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

(11) EP 2 428 159 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
20.04.2016 Bulletin 2016/16

(21) Application number: **11006415.1**

(22) Date of filing: **27.02.2004**

(51) Int Cl.:
A61B 5/024 (2006.01) *A61B 5/1455* (2006.01)
G01N 21/31 (2006.01) *A61B 5/11* (2006.01)
A61B 5/00 (2006.01) *G06K 9/00* (2006.01)
G06F 17/14 (2006.01)

(54) Analysing and processing photoplethysmographic signals by wavelet transform analysis

Analyse und Verarbeitung von photoplethysmographischen Signalen durch Wellentransformationsanalyse

Analyse et traitement de signaux photoplethysmographiques par analyse de transformées par ondelettes

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR

(30) Priority: **27.02.2003 GB 0304413**
12.02.2004 GB 0403066
07.03.2003 GB 0305168

(43) Date of publication of application:
14.03.2012 Bulletin 2012/11

(62) Document number(s) of the earlier application(s) in accordance with Art. 76 EPC:
04715386.1 / 1 628 571

(73) Proprietor: **Nellcor Puritan Bennett Ireland**
Mervue
Galway (IE)

(72) Inventors:
- **Addison, Paul Stanley**
Edinburgh
Midlothian EH10 6UR (GB)
- **Watson, James Nicholas**
Dunfermline
Fife KY11 8LE (GB)

(74) Representative: **Kinsler, Maureen Catherine et al**
Marks & Clerk LLP
Atholl Exchange
6 Canning Street
Edinburgh EH3 8EG (GB)

(56) References cited:
WO-A-03/000125 **WO-A2-01/25802**
US-A- 6 094 592 **US-A- 6 122 535**
US-A1- 2002 103 423

- **DOWLA F U ET AL: "NEURAL NETWORKS AND WAVELET ANALYSIS IN THE COMPUTER INTERPRETATION OF PULSE OXIMETRY DATA", NEURAL NETWORKS FOR SIGNAL PROCESSING. PROCEEDINGS OF THE IEEESIGNAL PROCESSING SOCIETY WORKSHOP, XX, XX, 1 January 1996 (1996-01-01), pages 527-536, XP001106543,**
- **KIM J M ET AL: "Signal processing using fourier & wavelet transform for pulse oximery", TECHNICAL DIGEST / CLEO/PACIFIC RIM 2001, THE 4TH PACIFIC RIM CONFERENCE ON LASERS AND ELECTRO-OPTICS, IEEE SERVICE CENTER, PISCATAWAY, NJ, US, vol. 2, 15 July 2001 (2001-07-15), pages 310-311, XP010567311, ISBN: 978-0-7803-6738-8**
- **RUSCH T L ET AL: "Signal processing methods for pulse oximetry", COMPUTERS IN BIOLOGY AND MEDICINE, NEW YORK, NY, US, vol. 26, no. 2, 1 March 1996 (1996-03-01), pages 143-159, XP004532247, ISSN: 0010-4825, DOI: 10.1016/0010-4825(95)00049-6**
- **LEONARD P ET AL: "Standard pulse oximeters can be used to monitor respiratory rate", JOURNAL OF ACCIDENT AND EMERGENCY MEDICINE, BMJ PUBLISHING GROUP, LONDON, GB, vol. 20, no. 6, 10 January 2003 (2003-01-10), pages 524-525, XP007901554, ISSN: 1351-0622**

EP 2 428 159 B1

- **PAUL S ADDISON ET AL: "RAPID COMMUNICATION; A novel time-frequency-based 3D Lissajous figure method and its application to the determination of oxygen saturation from the photoplethysmogram; Rapid Communication", MEASUREMENT SCIENCE AND TECHNOLOGY, IOP, BRISTOL, GB, vol. 15, no. 11, 1 November 2004 (2004-11-01), pages L15-L18, XP020066422, ISSN: 0957-0233, DOI: 10.1088/0957-0233/15/11/L01**
- **ADDISON P S ET AL: "Oxygen saturation determined using a novel wavelet ratio surface", MEDICAL ENGINEERING & PHYSICS, BUTTERWORTH-HEINEMANN, GB, vol. 27, no. 3, 1 April 2005 (2005-04-01), pages 245-248, XP004735493, ISSN: 1350-4533, DOI: 10.1016/J.MEDENGPHY.2004.10.002**

Description

1. Introduction: Problem Domain / Field of Invention

[0001] The present invention relates to a method of analysing and processing signals. More specifically the invention relates to the analysis and processing of photoplethysmogram (PPG) signals. The invention uses wavelet transform methods to derive clinically useful information from the PPG including information regarding the respiration, pulse, oxygen saturation, and patient movement. This information may be used within a device to monitor the patient within a range of environments including the hospital and home environments. The device may be used to detect irregularities in one or more of the derived signals: respiration, pulse, oxygen saturation and movement. The device allows output of this information in a clinically useful form and incorporates an alarm which is triggered when one or a combination of signal irregularities are detected. Of particular note is that the utility of current pulse oximeter devices is greatly increased through the provision of a robust measure of patient respiration directly from the PPG signal.

[0002] The present invention is defined by the independent claims, The dependent claims define preferred embodiments. Aspects, embodiments, examples or implementations of the present disclosure which do not fall under the appended claims do not form part of the present invention.

2. Background

2.1 Blood Oxygen Saturation and its Measurement

[0003] Oximetry is an optical method for measuring Oxygen saturation in blood. Oximetry is based on the ability of different forms of haemoglobin to absorb light of different wavelengths. Oxygenated haemoglobin (HbO_2) absorbs light in the red spectrum and deoxygenated or reduced haemoglobin (RHb) absorbs light in the near-infrared spectrum. When red and infrared light is passed through a blood vessel the transmission of each wavelength is inversely proportional to the concentration of HbO_2 and RHb in the blood. Pulse oximetere can differentiate the alternating light input from arterial pulsing from the constant level contribution of the veins and other non-pulsatile elements. Only the alternating light input is selected for analysis. Pulse oximetry has been shown to be a highly accurate technique. Modern pulse oximeter devices aim to measure the actual oxygen saturation of the blood (SaO_2) by interrogating the red and infrared PPG signals. This measurement is denoted SpO_2. The aim of modern device manufacturers is to achieve the best correlation between the pulse oximeter measurement given by the device and the actual blood oxygen saturation of the patient. It is known to those skilled in the art that in current devices a ratio derived from the photoplethysmogram (PPG) signals acquired at the patients body is used to determine the oxygen saturation measurement using a look up table containing a pluracy of corresponding ratio and saturation values. Modern pulse oximeter devices also measure patient heart rate. Current devices do not provide a measure of respiration directly from the PPG signal. Additional expensive and obtrusive equipment is necessary to obtain this measurement.

2.2 Time-Frequency Analysis in Wavelet Space

[0004] The wavelet transform of a signal $x(t)$ is defined as

$$T(a,b)=\frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty}x(t)\psi^*\left(\frac{t-b}{a}\right)dt \qquad [1]$$

where $\Psi^*(t)$ is the complex conjugate of the wavelet function $\Psi(t)$, a is the dilation parameter of the wavelet and b is the location parameter of the wavelet. The transform given by equation (1) can be used to construct a representation of a signal on a transform surface. The transform may be regarded as a time-scale representation or a time-frequency representation where the characteristic frequency associated with the wavelet is inversely proportional to the scale a. In the following discussion 'time-scale' and 'time-frequency' may be interchanged. The underlying mathematical detail required for the implementation within a time-scale or time-frequency framework can be found in the general literature, e.g. the text by Addison (2002).

[0005] The energy density function of the wavelet transform, the scalogram, is defined as

$$S(a,b)=|T(a,b)|^2 \qquad [2]$$

where'| |' is the modulus operator. The scalogram may be rescaled for useful purpose. One common rescaling is defined as

$$S_R(a,b) = \frac{|T(a,b)|^2}{a} \qquad [3]$$

and is useful for defiling ridges in wavelet space when, for example, the Morlet wavelet is used. Ridges are defined as the locus of points of local maxima in the plane. Any reasonable definition of a ridge may be employed in the method. We also include as a definition of a ridge herein paths displaced from the locus of the local maxima. A ridge associated with only the locus of points of local maxima in the plane we label a 'maxima ridge'. For practical implementation requiring fast numerical computation the wavelet transform may be expressed in Fourier space and the Fast Fourier Transform (FFT) algorithm employed. However, for a real time application the temporal domain convolution expressed by equation (1) may be more appropriate. In the discussion of the technology which follows herein the 'scalogram' may be taken to the include all reasonable forms of rescaling including but not limited to the original unscaled wavelet representation, linear rescaling and any power of the modulus of the wavelet transform may be used in the definition.

[0006] As described above the time-scale representation of equation (1) may be converted to a time-frequency representation. To achieve this, we must convert from the wavelet a scale (which can be interpreted as a representative temporal period) to a characteristic frequency of the wavelet function. The characteristic frequency associated with a wavelet of arbitrary a scale is given by

$$f = \frac{f_c}{a} \qquad [4]$$

where f_o, the characteristic frequency of the mother wavelet (i.e. at a=1), becomes a scaling constant and *f* is the representative or characteristic frequency for the wavelet at arbitrary scale a.

[0007] Any suitable wavelet function may be used in the method described herein. One of the most commonly used complex wavelets, the *Morlet* wavelet, is defined as:

$$\psi(t) = \pi^{-1/4}\left(e^{i2\pi f_0 t} - e^{-(2\pi f_0)^2/2}\right)e^{-t^2/2} \qquad [5]$$

where f_o is the central frequency of the mother wavelet. The second term in the brackets is known as the correction term, as it corrects for the non-zero mean of the complex sinusoid within the Gaussian window. In practice it becomes negligible for values of f_o>>0 and can be ignored, in which case, the Morlet wavelet can be written in a simpler form as

$$\psi(t) = \frac{1}{\pi^{1/4}} e^{i2\pi f_0 t} e^{-t^2/2} \qquad [6]$$

[0008] This wavelet is simply a complex wave within a Gaussian envelope. We include both definitions of the Morlet wavelet in our discussion here. However, note that the function of equation (6) is not strictly a wavelet as it has a non-zero mean, i.e. the zero frequency term of its corresponding energy spectrum is non-zero and hence it is inadmissible. However, it will be recognised by those skilled in the art that it can be used in practice with f_o>>0 with minimal error and we include it and other similar near wavelet functions in our definition of a wavelet herein. A more detailed overview of the underlying wavelet theory, including the definition of a wavelet function, can be found in the general literature, e.g, the text by Addison (2002). Herein we show how wavelet transform features may be extracted from the wavelet decomposition of pulse oximeter signals and used to provide a range of clinically useful information within a medical device.

3. Wavelet Feature Extraction

[0009] In this section, methods are described for the extraction and use of wavelet features from the PPG signals for use in the provision of clinically useful information. These are incorporated within a medical device and the information is output in a range of formats for use in the monitoring of the patient. The device comprises four key components for the utilization of the wavelet transform information, these are the Pulse Component, Respiration Monitoring Component, Oxygen Saturation Component and the Movement Component. The underlying theory pertaining to these components is detailed below.

