PSG studies. A best fit is optionally determined by a least squares analysis.

[0041] By way of a numerical example, features F1, F2, F3, F4, and F5 as defined above may assume values in the

following ranges:

17) F1: [0 to 0.5], F1: [0 to 1.5], F1: [0 to 1], F1: [0 to 500], and F1: [0 to 1].

Best fit values for α_o ...α_5 determined from a training group of about 90 people may have values,

18) $\alpha_0 = -3$, $\alpha_1 = 128.1$, $\alpha_2 = 18.8$, $\alpha_3 = 14.9$, $\alpha_4 = 0.0075$, and $\alpha_5 = -48.0143$.

[0042] ADI determined in accordance with equation 16) for the numerical values given in expressions 17) and 18) was found to be able to distinguish whether a person had: no or a clinically insignificant case of OSA; a mild case of OSA (AHI index greater than 10 and less than 30); or a severe case of OSA (AHI index greater than 30). Classification of OSA using ADI was found to agree well with classifications provided by values of AHI determined by PSG.

[0043] The confusion matrix below indicates correlation between the ADI index determined in accordance with an embodiment of the invention and an AHI determined by PSG. Rows in the table are labeled with a diagnosis of OSA, "NO OSA", MILD OSA", or "SEVERE OSA", determined by PSG. For each row, a diagnosis of OSA determined in accordance with the ADI index is given in columns headed "NO OSA", "MILD OSA", or "SEVERE OSA". From the matrix it is seen that the ADI and AHI indices give a same diagnosis 87% of the time for people with no OSA and 84% of the time for people with severe OSA. For mild cases of OSA agreement falls to about 56% but the two indices will agree 78% of the time as to whether or not a person has OSA.

		ADI INDEX		
		NO OSA	**MILD OSA**	**SEVERE OSA**
AHI INDEX	**NO OSA**	0.87	0.10	0.03
	MILD OSA	0.22	0.56	0.22
	SEVERE OSA	0.05	0.11	0.84

[0044] It is noted that whereas in the above description a linear regression function is used to provide a value of ADI and a diagnosis of OSA, practice of embodiments is not limited to linear regression classifiers. Non linear regression functions, support vector functions of F1...F5, and any of various other regression methods may be used to detect and classify cases of OSA.

[0045] In the description and claims of the present application, each of the verbs, "comprise" "include" and "have", and conjugates thereof, are used to indicate that the object or objects of the verb are not necessarily a complete listing of components, elements or parts of the subject or subjects of the verb.

[0046] Descriptions of embodiments of the invention in the present application are provided by way of example and are not intended to limit the scope of the invention. The described embodiments comprise different features, not all of which are required in all embodiments of the invention. Some embodiments utilize only some of the features or possible combinations of the features. Variations of embodiments of the invention that are described, and embodiments of the invention comprising different combinations of features noted in the described embodiments, will occur to persons of the art. The scope of the invention is limited only by the claims.

Claims

1. Apparatus for diagnosing obstructive sleep apnea (OSA), the apparatus comprising:

   a microphone (22) for acquiring a sleep sound signal (23) of a person; and
   a computer system (24) configured to:

      detect a plurality of snore sounds in the sleep sound signal;
      determine a set of mel-frequency cepstral coefficients for each of the snore sounds;
      determine a variance for each of the sets of mel-frequency cepstral coefficients;

   characterized in that the computer system (24) is further configured to:

      determine a sum of the variances for the plurality of snore sounds;
      determine a first characterizing feature for the sleep sound signal responsive to the sum of the variances; and
      use the first characterizing feature to diagnose OSA in the person.

2. Apparatus according to claim 1 wherein the computer system (24) is configured to :

   determine a plurality of groups of the snore sounds;
   determine a group feature for each of the groups;
   determine a second characterizing feature for the sleep sound signal responsive to the group features; and
   use the determined second characterizing feature for the sleep sound signal to diagnose OSA in the person.

3. Apparatus according to claim 2 wherein the computer system (24) is configured to determine a cluster of consecutive snore sounds in the detected snore sounds for which a time delay between any two temporally adjacent snore sounds is less than or equal to a predetermined time period.

4. Apparatus according to claim 2 or claim 3 wherein the time period is equal to about a minute.

5. Apparatus according to any of claims 2-4 wherein the group feature for each group comprises a measure of energy for each of the snore sounds in the group.

6. Apparatus according to claim 5 wherein the computer system (24) is configured to use the measure of energy for the snore sounds in the group to determine a measure of an average energy of the snore sounds in the group.

7. Apparatus according to claim 6 wherein the computer system (24) is configured to determine a variance of the measures of snore sound energies for the group.

8. Apparatus according to claim 7 wherein the computer system (24) is configured to determine the second characterizing feature of the sleep sound signal responsive to an average of the determined variances of the groups and use the second characterizing feature to diagnose OSA in the person.

9. Apparatus according to claim 7 or claim 8 wherein the computer system (24) is configured to determine a third characterizing feature of the sleep sound signal responsive to a number of groups in the sound signal for which the variance is greater than a predetermined threshold variance and use the third characterizing feature to diagnose OSA in the person.

10. Apparatus according to any of the preceding claims wherein the computer system (24) is operative to:

    determine a number of silent periods in the sleep sound signal that are indicative of substantially total suspension of breathing by the person;
    determine a fourth characterizing feature of the sleep sound signal responsive to the number of determined silent periods; and
    use the fourth characterizing feature to diagnose OSA in the person.

11. Apparatus according to any of the preceding claims wherein the computer system (24) is operative to:

determine a pitch density for each of the plurality of snore sounds in the sleep sound signal;
determine an average pitch density for the snore sounds;
determine a fifth characterizing feature of the sleep sound signal responsive to the average pitch density; and
use the fifth characterizing feature to diagnose OSA in the person.

12. Apparatus according to claim 1, wherein the computer system (24) is configured to:

determine a second characterizing feature determined responsive to a measure of an average of variances in energies of snore sounds in groups of the snore sounds;
determine a third characterizing feature determined responsive to a number of groups of snore sounds that have a variance in snore sounds energies greater than a predetermined variance; and
use the determined features to diagnose OSA in the person.

13. Apparatus according to claim 12 wherein the plurality of characterizing features comprises a fourth characterizing feature determined responsive to a number of silent periods in the sleep sound signal that are indicative of substantially total suspension of breathing by the person.

14. Apparatus according to claim 12 or claim 13 wherein the plurality of characterizing features comprises an additional feature determined responsive to an average pitch density for the snore sounds.

Patentansprüche

1. Gerät zur Diagnose von obstruktiver Schlafapnoe (OSA), wobei das Gerät umfasst:

ein Mikrofon (22) zur Erfassung eines Schlafgeräuschsignals (23) einer Person; und
ein Computersystem (24), dazu konfiguriert,

eine Vielzahl von Schnarchgeräuschen im Schlafgeräuschsignal zu erfassen; einen Satz von Mel-Frequenz-Cepstralkoeffizienten für jedes Schnarchgeräusch zu ermitteln;
eine Abweichung für jeden Satz Mel-Frequenz-Cepstralkoeffizienten zu ermitteln;
dadurch gekennzeichnet, dass das Computersystem (24) ferner dazu konfiguriert ist,

eine Summe der Abweichungen für die Vielzahl von Schnarchgeräuschen zu ermitteln;

ein erstes kennzeichnendes Merkmal für das Schlafgeräuschsignal, das auf die Summe der Abweichungen reagiert, zu ermitteln, und
das erste kennzeichnende Merkmal zur Diagnose von OSA bei der Person zu nutzen.

2. Gerät nach Anspruch 1, wobei das Computersystem (24) dazu konfiguriert ist,
eine Vielzahl von Gruppen von Schnarchgeräuschen zu ermitteln;
ein Gruppenmerkmal für jede der Gruppen zu ermitteln;
ein zweites kennzeichnendes Merkmal für das Schlafgeräuschsignal, das auf die Gruppenmerkmale reagiert, zu ermitteln, und
das ermittelte zweite kennzeichnende Merkmal für das Schlafgeräuschsignal zur Diagnose von OSA bei der Person zu nutzen.