3.1 Pulse Component

[0010] Pertinent repeating features in the signal gives rise to a time-frequency band in wavelet space or a resealed wavelet space. For example the pulse component of a photoplethysmogram (PPG) signal produces a dominant band in wavelet space at or around the pulse frequency. Figure 1(a) and (b) contains two views of a scalogram derived from a PPG signals. The figures show an example of the band caused by the pulse component in such a signal. The pulse band is located between the dashed lines in the plot of figure 1(a). The band is formed from a series of dominant coalescing features across the scalogram. This can be clearly seen as a raised band across the transform surface in figure 1(b) located within a region at just over 1Hz, i.e. 60 breaths per minute. The maxima of this band with respect to frequency is the ridge. The locus of the ridge is shown as a black curve on top of the band in figure 1(b). By employing a suitable rescaling of the scalogram, such as that given in equation 3, we can relate the ridges found in wavelet space to the instantaneous frequency of the signal. In this way the pulse frequency (pulse rate) may be obtained from the PPG signal. Instead of rescaling the scalogram, a suitable predefined relationship between the frequency obtained from the ridge on the wavelet surface and the actual pulse frequency may also be used to determined the pulse rate.

[0011] By mapping the time-frequency coordinates of the pulse ridge onto the wavelet phase information gained through the wavelet transform, individual pulses may be captured. In this way both times between individual pulses and the timing of components within each pulse can be monitored and used to detect heart beat anomalies, measure arterial system compliance, etc. Alternative definitions of a ridge may be employed. Alternative relationships between the ridge and the pulse frequency may be employed.

3.2 Respiration Monitoring Component

[0012] The respiration monitoring component uses wavelet based methods for the monitoring of patient respiration. This can include the measurement of breathing rate and the identification of abnormal breathing patterns including the cessation of breathing. A key part of the respiration monitoring component is the use of secondary wavelet feature decoupling (SWFD) described below. The information concerning respiration gained from the application of SWPD can then be compared and/or combined with respiration information from other methods to provide a respiration measure output.

[0013] As stated above, pertinent repeating features in the signal give rise to a time-frequency band in wavelet space or a rescaled wavelet space. For a periodic signal this band remains at a constant frequency level in the time frequency plane. For many real signals, especially biological signals, the band may be non-stationary; varying in characteristic frequency and/or amplitude over time. Figure 2 shows a schematic of a wavelet transform of a signal containing two pertinent components leading to two bands in the transform space. These bands are labeled band A and band B on the three-dimensional (3-D) schematic of the wavelet surface. We define the band ridge as the locus of the peak values of these bands with respect to frequency. For the purposes of the discussion of the method we assume that band B contains the signal information of interest. We will call this the 'primary band'. In addition, we assume that the system from which the signal originates, and from which the transform is subsequently derived, exhibits some form of coupling between the signal components in band A and band B.

[0014] When noise or other erroneous features are present in the signal with similar spectral characteristics of the features of band B then the information within band B can become ambiguous, i.e. obscured, fragmented or missing. In this case the ridge of band A can be followed in wavelet space and extracted either as an amplitude signal or a frequency signal which we call the '*ridge amplitude perturbation* (*RAP*) *signal*' and the '*ridge frequency perturbation* (*RFP*) *signal*' respectively. The RAP and RFP signals are extracted by projecting the ridge onto the time-amplitude or time-frequency planes respectively. The top plots of figure 3 shows a schematic of the RAP and RFP signals associated with ridge A in figure 2. Below these RAP and RFP signals we can see schematics of a further wavelet decomposition of these newly derived signals. This secondary wavelet decomposition allows for information in the spectral region of band B in figure 2 to be made available as band C and band D. The ridges of bands C and D can serve as instantaneous time-frequency characteristic measures of the signal components causing bands C and D. This method, which we call Secondary Wavelet Feature Decoupling (SWFD), therefore allows information concerning the nature of the signal components associated with the underlying physical process causing the primary band B (figure2) to be extracted when band B itself is obscured in the presence of noise or other erroneous signal features.

[0015] An example of the SWFD method used on a PPG signal to detect patient breathing from the ridge associated with patient pulse is shown in figures 4 and 5. During the experiment from which the signal was taken the patient was breathing regularly at breaths of 6 seconds duration (= 0.167Hz).

[0016] Figure 4(a) contains the scalogram derived from the PPG trace taken during the experiment. Two dominant bands appear in the plot: the pulse band and a band associated with patient breathing. These are marked P and B respectively in the plot. In this example we are concerned with the detection of breathing through time and hence here the breathing band is the primary band. The pulse band appears at just over 1Hz, or 60 beats per minute: the beat frequency of the heart and the breathing band appears at 0.167 Hz corresponding to the respiration rate. However, the identification of breathing features is often masked by other low frequency artefact in these signals. One such low frequency artefact feature, 'F', is indicated in the plot within the dotted ellipse marked on the scalogram where it can be seen to interfere with the breathing band. Figure 4(b) contains a 3-D view of the scalogram plot shown in figure 4(a). From the 3-D plot we can see that the low frequency artefact feature causes a bifurcation of the breathing band at the location shown by the arrow in the plot. The pulse ridge is also shown on figure 4(b), indicated by the black curve along the pulse band. This is the locus of the maxima with respect to frequency along the pulse band.

[0017] Figure 4(c) contains the RAP signal derived from the pulse ridge shown in figure 4(b) where the pulse ridge is followed and its amplitude is plotted against time. The top plot of figure 4(c) contains the whole RAP signal. The lower plot of figure 4(c) contains a blow up of the RAP signal over a 50 seconds interval. An obvious modulation with a period of 6 seconds can be seen in this blow up. The top plot of figure 4(d) contains the whole RFP signal corresponding to the pulse ridge in figure 4(b). The lower plot of figure 4(d) contains a blow up of the RFP signal over 50 seconds. Again an obvious modulation (of 6 second period) can be seen in this blow up.

[0018] A second wavelet transform was then performed on the RAP and RPP signals. The resulting scalograms corresponding to the RAP and RFP signals are shown in figures 5a and 5b respectively and the 3-D plots of these scalograms are shown in figures 5c and 5d respectively. The breathing ridges derived from the RAP and RFP scalograms are superimposed on the 3-D scalograms. The RAP scalogram is the cleaner of the two and can be seen not to contain interference from the artefact feature 'F' found in the original signal scalogram of figure 4(a). For this example the RAP scalogram provides the best solution for the removal of erroneous signal features and the identification of the breathing band when compared to the original scalogram and the RFP scalogram. In practice all three scalograms are compared and the optimal scalogram or combination of scalograms for the extraction of the information required is determined.

[0019] Through experimentation covering a variety of patient groups (e.g. adult, child, neonate) we have found that for certain signals the method can be enhanced by incorporating paths displaced from the band ridge in the SWFD method. In these cases the RAP signals derived from the displaced path exhibits much larger oscillations (compared to the low frequency background waveform) than those of the original ridge path. We find that this enhancement allows us to better detect the breathing component within the SWFD method. Hence we extend our definition of a surface ridge as employed in the method to include paths displaced from the locus of the peak values, contours at a selected level of the pulse band, and in general any reasonably constructed path within the vicinity of the pertinent feature under investigation, where the vicinity is taken to be within the region of the corresponding band.

[0020] From the above example it can be seen how a secondary wavelet transform of wavelet transform ridge information derived from the pulse band ridge may be used to provide a clearer manifestation of the breathing features in wavelet space from which pertinent breathing information may be derived.

[0021] The SWFD method described above can form the basis of completely new algorithms for incorporation within devices which require the detection of otherwise masked signal components. Herein, we show the application of the method to the detection of breathing features from within the photoplethysmogram, although it will be recognised by those skilled in the art that the method may be applied to other problematic signals.

[0022] In practice, both the original direct observation of the primary band and the indirect observation through perturbations to the secondary band may be employed simultaneously and the optimal time-frequency information extracted.

[0023] Those skilled in the art will recognise that the above methods may be performed using alternative time-frequency representations of the signals where the amplitude in the time-frequency transform space can be related to the amplitude of pertinent features within the signal. In addition the decomposition of the original signal and the subsequent decompositions of the RFP and RAP scalograms may be performed, each with a different time-frequency method. However, in the preferred method the continuous wavelet transform is employed in all decompositions, although different wavelet functions may be employed in each of the wavelet transforms employed in the method.

[0024] The preferred method detailed herein departs from alternate methods to probe the time-frequency information within wavelet space which follow paths of constant frequency in wavelet space. The current method involves following a selected path in wavelet space from which new signals are derived. This allows signal components with non-stationary frequency characteristics to be followed and analysed to provide information of other signal components which may also exhibit non-stationary behaviour.

[0025] It will be obvious to those skilled in the art that the method relies on high resolution in wavelet space hence the continuous wavelet transform is the preferred method. (The time-frequency discretisation employed by the discrete wavelet transform and the stationary wavelet transform is, in general, too coarse for the useful application of the method.) The continuous wavelet transform is implemented in the method through a fine discretisation in both time and frequency.

[0026] Although the method herein has been described in the context of the detection of breathing features from the pulse band of the wavelet transform of the photaplethysmogram, those skilled in the art will recognise that the method has wide applicability to other signals including, but not limited to: other biosignals (e.g. the electrocardiogram, electroencephalogram, electrogastrogram, electromyogram, heart rate signals, pathological sounds, and ultrasound), dynamic signals, nondestructive testing signals, condition monitoring signals, fluid signals, geophysical signals, astronomical signals, electrical signals, financial signals including financial indices, sound and speech signals, chemical signals, and meteorological signals including climate signals.

[0027] In summary a method for the decomposition of signals using wavelet transforms has been described which allows for underlying signal features which are otherwise masked to be detected. The method is described in the following steps

(a) A wavelet transform decomposition of the signal is made.
(b) The transform surface is inspected in the vicinity of the characteristic frequency of the pertinent signal feature to detect the dominant band (the primary band) associated with the pertinent feature. This band is then interrogated to reveal information corresponding to the pertinent feature. This interrogation may include ridge following methods for identification of localised frequencies in the time-frequency plane.
(c) A secondary band is then identified outwith the region of the pertinent feature and its ridge identified.
(d) The time-frequency and time-amplitude locus of points on the secondary ridge are then extracted. These new signals are denoted the 'ridge amplitude perturbation (*RAP*) *signal*' and the *'ridge frequency perturbation (RFP) signal'* respectively.
(e) A wavelet transformation of the RAP and RFP signals is then carried out to give the RAP and RFP scalograms respectively.
(f) These secondary scalograms are then interrogated to reveal information in the region of the primary band of the original scalogram. This interrogation may include ridge following methods for identification of localised frequencies in the time-frequency plane.
(g) The information gained from step (b) and step (f) are then used to provide the optimal signal information pertaining to the signal feature or features under investigation.

[0028] More than one secondary band may be present. These additional secondary bands may be interrogated in the same way, i.e. steps (c) to (g).

[0029] In the context of breathing detection from the photoplethysmogram the 'primary band' referred to in the above is the breathing band and the 'secondary band' is the pulse band. In the method one or more or a combination of PPG signals may be employed.

[0030] In an alternative methodology once the RAP and RFP signals have been abstracted in step (d) these are then interrogated over short segments using an alternative time-frequency or frequency based method (e.g. using a standard FFT routine to find a dominant peak associated with the primary band signal) or another method of signal repetition including, but not limited to, turning points of the signal. This may be employed to speed up the computation of the characteristic frequency of the RAP and RFP scalogram bands or to enhance the technique.

[0031] In step (d) above a combination of the RAP and RFP signals may also be used to generate a representative signal for secondary wavelet decomposition.