3. Gerät nach Anspruch 2, wobei das Computersystem (24) dazu konfiguriert ist,
ein Cluster von aufeinanderfolgenden Schnarchgeräuschen in den erfassten Schnarchgeräuschen zu ermitteln, für die eine Verzögerung zwischen zwei beliebigen zeitlich benachbarten Schnarchgeräuschen kleiner / gleich einem vorgegebenen Zeitraum ist.

4. Gerät nach Anspruch 2 oder Anspruch 3, wobei der Zeitraum etwa einer Minute entspricht.

5. Gerät nach einem der Ansprüche 2 bis 4, wobei das Gruppenmerkmal für jede Gruppe
ein Maß an Energie für jedes der Schnarchgeräusche in der Gruppe umfasst.

6. Gerät nach Anspruch 5, wobei das Computersystem (24) dazu konfiguriert ist,

das Maß an Energie für die Schnarchgeräusche in der Gruppe dazu zu nutzen, ein Maß einer durchschnittlichen Energie für die Schnarchgeräusche in der Gruppe zu nutzen.

7. Gerät nach Anspruch 6, wobei das Computersystem (24) dazu konfiguriert ist,
eine Abweichung der Maßzahlen der Schnarchgeräuschenergien für die Gruppe zu ermitteln.

8. Gerät nach Anspruch 7, wobei das Computersystem (24) dazu konfiguriert ist,
das zweite kennzeichnende Merkmal des Schlafgeräuschsignals zu ermitteln, das auf einen Durchschnittswert der ermittelten Abweichungen der Gruppen reagiert, und das zweite kennzeichnende Merkmal zur Diagnose von OSA bei der Person zu nutzen.

9. Gerät nach Anspruch 7 oder 8, wobei das Computersystem (24) dazu konfiguriert ist,
ein drittes kennzeichnendes Merkmal des Schlafgeräuschsignals zu ermitteln, das auf eine Anzahl von Gruppen im Geräuschsignal reagiert, deren Abweichung einen vorgegebenen Abweichungs-Schwellenwert überschreitet, und das dritte kennzeichnende Merkmal zur Diagnose von OSA bei der Person zu nutzen.

10. Gerät nach einem der vorstehenden Ansprüche, wobei das Computersystem (24) dazu dient,
eine Anzahl von Stilleperioden im Schlafgeräuschsignal zu ermitteln, die das im Wesentlichen vollständige Aussetzen der Atmung der Person anzeigen;
ein viertes kennzeichnendes Merkmal für das Schlafgeräuschsignal, das auf die Anzahl der ermittelten Stilleperioden reagiert, zu ermitteln, und
das vierte kennzeichnende Merkmal zur Diagnose von OSA bei der Person zu nutzen.

11. Gerät nach einem der vorstehenden Ansprüche, wobei das Computersystem (24) dazu dient,
eine Messpunktdichte für jeden aus der Vielzahl von Schnarchgeräuschen im Schlafgeräuschsignal zu ermitteln;
eine durchschnittliche Messpunktdichte für die Schnarchgeräusche zu ermitteln;
ein fünftes kennzeichnendes Merkmal für das Schlafgeräuschsignal, das auf die durchschnittliche Messpunktdichte reagiert, zu ermitteln, und
das fünfte kennzeichnende Merkmal zur Diagnose von OSA bei der Person zu nutzen.

12. Gerät nach Anspruch 1, wobei das Computersystem (24) dazu konfiguriert ist,
ein zweites kennzeichnendes Merkmal zu ermitteln, von dem ermittelt wurde, dass es auf ein Maß eines Durchschnitts von Abweichungen der Energien der Schnarchgeräusche in Gruppen von Schnarchgeräuschen reagiert;
ein drittes kennzeichnendes Merkmal zu ermitteln, von dem ermittelt wurde, dass es auf eine Anzahl von Gruppen von Schnarchgeräuschen reagiert, deren Abweichung bei den Schnarchgeräuschenergien eine vorgegebene Abweichung überschreitet, und
die ermittelten Merkmale zur Diagnose von OSA bei der Person zu nutzen.