[0032] Patient respiration information from the secondary wavelet feature decoupling incorporating the RAP and RFP signals is used directly to monitor patient respiration. This can include the measurement of breathing rate and the identification of abnormal breathing patterns including the cessation of breathing. Either the RAP-based SWFD or the RFP-based SWFD information may be chosen for patient respiration monitoring. Alternatively a combination of both may be employed where the respiration information derived from each method may be graded quantitatively according to a confidence measure.

[0033] Further, the respiration information gained from the RAP-based SWFD and the RFP-based SWFD may be compared to and/or combined with respiration information gained from other methods to provide an optimal output for respiration measures including respiration rate, breath timings, breathing anomalies, etc. These other methods may include that described in International Patent Application No PCT/GB02/02843 , "Wavelet-based Analysis of Pulse oximetry signals" by Addison and Watson published as WO 03/000125 and which discloses a method and a system for measuring physiological parameters based on a three dimensional wavelet transform surface of a pulse oximetry signal in order to determine respiration components, oxygen saturation, movement/noise" artefacts and pulse components in the pulse oximetry signal. The chosen respiration measure for output will be extracted using a polling mechanism based on a quantitative measure of the quality of the respiration information derived by each method.

[0034] Figures 6 to 10 illustrate the preferred embodiment of the respiration monitoring methodology. The wavelet transform of the PPG signal (figure 6(a)) is computed. A plot of the resulting scalogram is shown in figure 6 (b). The 10 second PPG signal used in this example was taken from a premature neonate. The same methodology also works for adult and child PPGs. The pulse ridge is shown plotted as a black path across the scalogram in figure 6(b) at around 2.5Hz - typical for these young patients. The RAP and RFP signals are then derived from the pulse ridge of the wavelet transform. The RAP and RFP signals are shown respectively in figure 6(c) and figure 6(d). Also shown in figure 6 (c) is the patient switch signal which shows inspiration and expiration of the patient as a high /low amplitude square wave trace. The switch signal was activated by an observer monitoring the movement of the chest wall of the neonate during the experiment. The turning points in the RAP and RFP signals may be used as an initial detection mechanism for individual breaths. The RFP and RAP signals are assessed for quality using a confidence measure. This measure may be based on any reasonable measure including but not limited to the entropy of the signals. The signal with the highest confidence is used to extract information on individual breaths and a breathing rate using the average duration of a number of recently detected breaths. A second wavelet transform is performed on both signals. The result of a second wavelet transform on the RAP signal of figure 6(c) is shown in figure 7(a) and the ridges of this transform surface are extracted as shown in figure 7(b). The result of a second wavelet transform on the RFP signal of figure 6(d) is shown in figure 7(c) and the ridges of this transform surface are extracted as shown in figure 7(d).

[0035] The extracted ridges from the RFP and RAP signal transforms and the ridges found in the original transform in the region of respiration, shown in figures 8(a), (b) and (c) respectively, are then analysed to determine a composite path which we call the 'selected respiration path' SRP. The analysis may include, but is not limited to, the intensities and locations of the ridges. The SRP represents the most likely breathing components. The SRP derived from the extracted ridges shown in figures 8 (a), (b) and (c) is shown in figure 8(d). The SRP will normally be determined within an initial predetermined "latch-on" time window and reassessed within an updated time window. The ridge selection procedure used to derive the SRP is based upon a decision tree implementing a weighted branching dependent upon, but not limited to, the following local (i.e. relationship between ridge components within a particular ridge set) and global (i.e. the inter-relationship between ridge components across ridge sets) criteria: start and end position, length, average and peak strengths, various spatial (i.e. movement range over the time-frequency surface) statistical parameters including variance and entropy, and a measurement of relative switchback positions (i.e. degree of overlap with other ridges). These criteria are based on results of our in house experimentation across a range of patient categories: adult, child and neonate.

[0036] A confidence metric for the accuracy of the SWFD ridge obtained from the RAP signal can also be acquired by comparing the resultant SWFD ridge intensities derived from the RAP signal of the band maxima ridge and ridges off-set from it. When compared to RAP-SWFD derived from the band maxima ridge, the off-ridge transform's ridges associated with respiration have been observed to increase (to a maximum) in intensity as the displacement of the off-ridge from the maxima ridge is increased. Those ridges associated with other features, however, remain relatively static in amplitudes. In this way, by interrogating the ridge amplitudes of a plurality of RAP signals derived from the band maxima offsets, the ridge or ridges associated with respiration can be identified through a significant change in amplitude relative to others.

[0037] The selected ridge path (SRP) is then used to provide an overall confidence as to breathing rate and/or provide individual breath monitoring and/or prediction. By superimposing the SRP shown in figure 8(d) onto the phase information derived from the original transform the phase along the SRP can be determined as shown in figure 9. In this way individual breaths may be identified through the behaviour of the phase cycling. This phase information along the SRP path may used to derive a breathing signal either by displaying the phase information as shown in figure 9 or by taking the cosine, or similar function, of the phase information to produce a sinusoidal waveform, or by some other method to provide a waveform of choice for visual display of the breathing signal. In an alternative example the phase information from one of the secondary transforms or a combination of the phase information from all transforms may be used in the method. In addition, the phase information used may be processed to remove erroneous phase information for example caused by movement artifact.

[0038] Parts of the SPR may contain missing segments caused by, for example, signal artefact. In these regions the SRP may be inferred using the last available path point and the next available path point as shown schematically in figure 10. In the preferred example this is carried out using a linear fit between the points. However, other methods may also be used.

3.3 Oxygen Saturation Measurement

[0039] The amplitude of signal features scale with their wavelet transform representation. Thus by dividing components of the wavelet transform of the red PPG signal by those of the infrared PPG signal we obtain new wavelet-based representations which contain useful information on the signal ratios for use in the determination of oxygen saturation. If a complex wavelet function is used this information may be extracted using a suitable path defined on the ratio of the moduli of the transforms or using a Lissajous plot from the real or imaginary parts of the transforms. If a wavelet function containing only a real part is employed then this information should be extracted using a Lissajous plot derived from the transforms. Two complimentary methods for the extraction of the wavelet-based ratio information required for the determination of oxygen saturation are given below.

[0040] Figure 11 shows the three dimensional plots of the real-parts of the wavelet transforms of the simultaneously collected red and infrared PPG signals. A complex Morlet wavelet was used in the transform. The dominant nature of the pulse band and breathing band regions is evident in the figure. These are marked 'B' and 'C' respectively in the figure. A secondary band containing pulse components can also be seen in the figure (marked 'A'). This band is associated with the double humped morphology of the PPG waveform. In the new wavelet-based Lissajous method a number of frequency levels are selected within a moving window. The moving window is shown schematically on the plot in figure 12. (Here we use a 4.56 second window for the purpose of illustration although alternative window lengths may be used as required.) The oscillatory nature of the pulse band and breathing band regions is evident in the plot. The wavelet transform values along each of these frequency levels for the red and infrared signals are plotted against each other to give a Wavelet-Based Lissajous (WBL) plot. This results in a multitude of WBL plots, one for each frequency level selected. In the method, the selected frequency levels lie in the range of expected pulse frequencies which is, for the purposes of illustration, herein defined as between 0.67 and 3.33 Hz. This range may be altered to reflect the application. The multitude of WBL plots may be displayed together to form a 3-D Lissajous figure, as shown in figure 13(a).

[0041] Note that, in the example shown here, a complex wavelet function was used and hence both real or both imaginary values of the transform can be utilized in the method. Further, information from the real WBL plots and imaginary WBL plots may be combined to provide an optimal solution. If a real-only wavelet function is used (i.e. a wavelet function containing only a real part and no imaginary part) then only one set of transforms (real) are available to use.

[0042] Each Lissajous plot making up the 3-D Lissajous figure is then probed to find its spread both along its principle axis and that axis orthogonal to it. To do this, any reasonable measure of spread may be used. Here we employ the standard deviation (SD). Figure 13 (b) shows an end on view of the 3-D Lissajous of figure 13(a). The region of the 3-D Lissajous figures 13(a) and 13(b) in the vicinity of the pulse frequency is marked by the letter 'B' in the figures and higher frequencies are marked by the letter 'A'. Figure 14 contains plots of the standard deviation of data spread along the principle axis (top plot) and minor axis (middle plot), and the ratio of the standard deviations (lower plot) for each Lissajous component making up the 3-D Lissajous plot in figure 13(a). In the preferred example the Lissajous component with the maximum spread is used in the determination of the oxygen saturation. The location of this component is marked by the arrow in the top plot of figure 14. This component, with the maximum spread along the major principle axis, is plotted in figure 13(c); the representative slope of which is computed and used to determine the local oxygen saturation value using a predefined look-up table. This maximum spread is usually found at or near the pulse frequency. A check is also made on the SD ratios: defined as the SD of spread along the major axis divided by the SD of spread along the minor axis. A low SD ratio implies good correlation between the two signals. The SD ratio for the component with maximum spread is indicated by the arrow in the lower plot of figure 14. We can see for this case that a relatively low SD ratio occurs at this location. The SD ratio check may be used to pick a more appropriate wavelet-based Lissajous plot and can form part of a noise identification and/or reduction algorithm. Alternate methods of picking an optimal wavelet-based Lissajous may also be employed as appropriate. During periods of excessive noise, the Lissajous components can become spread out in shape, and in some cases the direction of the major and minor principle axis can significantly change from that of the relatively noise free portions of the signals. A check can therefore be made to determine if this has occurred by retaining a recent history of the selected Lissajous components. This can further be used as a confidence check on the selected Lissajous figure used in the determination of oxygen saturation.

[0043] Note that the ratio of the amplitudes of the independent wavelet signals making up the selected Lissajous component may also be used to determine the oxygen saturation. Note also that the inverse transform of these wavelet signals may be used in the method to determine oxygen saturation. The method described can be used to extract the pertinent ratio information from wavelet transforms computed using either complex or real-only wavelet functions.

[0044] Figure 15 shows the oxygen saturation determined using the 3-D Lissajous method (solid black line) compared with the traditional signal amplitude method (dotted) and signal Lissajous method (dashed) . All three methods employed a 4 second smoothing window. It can be seen that for the particular example signal interrogated here (the signals taken from the finger of a healthy male patient aged 42 sitting in an upright position at rest) the wavelet method produces a more consistent value.

[0045] Figures 16 contains three-dimensional views of the red and infrared scalograms corresponding to an example PPG signal. Here the modulus of the complex transform is used. The locations of the band associated with the pulse component are indicated in the plots (denoted 'B' in the figures). We define the collection of points corresponding to the path of the maxima of the band projected onto the time frequency plane as P. A wavelet ratio surface (R_{WT}) can be constructed by dividing the wavelet transform of the logarithm of red signal by the wavelet transform of the logarithm of the infrared signal to get a time-frequency distribution of the wavelet ratio surface, i.e.

$$R_{WT} = \frac{|T(a,b)_R|}{|T(a,b)_{IR}|} \qquad [7]$$

where where the subscripts R and IR identify the red and infrared signals respectively. The wavelet ratio surface derived from the two scalograms in figure 16 is shown schematically in figure 17. Note that as described previously in our definition of scalogram we include all reasonable forms of descaling including the original unscaled wavelet representation, linear rescaling and any power of the modulus of the wavelet transform may be used in the definition. As the amplitude of the wavelet components scale with the amplitude of the signal components then for regions of the surface not affected by erroneous signal components the wavelet ratio surface will contain values which can be used to determined the oxygen saturation using a predefined look-up table.