13. Gerät nach Anspruch 12, wobei die Vielzahl von kennzeichnenden Merkmalen ein viertes kennzeichnendes Merkmal umfasst, von dem ermittelt wurde, dass es auf eine Gruppe von Stilleperioden im Schlafgeräuschsignal reagiert, die das im Wesentlichen vollständige Aussetzen der Atmung der Person anzeigen.

14. Gerät nach Anspruch 12 oder Anspruch 13, wobei die Vielzahl von kennzeichnenden Merkmalen ein zusätzliches Merkmal umfasst, von dem ermittelt wurde, dass es auf eine durchschnittliche Messpunktdichte für die Schnarchgeräusche reagiert.

Revendications

1. Dispositif de diagnostic de l'apnée obstructive du sommeil (AOS), l'appareil comprenant :

un microphone (22) destiné acquérir un signal acoustique de sommeil (23) d'une personne ; et un système informatique (24) configuré pour :

détecter une pluralité de sons de ronflement dans le signal acoustique de sommeil ;
déterminer un ensemble de coefficients cepstraux sur une échelle de fréquences de Mel pour chacun des sons de ronflement ;
déterminer une variance pour chacun des ensembles de coefficients cepstraux sur une échelle de fréquen-

ces de Mel ;
caractérisé en ce que le système informatique (24) est en outre configuré pour : déterminer une somme des variances pour la pluralité de sons de ronflement ;
déterminer une première caractéristique du signal acoustique de sommeil en réponse à la somme des variances ; et
utiliser la première caractéristique pour diagnostiquer l'AOS chez la personne.

2. Dispositif selon la revendication 1, dans lequel le système informatique (24) est configuré pour :

déterminer une pluralité de groupes de sons de ronflement:

déterminer une caractéristique de groupe pour chacun des groupes ;
déterminer une deuxième caractéristique du signal acoustique de sommeil en réponse aux caractéristiques de groupe ; et
utiliser la deuxième caractéristique déterminée di signal acoustique de sommeil pour diagnostiquer l'AOS chez la personne.

3. Dispositif selon la revendication 2, dans lequel le système informatique (24) est configuré pour déterminer un amas de sons de ronflement consécutifs dans les sons de ronflement détectés pour lesquels un retard temporel entre deux sons de ronflement quelconques temporellement adjacents est inférieur ou égal à une durée prédéterminée.

4. Dispositif selon la revendication 2 ou la revendication 3, dans lequel la durée est égale à environ une minute.

5. Dispositif selon l'une quelconque des revendications 2 à 4, dans lequel la caractéristique de groupe pour chaque groupe comprend une mesure d'énergie pour chacun des sons de ronflement dans le groupe.

6. Dispositif selon la revendication 5, dans lequel le système informatique (24) est configuré pour utiliser la mesure de l'énergie pour les sons de ronflement dans le groupe pour déterminer une mesure d'une énergie moyenne des sons de ronflement dans le groupe.

7. Dispositif selon la revendication 6, dans lequel le système informatique (24) est configuré pour déterminer une variance des mesures d'énergies des sons de ronflement pour le groupe.

8. Dispositif selon la revendication 7, dans lequel le système informatique (24) est configuré pour déterminer la deuxièmes caractéristique du signal acoustique de sommeil en réponse à une moyenne des variances déterminées des groupes et pour utiliser la deuxièmes caractérisation pour diagnostiquer l'AOS chez la personne.

9. Dispositif selon la revendication 7 ou la revendication 8, dans lequel le système informatique (24) est configuré pour déterminer une troisième caractéristique du signal acoustique de sommeil en réponse à un certain nombre de groupes dans le signal acoustique pour lequel la variance est supérieure à une variance seuil prédéterminé et pour utiliser la troisième caractéristique pour diagnostiquer l'AOS chez la personne.