[0046] As can be seen in figure 17, the time frequency wavelet ratio surface along, and in close proximity to, the projection of the pulse ridge path P onto the wavelet ratio surface are stable and hence may be used in the robust determination of the oxygen saturation. In the preferred example the values obtained along the projection of P onto R_{WT} are used to determine oxygen saturation via a pre-defined look-up table which correlates R_{WT} to oxygen saturation.

[0047] A 2-D or 3-D view of the R_{WT} plot may be computed and displayed in real time to provide a visual indication of the quality of the ratio of ratios obtained by the method, and hence the quality of the measurement of oxygen saturation.

[0048] Figure 18 contains a plot of the end view of the wavelet ratio surface shown in figure 17. From the figure we see that a relatively stable, flat region is also found at or near the respiration frequency (R in the figure). It has been noted from experimentation that for some cases the respiration region of the wavelet ratio surface may lie at a different level from the pulse band region. Hence, for these cases, using R_{WT} obtained in the breathing region would produce erroneous values of oxygen saturation. By following a path in the region of the pulse band our method automatically filters out erroneous breathing components in the signal.

[0049] Figure 19 contains a plot of the oxygen saturation determined by the wavelet ratio surface method as a function of time as compared with two standard methods: the traditional signal amplitude method and the traditional Lissajous method. The PPG signals were again taken from the finger of a healthy male patient aged 42 sitting in an upright position at rest. From visual inspection of the plot it can be seen that, for this example, the wavelet-based method produces a more consistent value of oxygen saturation compared to contemporary methods.

[0050] It will be recognized by those skilled in the art that the pulse band ridge path P can also be projected onto the real or imaginary transform components. Prom the values of the transform components along this path over a selected time interval a Lissajous figure may be obtained and used in the determination of oxygen saturation. It will also be recognized by those skilled in the art that alternative paths may be projected onto the wavelet ratio surface and used for the determination of oxygen saturation. For example in regions where the pulse band exhibits noise causing the path of the ridge maxima to move far from the actual pulse frequency a method for detecting such noisy events and holding the path to the most appropriate recent pulse frequency may be used until the event has passed or until a preset period of time whereby an alarm is triggered.

[0051] The 3-D Lissajous and wavelet ratio surface methodologies for the determination of oxygen saturation, as described above, can form the basis of an algorithm for incorporation within pulse oximeter devices. Furthermore the ability of the methodologies to restrict themselves to the optimal wavelet transform values by picking the optimal Lissajous or following the pulse band respectively, allows for erroneous signal elements to be discarded automatically; so leading to a more robust algorithm for the determination of oxygen saturation.

[0052] Note that in both new methods the inverse transform of the selected wavelet values may also be used as they too scale with the signal features.

[0053] In the preferred example, both the 3-D Lissajous and wavelet ratio surface methods are employed simultaneously and the optimal measured saturation value determined. It is obvious from the above description that the initial inputted signals and wavelet transformation of these signals form common elements to both methods.

[0054] Those skilled in the art will recognise that the above methods may be performed using alternative time-frequency representations of the signals where the amplitude in the time-frequency transform space can be related to the amplitude of pertinent features within the signal. However, in the preferred method the continuous wavelet transform is employed.

[0055] In summary a method for the decomposition of pulse oximetry signals using wavelet transforms has been described which allows for underlying characteristics which are of clinical use to be measured and displayed. These wavelet decompositions can then be used to:

(a) provide, using information derived from the signal wavelet transforms (i.e. from the original transform, the rescaled wavelet transforms, the ratio of derived wavelet transforms, the scalograms, wavelet ridges, etc.) a method for measuring oxygen saturation.

(b) construct, using information derived from the wavelet transform (i.e. from the original transform, the rescaled wavelet transforms, the ratio of derived wavelet transforms, the scalograms, wavelet ridges, etc.), a plurality of wavelet-based Lissajous figures from which the optimum Lissajous representation is chosen using preset criteria and the slope of which is used to determine the oxygen saturation of the signal using a look-up table.

(c) construct, using information derived from the wavelet transform (i.e. from the original transform, the rescaled wavelet transforms, the ratio of derived wavelet transforms, the scalograms, wavelet ridges, etc.), a time-frequency equivalent of the ratio of ratios, the wavelet ratio surface, from which to determine the oxygen saturation of the signal by following a selected path through the time frequency plane. The preferred path through the time frequency plane to be that corresponding to the pulse band.

(d) provide an optimal oxygen saturation value from those derived in (b) and (c).

3.4 The Monitoring of Patient Movement

[0056] Current devices are configured to remove detrimental movement artifact from the signal in order to clean it prior to determination of the clinical parameter of interest, e.g. the pulse rate or oxygen saturation. However, the method described herein as embodied within a device monitors general patient movement, including large scale body movements, respiration and the beating heart. In this way the absence of patient movement and/or irregularity of movement can be detected and an alarm triggered.

[0057] Patient movement results in PPG signal artifact. The manifestation of this artifact can be observed in the wavelet transform of the signal. An example of a movement artifact in the scalogram is shown in figure 20(a). The PPG signal from which the wavelet plot was derived was acquired from a premature baby a few weeks after birth. The location of the movement artifact is marked by the arrow in the plot. The breathing band ridge has been superimposed on the wavelet plot (marked R in the figure). The pulse band is marked P in the figure. Notice that the artifact causes a drop-out in the detected breathing ridge (i.e. a missing fragment), and also cuts through the pulse band where it can cause similar drop outs to occur in the detection of the pulse ridge. It has been the focus of pulse oximeter device manufacturers to remove as much of the movement artifact component from the signal while leaving the information necessary to obtain accurate oxygen saturation and pulse rate measurements. In the methods described herein we extract a movement component from the PPG signals for use in the monitoring of patient movement and, in particular, for the monitoring of the movement of infants .

[0058] A three-dimensional view of the scalogram of figure 20 (a) is plotted in figure 20(b). Here we see the dominance of the movement artifact feature in wavelet space. By identifying such features we can monitor patient movement. It is common for young babies to exhibit very variable respiration patterns and to cease breathing for short periods of time, especially when making a movement of the body. Hence inspecting the derived movement signal when an irregular respiration signal occurs, including cessation of breathing, gives a further measure of patient status.

[0059] The modulus maxima of the wavelet surface is the loci of the maxima of the wavelet surface with respect to time. Figure 21(a) plots the modulus maxima lines associated with figure 20(a). Figure 21(b) shows a three-dimensional view of the transform surface with the modulus maxima lines superimposed. Figure 22(a) shows an end view of the maxima lines (without the surface shown) corresponding to those shown in figures 21(a) and 21(b). We can see from the end view that the modulus maxima line corresponding to the movement artifact has a significantly different morphology to the other maxima lines: it covers a large frequency range and contains significantly more energy than the other maxima, especially at low frequencies. By setting amplitude threshold criteria at a frequency or range of frequencies we can differentiate the modulus maxima of the artifact from other features.

[0060] An example of this is shown schematically by the threshold level and frequency range depicted on figure 22(b), where maxima above the pre-defined amplitude threshold within a frequency range given by $f_{(1)}<f<f_{(2)}$ are identified as corresponding to movement artifact. In addition a check of local anomalies in the detected pulse and breathing ridge may also be made. For example modulus maxima which are at significantly higher amplitudes than the pulse ridge mean value in their vicinity are deemed to correspond to movement artifact. This is depicted in figure 22(c). In addition, modulus maxima which are at a significantly higher amplitude than the respiration ridge mean value in their vicinity are deemed to correspond to movement artifact. This is depicted in figure 22(d).

[0061] A region in the time frequency plane within the support of the wavelet is then deemed to contain artifact. The support of the wavelet is taken as a predefined measure of temporal 'width' of the wavelet. For wavelets with theoretical infinite width, such as the Morlet wavelet, the width is defined in terms of the standard deviation of temporal spread: for example we use three times the standard deviation of spread each side from the wavelet centre. Thus a cone of influence of the artifact may be defined in the transform plane.

[0062] Using the above method we can monitor patient movement by detecting modulus maxima corresponding to movement artifact. This information can be used to monitor patient movement and/or to provide a measure of confidence on the derived values of other measurements (e.g. oxygen saturation, pulse and respiration). These measurements may, for example be held at a previous value until the detected movement event has passed.

[0063] Other artefact may exist in the signal which may originate from the drive and control electronics including, but not limited to, automatic gain adjustments. The occurrence of this type of artifact will be known and can be accounted for in the signal and hence differentiated from movement artifact.

4. Device Configuration and Usage

[0064] The device may be used to monitor one or more of the following signals: respiration, pulse, breathing and movement. Useful information regarding these signals would be displayed on the device or output in a suitable format for use.

[0065] In one example the device would be used to continually monitor one or more of these signals.

[0066] In another example the device would be used to monitor one or more of these signals intermittently.

4.1 Device Configuration

[0067] Detailed block diagrams of the device are provided in figures 23,24, 25 and 26.

[0068] The following is with reference to figure 23. In the present device signals are acquired at the patient's body 10. These are sent for digitization 11. The links between components of the system may be fixed physical or wireless links, for example radiofrequency links. In particular, either or both of the links between 10 and 11 or 11 and 12, or the links between the analyser component and a visual display may a wireless link enabled by a radiofrequency transmitter. The digitised cardiac signals 11 are sent to 12 where the natural logarithm of the signals are computed. These are then sent to 13 where the wavelet transforms of the signals are performed. The components of the wavelet transformed signals, including modulus, phase, real part, imaginary part are then sent to 14 where the pulse ridge is identified. The information from 13 and 14 is then used in the extraction of patient pulse information 15, oxygen saturation 16, patient movement information 17 and respiration information 18. The information regarding oxygen saturation, pulse, respiration and patient movement is all sent to the Analyser component 19 where it is collected and collated ready for outputting at 20. The oxygen saturation, respiration, pulse rate and movement information is output from the device 20 through a number of methods, which may include a printout, a display screen or other visual device, an audable tone, and electronically via a fixed or remote link. The output information may be sent to a location remote from the patient, for example sent via telephone lines, satellite communication methods, or other methods. Further, real-time wavelet-based visualisations of the signal (including the original transform and/or the wavelet ratio surface with projected pulse ridge path) may be displayed on the device 20. These visualisations will highlight salient information concerning the quality of the outputted measurements. Additional useful information regarding movement artefact and breathing information may be apparent from such a real time display.

[0069] The workings of components 15, 16, 17 and 18 shown in figure 23 are described below in more detail. Pulse Component 15: with reference to figure 23, pulse information including pulse rate and pulse irregularities are derived at 15 using the instantaneous frequency of the pulse band ridge determined at 14. The instantaneous frequency may correspond directly with the instantaneous ridge frequency or require a mapping from the instantaneous ridge frequency and the true respiration rate. Further the method allows for a smoothing of this value over a fixed time interval. Further the method allows for erroneous values of the pulse rate derived in this way to be excluded from the outputted values. This component 15 may also be used to measure inter-beat intervals and pertinent pulse wave timings. The pulse information determined at 15 is then sent to the Analyser Component 19.