10. Dispositif selon l'une quelconque des revendications précédentes, dans lequel le système informatique (24) est opérant pour :

déterminer un nombre de périodes de silence dans le signal acoustique de sommeil qui sont indicatives du fait que la respiration de la personne est sensiblement totalement suspendue ;
déterminer une quatrième caractéristique du signal acoustique de sommeil en réponse au nombre de périodes de silence déterminées ; et
utiliser la quatrième caractéristique pour diagnostiquer l'AOS chez la personne.

11. Dispositif selon l'une quelconque des revendications précédentes, dans lequel le système informatique (24) est opérant pour :

déterminer une densité de hauteurs pour chaque son de la pluralité de sons de ronflement dans le signal acoustique de sommeil ;
déterminer une densité de hauteurs moyenne pour les sons de ronflement ;
déterminer une cinquième caractéristique du signal acoustique de sommeil en réponse à la densité de hauteurs

moyenne de pas; et
utiliser la cinquième caractéristique pour diagnostiquer l'AOS chez la personne.

12. Dispositif selon la revendication 1, dans lequel le système informatique (24) est configuré pour :

déterminer une deuxième caractéristique déterminée en réponse à une mesure d'une moyenne de variances dans les énergies de sons de ronflement dans des groupes de sons de ronflement ;
déterminer une troisième caractéristique déterminée en réponse à un certain nombre de groupes de sons de ronflement qui présentent une variance en termes d'énergies de sons de ronflement supérieure à une variance prédéterminée ; et
utiliser les caractéristiques déterminées pour diagnostiquer l'AOS chez la personne.

13. Dispositif selon la revendication 12, dans lequel la pluralité de caractéristiques comprend une quatrième caractéristique déterminée en réponse à un certain nombre de périodes de silence dans le signal acoustique de sommeil qui sont indicatives du fait que la respiration de la personne est sensiblement totalement suspendue.

14. Dispositif selon la revendication 12 ou 13, dans lequel la pluralité de caractéristiques comprennent une caractéristique additionnelle déterminée en réponse à une densité de hauteurs moyenne pour les sons de ronflement.

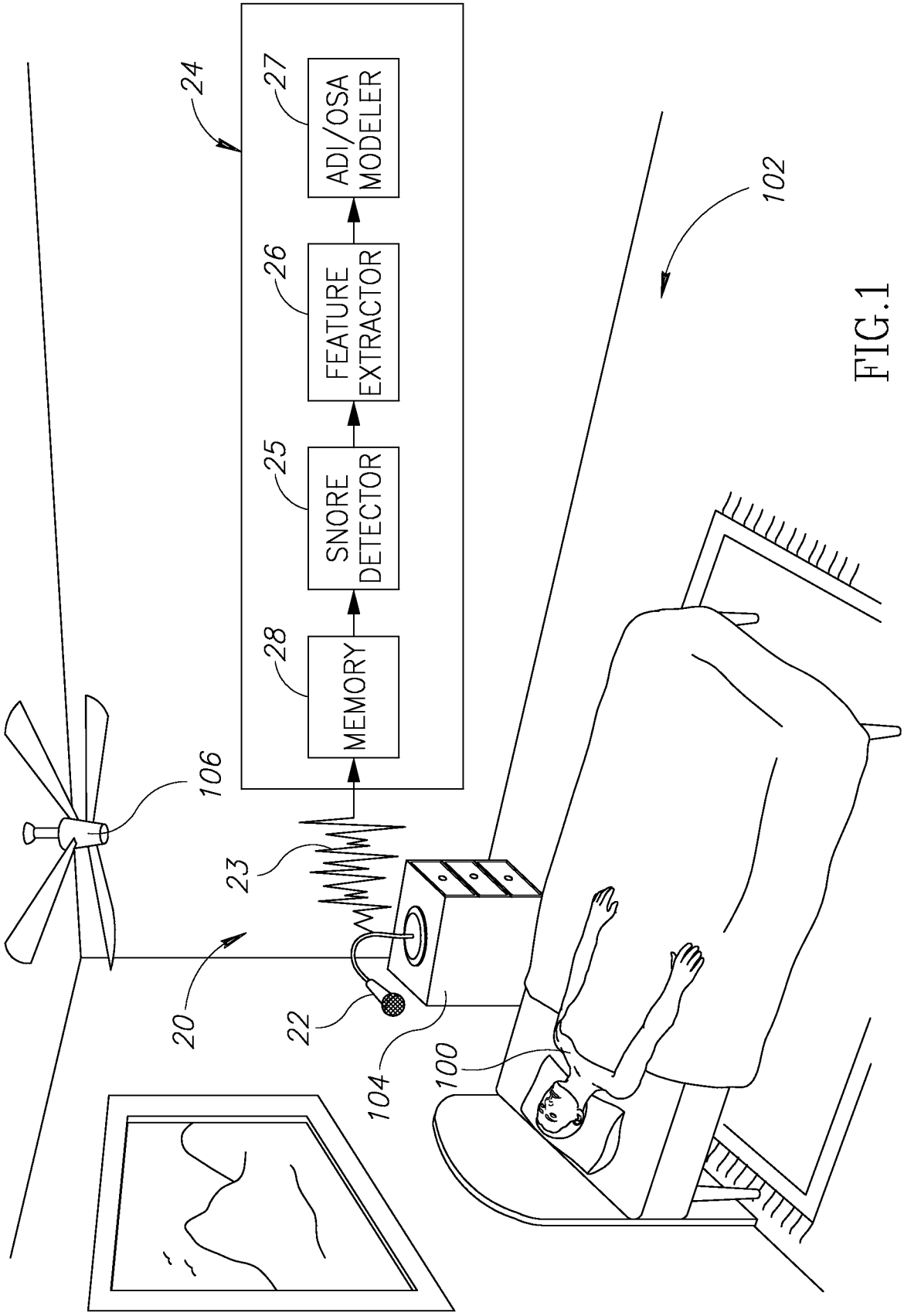
24
27
ADI/OSA MODELER
26
FEATURE EXTRACTOR
25
SNORE DETECTOR
28
MEMORY
102
106
23
20
22
104
100