[0070] The Oxygen Saturation Component 16: The following is with reference to figures 23 and 24. The oxygen saturation component 16 shown in figure 23 comprises the subcomponents 31, 32, 33, 34, 35, 36 and 37 as shown in figure 24. The wavelet transform information and pulse ridge information from 14 is input into this module at the feature sorter 31 which sends the relevant information to the Lissajous computation unit (components 32, 33 and 34) and the pulse ridge computational unit (components 35 and 36). A predetermined number of wavelet-based Lissajous are computed over the pulse region 32. An automated procedure is employed for the determination of the optimal Lissajous for use in the oxygen saturation calculation 33. In the preferred example this would be achieved by comparing the standard deviations of the data spread along of the principle axes of the Lissajous plot. The slope of the principle axis is then used to determine the oxygen saturation using a suitable look-up table which correlates the slope to oxygen saturation 34. The oxygen saturation determined at 34 is denoted 'Oxygen Saturation Determination (1)'.

[0071] The information regarding the wavelet transforms of the PPG signals and the path of the pulse ridge is collected at the feature sorter 31 used to compute the wavelet ratio surface 35. The wavelet ratio corresponding to the pulse path is determined by projecting the pulse path onto the wavelet ratio surface. This ratio is then used to determine the oxygen saturation using a look-up table which correlates the wavelet ratio to oxygen saturation 36. The oxygen saturation determined at 36 is denoted 'Oxygen Saturation Determination (2)'. The two oxygen saturation values (1) and (2) are then used to determine the most appropriate value of oxygen saturation 37. This value is then sent to the Analyzer Component 19.

[0072] Movement Component 17: The following is with reference to figures 23 and 26. The Movement component 17 of figure 23 comprises the subcomponents 51, 52, 53, 54, 55 as shown in figure 26. The wavelet transform information and pulse ridge information is sent from 14 to the modulus maxima component 51 where the modulus maxima of the wavelet surfaces are computed. The modulus maxima information is then sent to be analysed for movement artifact. The modulus maxima information is sent to the components 52, 53 and 54. These are described as follows. The Threshold component 52 detects maxima above a preset threshold and within a preset frequency range which are them defined as movement artifact. The Pulse Check component 53 checks the maxima corresponding to the pulse band to see if anomalously large excursion from the local mean level has occurred. If so movement artifact is detected. The Respiration Check component 54 checks the maxima in the vicinity of the selected respiration path SRP obtained from 18 to determine if anomalously large excursion from the local mean level has occurred. If so movement artifact is detected. The information from components 52, 53 and 54 are then collected and collated at the Movement Signal component 55 where a movement signal is generated. This is then sent to the Analyser Component 19.

[0073] Respiration Component 18: The following is with reference to figures 23 and 25. The respiration component 17 of figure 23 comprises the subcomponents 61, 62, 63 and 64 as shown in figure 25. The wavelet transform and pulse ridge information from 14 are input into this module at component 61 which uses the information to derive the ridge amplitude perturbation (RAP) signal and the ridge frequency perturbation (RFP) signals. The RAP and RFP signals are derived using the path defined by the projection of the maxima of the pulse band or a locus of points displaced from this maxima path. A secondary wavelet transform is performed on these signals 62 and then passed to the respiration detection component 63 where the respiration ridges are detected for the wavelet transforms of the RFP and RAP signals. These are then used within an algorithm which decides the selected respiration path (SRP). This algorithm may also incorporate respiration information using complementary methods 64. Note that in the method the original transform obtained at 13 and the secondary transform 62 may be computed using different wavelet functions. The respiration information is then sent to the Analyzer Component 19 and also to the Movement component 17.

[0074] The Analyser Component 19: With reference to Fig. 23, the Analyzer Component collects the information from the pulse component 15, Oxygen Saturation Component 16, Movement Component 17 and Respiration Component 18. During periods of detected motion or other signal artifact the analyzer makes a decision to hold the most appropriate recent values of these signals until the artifact event passes or until predetermined interval has passed at which point an alarm signal sent to the device output 20. Further the analyzer checks the incoming signals for anomalous behaviour including, but not limited to: low and or high pulse rates, pulse irregularities, low and high breathing rates, breathing irregularities, low and high oxygen saturation rates, movement irregularities including excessive movement and absence of movement. Detected anomalous behaviour or combination of behaviours will trigger an alarm signal sent to the device output 20.

4.2 Physical Attachment of Probes and Transmission of PPG Signals

[0075] Referring to figure 23, the acquisition of the signal 10 takes place at a suitable site on the patient's body. This signal is then sent to component 11 where the signals are digitized then to component 12 where their natural logarithm is computed prior to the wavelet analysis at 13. The patient signal may be taken using a standard probe configuration. For example a finger or toe probe, foot probe, forehead probe, ear probe and so on. Further the probe may function in either transmittance or reflectance mode.

[0076] In one example for use with neonates a foot/ankle mounted device such as a cuff is employed as depicted schematically in figure 27. The cuff is used to house the probe electronics, radio frequency transmitter modules and battery. Figure 27(a) shows the patients lower leg 80 and foot with the cuff 83 attached to the foot. The patients heel 81 and toes 82 protrude from the cuff. Figure 27(b) shows two views, one from each side of the foot showing the cuff with compartments for housing the electronic equipment required for signal acquisition and transmission. The PPG signals may be taken directly through the foot using Light Emitting Diodes (LEDs) 86 and photodetector 88 located as shown or they may be taken at the toe using a short length of cable attaching the pulse oximeter probe to the electronics contained in the cuff. In a further alternative example reflectance mode photoplethysmography may be employed. In a further Alternative example more suitable for adult monitoring the electronic equipment is packaged within a soft housing which is wrapped and secured around the wrist as shown in figure 28. The electronic components for receiving processing and transmitting the PPGs are housed in a unit 90 secured by a band 91 to the patients wrist. The PPG signals are acquired at a site local to the wrist band. For example from a finger 93 via a lead 92 from the wrist unit 90, or at the site of the wrist band and housing using, for example, reflectance mode photoplethysmography. In yet another alternative example, the signal from the pulse oximeter probe would be sent to the monitor device using a physical lead instead of the wireless method described here.

[0077] Light transmitters other than LEDs may be used in the device.

[0078] In an Alternative example, the digitised signal from 11 may input directly to the wavelet transform component 13 without taking the natural logarithm.

[0079] In an alternativetive example, more than two wavelengths or combination of more than two wavelengths of light may be employed in the Oximetry method.

4.3 Use of the Device

4.3.1 General Use

[0080] The device may be used for general patient monitoring in the hospital, home, ambulatory or other environment. For example for a device for use within a hospital setting it may be used to continually or intermittently monitor patient respiration together with oxygen saturation and pulse rate.

4.3.2 Implementation as an Apnea Monitor

[0081] In another implementation of the device it would be used as an apnea monitor. Apnea is the cessation of breathing usually occurring during sleep. There is increasing awareness of this sleep disorder as the cause of a number of serious medical conditions in adults and infants. Separate areas of use are envisaged for the device as an apnea monitor. Examples of this use include, but are not limited to: (1) adult monitoring, where it can be used as a *home screening diagnostic tool* for potential apnea patients and (2) infant monitoring, where it can be used as either an in hospital or *home monitoring tool* to alert the child's carer to this potentially fatal respiration irregularity.
[0082] Apnea monitors monitor heart and respiratory signals to detect apnea episodes - usually defined as cessation of breathing for >20 seconds. Apnea is associated with slowing of the pulse (bradycardia) or bluish discoloration of the skin due to lack of oxygenated haemoglobin (cyanosis). Long term effects of apnea in adults are quite serious and have been reported to include: heavy snoring, weariness and obsessive drive to fall asleep, reduced physical and mental fitness, strokes, nervousness, fall in concentration and headaches, psychic symptoms up to depressions, sexual dysfunctions, impotence, dizziness and nightly perspiration. In babies apnea may lead to death if suitable resuscitation measures are not taken.
[0083] As it measures respiration and movement directly from the pulse oximeter signal (in addition to oxygen saturation and pulse), the device can be fitted remote from the head; e.g. the foot or arm of the patient. This has the advantage over current devices which comprise of probes located on the patients head and face to measure breathing at the patients nose and/or mouth. As such they are uncomfortable for adult patients and are quite impractical for fitting to babies for the obvious reason of causing a potential choking hazard. The device allows the PPG signal collected at the patient to be sent via a wireless link to a remotely located device.
[0084] In summary, embodied as an apnea monitor, the device provides a method for the acquisition analysis and interpretation of pulse oximeter signals to provide clinically useful information on patient pulse rate, oxygen saturation, respiration and movement. From a combination of some or all of this information clinical decisions can be made with regard to the patient's health. The patient respiration information is used to monitor the patient in order to compute a respiration rate and to detect breathing abnormalities, for example: apnea events, cessation in breathing, sharp intakes of breaths, coughing, excessively fast breathing, excessively slow breathing, etc. Information derived from one or more of the respiration, movement, oxygen saturation and pulse measurements may be used to trigger an alarm to call for medical help or to initiate an automated process for the administration of a therapeutic intervention. A method may be employed for the archiving of the derived signals during the analysis period of the patient which may be used at a later date for analysis by the clinician.
[0085] The device may be used to monitor the patient both during sleep and when awake.
[0086] The device may be used to detect the onset of sudden infant death syndrome SIDS by detecting and analysing abnormalities in the measurement of one or more of the following: oxygen saturation, respiration, movement and pulse.

4.3.3 Alarm

[0087] As described above, it is envisaged that the gathered information is used to trigger an alarm at the bedside and/or at a remote nursing station. This alarm would be graded according to a classification of patient information. For example a reduction in oxygen saturation below a predefined threshold with associated loss or irregularity of patient movement, irregularity of pulse rate and loss or irregularity of patient respiration could trigger the highest level of alarm, whereas a reduction of oxygen saturation below a predefined threshold with a normal level of patient movement and/or a regular respiration pattern could trigger a lower level of alarm.

5 . Brief Description of Drawings

[0088]

Figures 1(a): A wavelet transform surfaces showing the pulse band (located between the dashed lines). (High to Low energy is graded from white to black in the grey scale plot.)
Figure 1(b): Three-dimensional view of the wavelet transform surface of figure 1(a) showing the maxima of the pulse band with respect to frequency (the ridge) superimposed as a black path across the band maxima. (High to Low energy is graded from white to black in the grey scale plot.)
Figure 2: 3-D Schematic of a wavelet transform surface containing two bands. The locus of the local maxima on the bands (the 'ridges') are shown by dashed lines.
Figure 3: Schematics of the RAP (top left) and RFP (top right) signals derived from ridge A in figure 1 together with

their corresponding wavelet transforms shown below each (in 2D).

Figure 4(a): The SWFD method as applied to a pulse oximeter signal - Scalogram of original Signal.. (High to Low energy is graded from white to black in the grey scale plot.)

figure 4 (b): The SWFD method as applied to a pulse oximeter signal - 3-D view of scalogram in (a) with the path of the pulse band ridge superimposed. (High to Low energy is graded from white to black in the grey scale plot.)

Figure 4 (a): The SWFD method as applied to a pulse oximeter signal - RAP signal (Top: full signal. Lower: blow up of selected region)

Figure 4 (d): The SWFD method as applied to a pulse oximeter signal - RFP signal (Top: full signal. Lower: blow up of selected region)

Figure 5(a): The SWFD method as applied to a pulse oximeter signal - RAP scalogram. (High to Low energy is graded from white to black in the grey scale plot.)

Figure 5(b): The SWFD method as applied to a pulse oximeter signal - RFP scalogram. (High to Low energy is graded from white to black in the grey scale plot.)

Figures 5(c): The SWFD method as applied to a pulse oximeter signal - 3-D view of RAP scalograms with breathing band ridge shown. (High to Low energy is graded from white to black in the grey scale plot.)

Figure 5(d): The SWFD method as applied to a pulse oximeter signal - 3-D view of RFP scalogram with ridge shown. (High to Low energy is graded from white to black in the grey scale plot.) Figure 6(a): PUG Signal

Figure 6(b): Pulse band and ridge corresponding to signal (a) . (High to Low energy is graded from white to black in the grey scale plot.)

Figures 6(a): RAP signal derived from ridge in (b) with breathing switch (square waveform) superimposed.

Figure 6(d): RFP signal derived from ridge in (b)

Figure 7(a): Wavelet Transform of RAP signal. (High to Low energy is graded from white to black in the grey scale plot.)

Figure 7(b): Extracted ridges from wavelet transform in (a). (High to Low energy is graded from white to black in the grey scale plot.)

Figure 7(c): Wavelet Transform of RFP signal. (High to Low energy is graded from white to black in the grey scale plot.)

Figure 7(d): Extracted ridges from wavelet transform in (c). (High to Low energy is graded from white to black in the grey scale plot.)

Figure 8(a): Breathing ridges extracted from the original wavelet transform

Figure 8(b): Breathing ridges extracted from the secondary wavelet transform of the RAP signal

Figure 8(c): Breathing ridges extracted from the secondary wavelet transform of the RFP signal

Figure 8(d): Selected respiration path (SRP).

Figure 9: Transform Phase along the SRP

Figure 10: Filling in missing segments of the SRP

Figure 11: Wavelet Representations of the Red PPG (top) and Infrared PPG (bottom)

Figure 12: Schematic of the Sliding Window used to Obtain the Wavelet Components for the 3-D Lissajous

Figure 13(a): Wavelet-based 3-D Lissajous: 3-D View.

Figure 13(b): Wavelet-based 3-D Lissajous: End on View of (a).

Figure 13(c): Wavelet-based 3-D Lissajous: End on View of Selected Component.

Figure 14: Standard Deviation of Lissajous Components in Figure 3. Top plot: SD of principle component; Middle plot: SD of minor component; Lower plot: Ratio of SD components. All three plots plotted against frequency in Hz.

Figure 15: Computed Oxygen Saturation Curves. Dotted line: Signal Amplitude Method; Dashed Line traditional Signal Lissajous Method; Solid Line: Wavelet-based 3-D Lissajous Method.

Figure 16: The red and infrared wavelet modulus surfaces corresponding to a 45 second segment of PPG signals. (High to Low energy is graded from white to black in the grey scale plot.)

Figure 17: The wavelet ratio surface derived from the division of the red by the infrared wavelet representations shown in Figure 16.

Figure 18: An end view of the wavelet ratio surface shown in figure 17.

Figure 19: Computed Oxygen Saturation curves. Dotted line: Oxygen Saturation from Traditional signal Amplitude Method; Dashed Line: Oxygen saturation from Traditional Signal Lissajous Method; Solid Line: Oxygen Saturation from Traditional Wavelet-Ratio Surface Method

Figure 20(a): Wavelet transform plot of a PPG signal taken from a young baby showing a corresponding to patient movement. Low to high energy is depicted from black to white in the greyscale plot.

Figure 20(b): Three-dimensional view of (a). Low to high energy is depicted from black to white in the greyscale plot.

Figure 21(a): Transform plot of figure 20(a) with modulus maxima superimposed. Low to high energy is depicted from black to white in the greyscale plot.

Figure 21(b): Three-dimensional view of figure 21(a). Low to high energy is depicted from black to white in the greyscale plot.

Figure 22(a): End view of modulus maxima lines in figure 21(b).

6. General

[0089] The invention has been described and shown with specific reference to specific embodiments. However it will be understood by those skilled in the art that changes to the form and details of the disclosed embodiments may be made without departing from the scope of the invention defined by the appended claims.

7. Reference

[0090] Addison P.s., 'The Illustrated Wavelet Transform Handbook', Institute of Physics Publishing, 2002, Bristol, UK.

Claims

1. A method of measuring physiological parameters, comprising: using a signal acquisition means (10) to obtain a red pulse oximetry signal in the red light spectrum and an infra-red pulse oximetry signal in the infra-red spectrum; decomposing each pulse oximetry signal by wavelet transform analysis to provide a three dimensional wavelet transform surface for the red pulse oximetry signal and a three dimensional wavelet transform surface for the infra-red pulse oximetry signal; and combining the three dimensional wavelet transform surfaces to obtain a measure of a physiological parameter.

2. The method of claim 1, wherein the step of combining the three dimensional wavelet transform surfaces to obtain a measure of a physiological parameter comprises; for each three dimensional wavelet transform surface, selecting a plurality of frequencies and a first set time period; and plotting the transform values over the set time period at each frequency of the three dimensional wavelet transform surface for the red pulse oximetry signal against those of the three dimensional wavelet transform surface for the infra-red pulse oximetry signal as a plurality of Lissajous figures.

3. The method of claim 2 wherein the Lissajous figures are three-dimensional.

4. The method of claim 2 or claim 3 further comprising plotting Lissajous figures for the selected frequencies over a second set time period, the start of which is later than the start of the first set time period.

5. The method of claim 4 wherein a plurality of successive later time periods is selected such that a frequency window moves across the time-frequency plane of each three dimensional wavelet transform surface.

6. The method of any of claims 2 to 5 further comprising the steps of analysing a characteristic parameter of each Lissajous figure; using the value of the characteristic parameter to select a Lissajous figure from the plurality of Lissajous figures; and using the selected Lissajous figure to determine a physiological parameter.

7. The method of claim 6, wherein the characteristic parameter of a Lissajous figure is derived from its spread along its principle components, and wherein the selected Lissajous figure is the one having the maximum spread.

8. A method as claimed in claim 7 wherein the spread of a Lissajous figure is represented by the standard deviation

along the principle component or components.

9. A method as claimed in claim 8 wherein the ratio of standard deviations along two orthogonal principle components is calculated to give a further aid to the selection of the Lissajous figure for use in determining the physiological parameter.

10. The method of any of claims 2 to 9, wherein the slope of the selected Lissajous figure is used as a measure of the patient oxygen saturation.

11. The method of claim 10 wherein a predefined look-up table is used to deduce the relationship between the slope and the oxygen saturation.

12. The method of claim 1, wherein the step of combining the three dimensional wavelet transform surfaces to obtain a measure of a physiological parameter comprises the steps of: constructing a wavelet ratio surface based on the ratio of one of the three dimensional wavelet transform surfaces to the other of the three dimensional wavelet transform surfaces; and deriving one or more physiological parameters from the wavelet ratio surface.

13. The method of claim 12, wherein the step of deriving one or more physiological parameters from the wavelet ratio surface comprises the steps of: selecting a region of the wavelet ratio surface for use in determining the physiological parameter.

14. The method of claim 13 wherein the selected region is derived from a path in the wavelet ratio surface formed from a collection of points in the vicinity of the maxima of a pulse band.

15. The method of claim 14 wherein the selected region is derived from a path in the wavelet ratio surface formed from a collection of points corresponding to the maxima of a pulse band.

16. The method of claim 14 or claim 15 further comprising the step of inspecting a predefined look-up table to determine the correlation between the path and the oxygen saturation.

17. The method of any of claims 12 to 16, further comprising the step of, when a local disturbance occurs in the pulse band maxima, holding the previously determined oxygen saturation value for a specified duration or until the local disturbance ceases.

18. The method of any of the preceding claims, wherein the pulse oximetry signal is a photoplethysmogram (PPG) signal and/or wherein the wavelet transform analysis employs a continuous wavelet transform

19. A physiological measurement system comprising: a signal acquisition means (10) which includes a light emitting device and a photodetector attachable to a subject to obtain a red pulse oximetry signal in the red light spectrum and an infra-red pulse oximetry signal in the infra-red spectrum; analogue to digital converter means (11) arranged to convert said pulse oximetry signals into digital pulse oximetry signals; signal processing means suitable to receive said digital pulse oximetry signals and arranged to decompose those signals by wavelet transform means (13) to provide a three dimensional wavelet transform surface for the red pulse oximetry signal and a three dimensional wavelet transform surface for the infra-red pulse oximetry signal; and an oxygen saturation component (16) arranged to combine the three dimensional wavelet transform surfaces for the red pulse oximetry signal and the infra-red pulse oximetry signal to obtain a measure of a physiological parameter.

20. The system of claim 19, wherein the oxygen saturation component (16) comprises one or more of:

a Lissajous computation unit (32) arranged to receive the three dimensional wavelet transform surfaces for the red pulse oximetry signal and the infra-red pulse oximetry signal from the signal processing means, and, for each three dimensional wavelet transform surface, to: select a plurality of frequencies and a first set time period; and plot the transform values over the first set time period at each frequency of the three dimensional wavelet transform surface of the red pulse oximetry signal against those of the three dimensional wavelet transform surface of the infra-red pulse oximetry signal as a plurality of Lissajous figures;
a pulse ridge computation unit (35) arranged to: receive the three dimensional wavelet transform surfaces for the red pulse oximetry signal and the infra-red pulse oximetry signal from the signal processing means; to construct a wavelet ratio surface based on the ratio of one of the three dimensional wavelet transform surfaces

to the other of the three dimensional wavelet transform surfaces; and to derive one or more physiological parameters from the wavelet ratio surface.

21. The system of claim 19 or claim 20, in which the signal processing means and the Lissajous computation unit (32) are arranged to perform the method of any of claims 1 to 11 and/or the signal processing means and the pulse ridge computational unit are arranged to perform the method of any of claims 12 to 18.

22. The system of claim 19 or claim 20, wherein said system further comprises a signal sorting component (31) arranged to receive a signal from the signal processing means and to allocate that signal to both the Lissajous computation unit (32) and the pulse ridge computational unit (35).

23. The system of claim 22 wherein the system further comprises comparison means (37) arranged to receive a signal from each of the Lissajous computation unit and the pulse ridge computational unit and to select a signal to be representative of the physiological parameter.

24. The system of any of claims 19 to 23, further comprising an analyser component (19) arranged to collect information from the oxygen saturation component (16), and a device output (20) arranged in communication with the analyser component.

25. The system of claim 24 wherein the analyser component (16) is arranged to generate an alarm signal upon detection of a predetermined set of conditions.

26. The system of claim 25 wherein the predetermined set of conditions includes the existence of abnormal oxygen saturation for at least a given time.

Patentansprüche

1. Verfahren zum Messen von physiologischen Parametern, umfassend: Verwenden eines Signalerfassungsmittels (10) zum Erhalten eines Rot-Pulsoxymetriesignals im roten Lichtspektrum und eines Infrarot-Pulsoxymetriesignals im Infrarotspektrum; Zerlegen jedes Pulsoxymetriesignals durch Wavelettransformationsanalyse, um eine dreidimensionale Wavelettransformationsoberfläche für das Rot-Pulsoxymetriesignal und eine dreidimensionale Wavelettransformationsoberfläche für das Infrarot-Pulsoxymetriesignal bereitzustellen; und Kombinieren der dreidimensionalen Wavelettransformationsoberflächen, um ein Maß eines physiologischen Parameters zu erhalten.