FIG.1

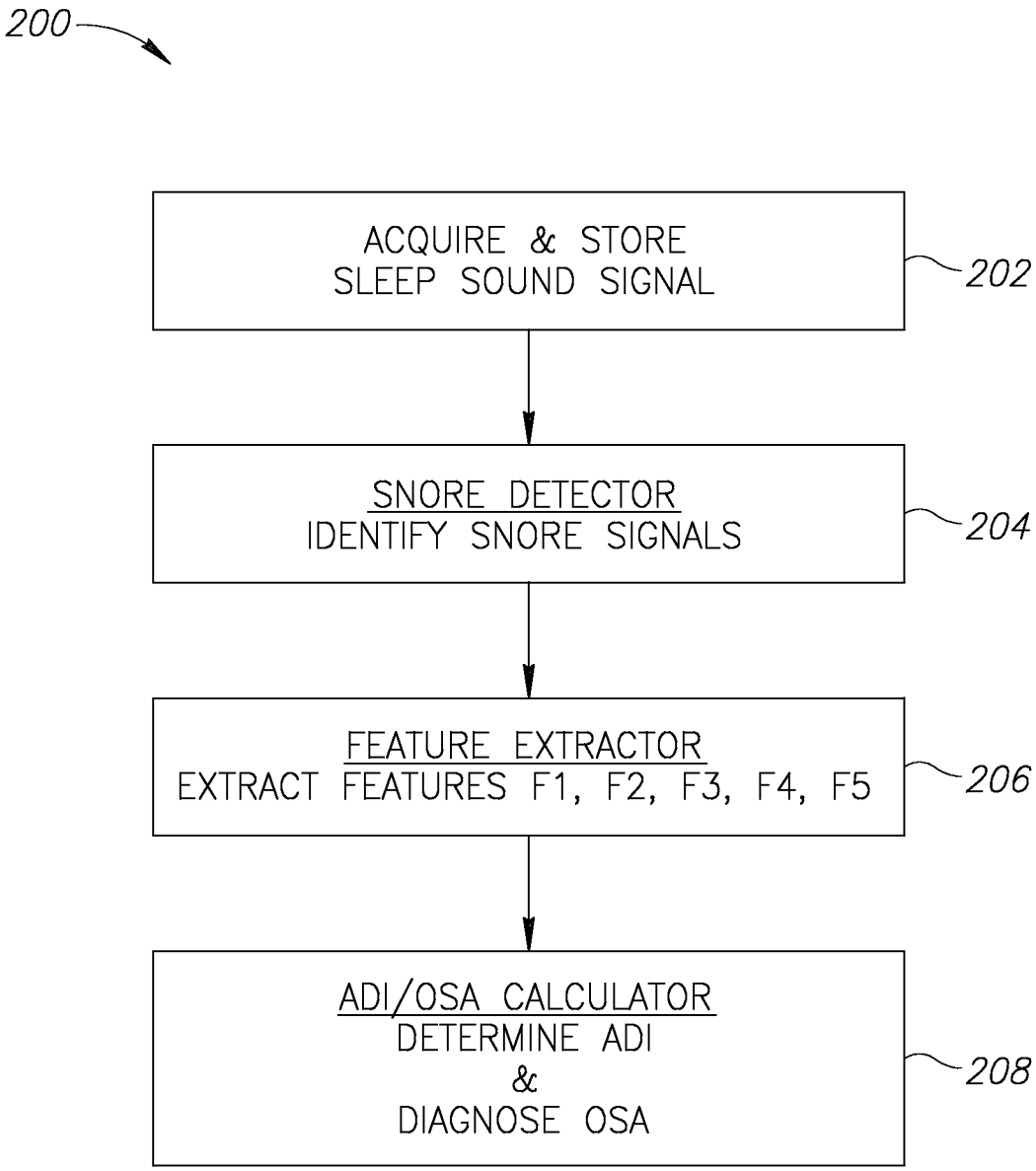
200
ACQUIRE & STORE
SLEEP SOUND SIGNAL
202
SNORE DETECTOR
IDENTIFY SNORE SIGNALS
204
FEATURE EXTRACTOR
EXTRACT FEATURES F1, F2, F3, F4, F5
206
ADI/OSA CALCULATOR
DETERMINE ADI
&
DIAGNOSE OSA
208

FIG.2

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2010066008 A1 **[0007]**

Non-patent literature cited in the description

- **L. XU et al.** The optimization of perceptually-based features for speaker identification. *Proc. IEEE Conf. Acoustics, Speech and Signal (ICASSP),* 1999, 520-523 **[0007]**

专利名称(译)	用于诊断阻塞性睡眠呼吸暂停的装置		
公开(公告)号	EP2608717B1	公开(公告)日	2016-05-11
申请号	EP2011819507	申请日	2011-08-24
[标]申请(专利权)人(译)	莫尔研究应用有限公司		
申请(专利权)人(译)	内盖夫沙研究和发展管理局本古里安大学 铁道部研究应用有限公司.		
当前申请(专利权)人(译)	内盖夫沙研究和发展管理局本古里安大学 铁道部研究应用有限公司.		
[标]发明人	ZIGEL YANIV TARASIUK ARIEL BEN ISRAEL NIR		
发明人	ZIGEL, YANIV TARASIUK, ARIEL BEN ISRAEL, NIR		
IPC分类号	A61B5/12 A61B5/00		
CPC分类号	A61B5/4818 A61B5/7253 A61B7/003		
优先权	61/377105 2010-08-26 US		
其他公开文献	EP2608717A4 EP2608717A2		
外部链接	Espacenet		

摘要(译)

本发明的一个实施例提供了一种诊断阻塞性睡眠呼吸暂停的方法，该方法包括：获取包括人在睡眠期间发出的声音的睡眠声音信号;检测睡眠声音信号中的多个打鼾声音;为每个打鼾声音确定一组mel频率倒频谱系数;响应于倒频谱系数的方差之和，确定睡眠声音信号的特征特征;并利用特征来诊断人的阻塞性睡眠呼吸暂停。