2. Verfahren nach Anspruch 1, wobei der Schritt des Kombinierens der dreidimensionalen Wavelettransformationsoberflächen, um ein Maß eines physiologischen Parameters zu erhalten, umfasst: Auswählen für jede dreidimensionale Wavelettransformationsoberfläche einer Mehrzahl von Frequenzen und einer ersten festgelegten Zeitdauer; und Auftragen der Transformationswerte über die festgelegte Zeitdauer bei jeder Frequenz der dreidimensionalen Wavelettransformationsoberfläche für das Rot-Pulsoxymetriesignal gegen jene der dreidimensionalen Wavelettransformationsoberfläche für das Infrarot-Pulsoxymetriesignal als eine Mehrzahl von Lissajous-Figuren.

3. Verfahren nach Anspruch 2, wobei die Lissajous-Figuren dreidimensional sind.

4. Verfahren nach Anspruch 2 oder Anspruch 3, ferner umfassend ein Auftragen von Lissajous-Figuren für die ausgewählten Frequenzen über eine zweite festgelegte Zeitdauer, deren Beginn später als der Beginn der ersten festgelegten Zeitdauer ist.

5. Verfahren nach Anspruch 4, wobei eine Mehrzahl von nachfolgenden späteren Zeitdauern derart ausgewählt wird, dass sich ein Frequenzfenster über die Zeit-Frequenz-Ebene jeder dreidimensionalen Wavelettransformationsoberfläche bewegt.

6. Verfahren nach einem der Ansprüche 2 bis 5, ferner umfassend die folgenden Schritte: Analysieren eines charakteristischen Parameters jeder Lissajous-Figur; Verwenden des Wertes des charakteristischen Parameters zum Auswählen einer Lissajous-Figur aus der Mehrzahl von Lissajous-Figuren; und Verwenden der ausgewählten Lissajous-Figur zum Bestimmen eines physiologischen Parameters.

7. Verfahren nach Anspruch 6, wobei der charakteristische Parameter einer Lissajous-Figur von ihrer Ausdehnung entlang ihrer Hauptkomponenten abgeleitet wird, und wobei die ausgewählte Lissajous-Figur diejenige mit der maximalen Ausdehnung ist.

8. Verfahren nach Anspruch 7, wobei die Ausdehnung einer Lissajous-Figur durch die Standardabweichung entlang der Hauptkomponente oder -komponenten dargestellt wird.

9. Verfahren nach Anspruch 8, wobei das Verhältnis von Standardabweichungen entlang zweier orthogonaler Hauptkomponenten berechnet wird, um eine weitere Hilfe für die Auswahl der Lissajous-Figur zur Verwendung beim Bestimmen des physiologischen Parameters zu ergeben.

10. Verfahren nach einem der Ansprüche 2 bis 9, wobei die Neigung der ausgewählten Lissajous-Figur als ein Maß der Sauerstoffsättigung eines Patienten verwendet wird.

11. Verfahren nach Anspruch 10, wobei eine vordefinierte Nachschlagetabelle zum Ableiten der Beziehung zwischen der Neigung und der Sauerstoffsättigung verwendet wird.

12. Verfahren nach Anspruch 1, wobei der Schritt des Kombinierens der dreidimensionalen Wavelettransformationsoberflächen, um ein Maß eines physiologischen Parameters zu erhalten, die folgenden Schritte umfasst: Erstellen einer Waveletverhältnisoberfläche basierend auf dem Verhältnis von einer der dreidimensionalen Wavelettransformationsoberflächen zu der anderen der dreidimensionalen Wavelettransformationsoberflächen; und Ableiten eines oder mehrerer physiologischer Parameter von der Waveletverhältnisoberfläche.

13. Verfahren nach Anspruch 12, wobei der Schritt des Ableitens einer oder mehrerer physiologischer Parameter von der Waveletverhältnisoberfläche die folgenden Schritte umfasst: Auswählen einer Region der Waveletverhältnisoberfläche zur Verwendung beim Bestimmen des physiologischen Parameters.

14. Verfahren nach Anspruch 13, wobei die ausgewählte Region von einem Weg in der Waveletverhältnisoberfläche abgeleitet wird, der aus einer Sammlung von Punkten in der Nachbarschaft der Maxima eines Pulsbandes gebildet ist.

15. Verfahren nach Anspruch 14, wobei die ausgewählte Region von einem Weg in der Waveletverhältnisoberfläche abgeleitet wird, der aus einer Sammlung von Punkten gebildet ist, die den Maxima eines Pulsbandes entsprechen.

16. Verfahren nach Anspruch 14 oder Anspruch 15, ferner umfassend den Schritt des Nachschlagens in einer vordefinierten Nachschlagetabelle, um die Korrelation zwischen dem Weg und der Sauerstoffsättigung zu bestimmen.

17. Verfahren nach einem der Ansprüche 12 bis 16, ferner umfassend, bei Auftreten einer lokalen Störung bei den Maxima des Pulsbandes, den Schritt des Haltens des vorher bestimmten Sauerstoffsättigungswerts für eine spezifizierte Dauer oder bis die lokale Störung aufhört.

18. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Pulsoxymetriesignal ein Photoplethysmogramm (PPG)-Signal ist, und/oder wobei die Wavelettransformationsanalyse eine kontinuierliche Wavelettransformation einsetzt.

19. Physiologisches Messsystem, umfassend: ein Signalerfassungsmittel (10), das eine Licht abgebende Vorrichtung und einen Fotodetektor enthält, das an einer Person anbringbar ist, um ein Rot-Pulsoxymetriesignal im roten Lichtspektrum und ein Infrarot-Pulsoxymetriesignal im Infrarotspektrum zu erhalten; ein Analog-zu-Digital-Umwandlermittel (11), das zum Umwandeln der Pulsoxymetriesignale in digitale Pulsoxymetriesignale angeordnet ist; ein Signalverarbeitungsmittel, das zum Empfangen der digitalen Pulsoxymetriesignale geeignet ist und zum Zerlegen dieser Signale durch ein Wavelettransformationsmittel (13) angeordnet ist, um eine dreidimensionale Wavelettransformationsoberfläche für das Rot-Pulsoxymetriesignal und eine dreidimensionale Wavelettransformationsoberfläche für das Infrarot-Pulsoxymetriesignal bereitzustellen; und eine Sauerstoffsättigungskomponente (16), die zum Kombinieren der dreidimensionalen Wavelettransformationsoberfläche für das Rot-Pulsoxymetriesignal und das Infrarot-Pulsoxymetriesignal angeordnet ist, um ein Maß eines physiologischen Parameters zu erhalten.

20. System nach Anspruch 19, wobei die Sauerstoffsättigungskomponente (16) eine oder mehrere umfasst von:

einer Lissajous-Berechnungseinheit (32), die angeordnet ist zum Empfangen der dreidimensionalen Wavelettransformationsoberflächen für das Rot-Pulsoxymetriesignal und das Infrarot-Pulsoxymetriesignal von dem Si-

gnalerarbeitungsmittel und für jede dreidimensionale Wavelettransformationsoberfläche zum: Auswählen einer Mehrzahl von Frequenzen und einer ersten festgelegten Zeitdauer; und Auftragen der Transformationswerte über die erste festgelegte Zeitdauer bei jeder Frequenz der dreidimensionalen Wavelettransformationsoberfläche des Rot-Pulsoxymetriesignals gegen jene der dreidimensionalen Wavelettransformationsoberfläche des Infrarot-Pulsoxymetriesignals als eine Mehrzahl von Lissajous-Figuren;
einer Pulskammberechnungseinheit (35), die angeordnet ist zum: Empfangen der dreidimensionalen Wavelettransformationsoberflächen für das Rot-Pulsoxymetriesignal und das Infrarot-Pulsoxymetriesignal von dem Signalerarbeitungsmittel; Erstellen einer Waveletverhältnisoberfläche basierend auf dem Verhältnis von einer der dreidimensionalen Wavelettransformationsoberflächen zu der anderen der dreidimensionalen Wavelettransformationsoberflächen; und Ableiten eines oder mehrerer physiologischer Parameter von der Waveletverhältnisoberfläche.

21. System nach Anspruch 19 oder 20, wobei das Signalverarbeitungsmittel und die Lissajous-Berechnungseinheit (32) zum Durchführen des Verfahrens nach einem der Ansprüche 1 bis 11 angeordnet sind, und/oder das Signalverarbeitungsmittel und die Pulskammberechnungseinheit zum Durchführen des Verfahrens nach einem der Ansprüche 12 bis 18 angeordnet sind.

22. System nach Anspruch 19 oder Anspruch 20, wobei das System ferner eine Signalsortierungskomponente (31) umfasst, die zum Empfangen eines Signals von dem Signalverarbeitungsmittel und zum Zuordnen dieses Signals sowohl zur Lissajous-Berechnungseinheit (32) als auch zur Pulskammberechnungseinheit (35) angeordnet ist.

23. System nach Anspruch 22, wobei das System ferner ein Vergleichsmittel (37) umfasst, das zum Empfangen eines Signals von jeder von der Lissajous-Berechnungseinheit und der Pulskammberechnungseinheit und zum Auswählen eines für den physiologischen Parameter repräsentativen Signals angeordnet ist.

24. System nach einem der Ansprüche 19 bis 23, ferner umfassend eine Analysatorkomponente (19), die zum Sammeln von Informationen von der Sauerstoffsättigungskomponente (16) angeordnet ist, und eine Vornchtungsausgabe (20), die in Kommunikation mit der Analysatorkomponente angeordnet ist.

25. System nach Anspruch 24, wobei die Analysatorkomponente (16) zum Erzeugen eines Alarmsignals nach Detektion eines im Voraus bestimmten Satzes von Bedingungen angeordnet ist.

26. System nach Anspruch 25, wobei der im Voraus bestimmte Satz von Bedingungen die Existenz einer anomalen Sauerstoffsättigung für mindestens eine gegebene Zeit enthält.

Revendications

1. Procédé de mesure de paramètres physiologiques comprenant: l'utilisation d'un moyen d'acquisition de signal (10) pour obtenir un signal d'oxymétrie pulsée rouge dans le spectre de lumière rouge et un signal d'oxymétrie pulsée infrarouge dans le spectre infrarouge ; la décomposition de chaque signal d'oxymétrie pulsée par analyse par transformée en ondelettes pour fournir une surface de transformée en ondelettes tridimensionnelle pour le signal d'oxymétrie pulsée rouge et une surface de transformée en ondelettes tridimensionnelle pour le signal d'oxymétrie pulsée infrarouge ; et la combinaison des surfaces de transformée en ondelettes tridimensionnelles pour obtenir une mesure d'un paramètre physiologique.

2. Procédé selon la revendication 1, dans lequel l'étape de combinaison des surfaces de transformée en ondelettes tridimensionnelles pour obtenir une mesure d'un paramètre physiologique comprend, pour chaque surface de transformée en ondelettes tridimensionnelle, la sélection d'une pluralité de fréquences et d'une première période de temps définie ; et la représentation des valeurs de transformée sur la période de temps définie à chaque fréquence de la surface de transformée en ondelettes tridimensionnelle pour le signal d'oxymétrie pulsée rouge par rapport à celles de la surface de transformée en ondelettes tridimensionnelle pour le signal d'oxymétrie pulsée infrarouge sous la forme d'une pluralité de figures de Lissajous.

3. Procédé selon la revendication 2, dans lequel les figures de Lissajous sont tridimensionnelles.

4. Procédé selon la revendication 2 ou la revendication 3, comprenant en outre la représentation de figures de Lissajous pour les fréquences sélectionnées sur une seconde période de temps définie, dont le début est postérieur au début de la première période de temps définie.

5. Procédé selon la revendication 4, dans lequel une pluralité de périodes de temps postérieures successives est sélectionnée de telle sorte qu'une fenêtre de fréquence se déplace à travers le plan temps-fréquence de chaque surface de transformée en ondelettes tridimensionnelle.

6. Procédé selon l'une quelconque des revendications 2 à 5, comprenant en outre les étapes d'analyse d'un paramètre caractéristique de chaque figure de Lissajous ; d'utilisation de la valeur du paramètre caractéristique pour sélectionner une figure de Lissajous à partir de la pluralité de figures de Lissajous ; et d'utilisation de la figure de Lissajous sélectionnée pour déterminer un paramètre physiologique.

7. Procédé selon la revendication 6, dans lequel le paramètre caractéristique d'une figure de Lissajous est dérivé de son étalement le long de ses composantes principales, et dans lequel la figure de Lissajous sélectionnée est celle ayant l'étalement maximum.

8. Procédé selon la revendication 7, dans lequel l'étalement d'une figure de Lissajous est représenté par l'écart standard le long de la composante ou des composantes principale(s).

9. Procédé selon la revendication 8, dans lequel le rapport des écarts standards le long de deux composantes principales orthogonales est calculé pour fournir une aide complémentaire à la sélection de la figure de Lissajous pour utilisation dans la détermination du paramètre physiologique.

10. Procédé selon l'une quelconque des revendications 2 à 9, dans lequel la pente de la figure de Lissajous sélectionnée est utilisée comme une mesure de la saturation en oxygène du patient.

11. Procédé selon la revendication 10, dans lequel une table de recherche prédéfinie est utilisée pour déduire la relation entre la pente et la saturation en oxygène.

12. Procédé selon la revendication 1, dans lequel l'étape de combinaison des surfaces de transformée en ondelettes tridimensionnelles pour obtenir une mesure d'un paramètre physiologique comprend les étapes suivantes : la construction d'une surface de rapport d'ondelettes basée sur le rapport de l'une des surfaces de transformée en ondelettes tridimensionnelles sur l'autre des surfaces de transformée en ondelettes tridimensionnelles ; et la dérivation d'un ou plusieurs paramètres physiologiques de la surface de rapport d'ondelettes.

13. Procédé selon la revendication 12, dans lequel l'étape de dérivation d'un ou plusieurs paramètres physiologiques à partir de la surface de rapport d'ondelettes comprend les étapes suivantes : la sélection d'une région de la surface de rapport d'ondelettes pour utilisation dans la détermination du paramètre physiologique.

14. Procédé selon la revendication 13, dans lequel la région sélectionnée est dérivée d'un chemin dans la surface de rapport d'ondelettes formé à partir d'une collection de points au voisinage du maxima d'une bande d'impulsions.

15. Procédé selon la revendication 14, dans lequel la région sélectionnée est dérivée d'un chemin dans la surface de rapport d'ondelettes formé à partir d'une collection de points correspondant au maxima d'une bande d'impulsions.

16. Procédé selon la revendication 14 ou la revendication 15, comprenant en outre une étape d'inspection d'une table de recherche prédéfinie pour déterminer la corrélation entre le chemin et la saturation en oxygène.

17. Procédé selon l'une quelconque des revendications 12 à 16, comprenant en outre, lorsqu'une perturbation locale survient dans le maxima de la bande d'impulsions, le maintien de la valeur de saturation en oxygène préalablement déterminée pendant une durée spécifiée ou jusqu'à ce que la perturbation locale cesse.

18. Procédé selon l'une quelconque des revendications précédentes, dans lequel le signal d'oxymétrie pulsée est un signal de photopléthysmogramme (PPG) et/ou dans lequel l'analyse par transformée en ondelettes emploie une transformée en ondelettes continues.

19. Système de mesure physiologique comprenant : un moyen d'acquisition de signal (10) qui comprend un dispositif électroluminescent et un photodétecteur, attachable à un sujet pour obtenir un signal d'oxymétrie pulsée rouge dans le spectre de lumière rouge et un signal d'oxymétrie pulsée infrarouge dans le spectre infrarouge ; un moyen de

conversion analogique-numérique (11) conçu pour convertir lesdits signaux d'oxymétrie pulsée en signaux d'oxymétrie pulsée numériques ; un moyen de traitement de signaux adapté pour recevoir lesdits signaux d'oxymétrie pulsée numériques et conçu pour décomposer ces signaux par un moyen de transformée en ondelettes (13) pour fournir une surface de transformée en ondelettes tridimensionnelle pour le signal d'oxymétrie pulsée rouge et une surface de transformée en ondelettes tridimensionnelle pour le signal d'oxymétrie pulsée infrarouge ; et un composant de saturation en oxygène (16) conçu pour combiner les surfaces de transformée en ondelettes tridimensionnelles pour le signal d'oxymétrie pulsée rouge et le signal d'oxymétrie pulsée infrarouge pour obtenir une mesure d'un paramètre physiologique.

20. Système selon la revendication 19, dans lequel le composant de saturation en oxygène (16) comprend un ou plusieurs parmi :

une unité de calcul de Lissajous (32) conçue pour recevoir les surfaces de transformée en ondelettes tridimensionnelles pour le signal d'oxymétrie pulsée rouge et le signal d'oxymétrie pulsée infrarouge à partir du moyen de traitement de signaux, et, pour chaque surface de transformée en ondelettes tridimensionnelle, pour : sélectionner une pluralité de fréquences et une première période de temps définie ; et représenter les valeurs de transformée sur la période de temps définie à chaque fréquence de la surface de transformée en ondelettes tridimensionnelle pour le signal d'oxymétrie pulsée rouge par rapport à celles de la surface de transformée en ondelettes tridimensionnelle pour le signal d'oxymétrie pulsée infrarouge sous la forme d'une pluralité de figures de Lissajous ;
une unité de calcul de crête d'impulsion (35) conçue pour : recevoir les surfaces de transformée en ondelettes tridimensionnelles pour le signal d'oxymétrie pulsée rouge et le signal d'oxymétrie pulsée infrarouge à partir du moyen de traitement de signaux ; construire une surface de rapport d'ondelettes sur la base du rapport de l'une des surfaces de transformée en ondelettes tridimensionnelles sur l'autre des surfaces de transformée en ondelettes tridimensionnelles ; et dériver un ou plusieurs paramètres physiologiques de la surface de rapport d'ondelettes.

21. Système selon la revendication 19 ou la revendication 20, dans lequel le moyen de traitement de signaux et l'unité de calcul de Lissajous (32) sont conçus pour effectuer le procédé selon l'une quelconque des revendications 1 à 11 et/ou le moyen de traitement de signaux et l'unité de calcul de crête d'impulsion sont conçus pour effectuer le procédé selon l'une quelconque des revendications 12 à 18.

22. Système selon la revendication 19 ou la revendication 20, dans lequel ledit système comprend en outre un composant de tri de signaux (31) conçu pour recevoir un signal du moyen de traitement de signaux et pour allouer ce signal à la fois à l'unité de calcul de Lissajous (32) et à l'unité de calcul de crête d'impulsion (35).

23. Système selon la revendication 22, dans lequel le système comprend en outre un moyen de comparaison (37) conçu pour recevoir un signal de chacune de l'unité de calcul de Lissajous et de l'unité de calcul de crête d'impulsion et pour sélectionner un signal qui sera représentatif du paramètre physiologique.

24. Système selon l'une quelconque des revendications 19 à 23, comprenant en outre un composant analyseur (19) conçu pour collecter des informations provenant du composant de saturation en oxygène (16), et une sortie de dispositif (20) agencée en communication avec le composant analyseur.

25. Système selon la revendication 24, dans lequel le composant analyseur (16) est conçu pour générer un signal d'alarme lors de la détection d'un ensemble prédéterminé de conditions.

26. Système selon la revendication 25, dans lequel l'ensemble prédéterminé de conditions comprend l'existence d'une saturation en oxygène anormale pendant au moins un temps donné.

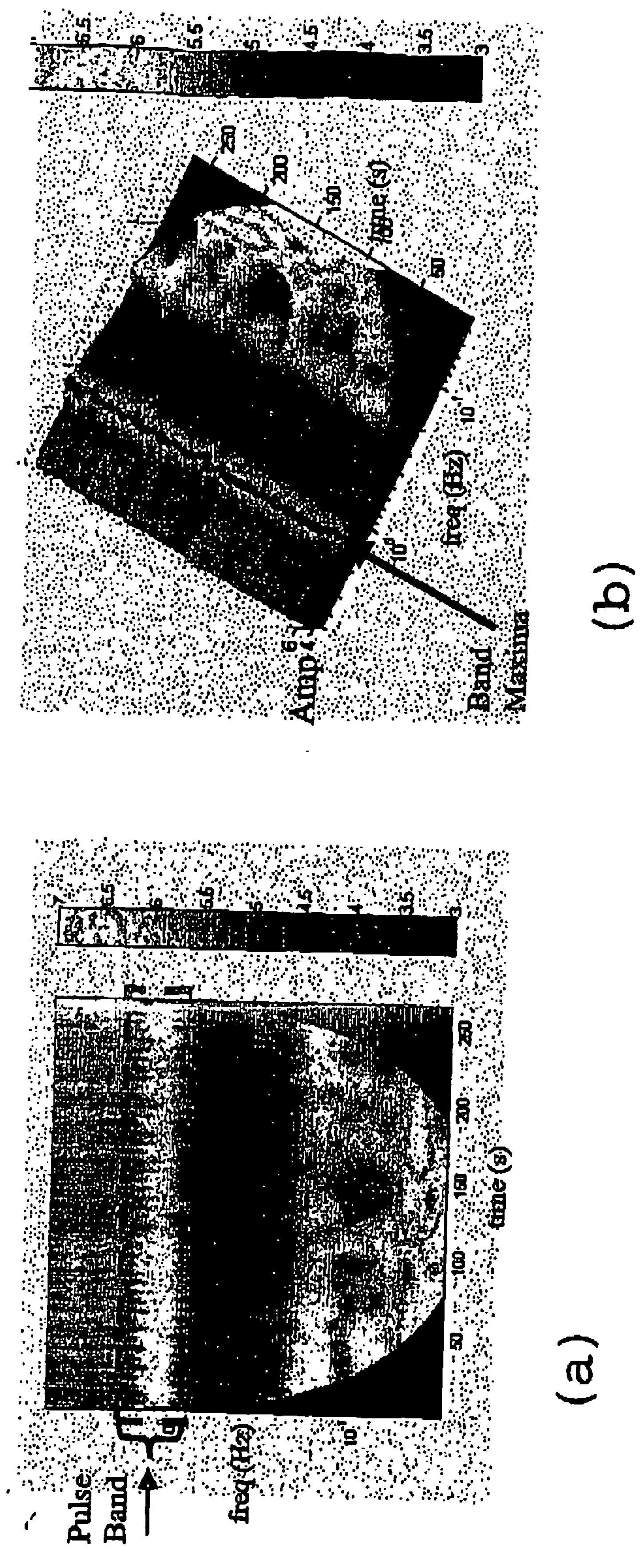


Figure 1

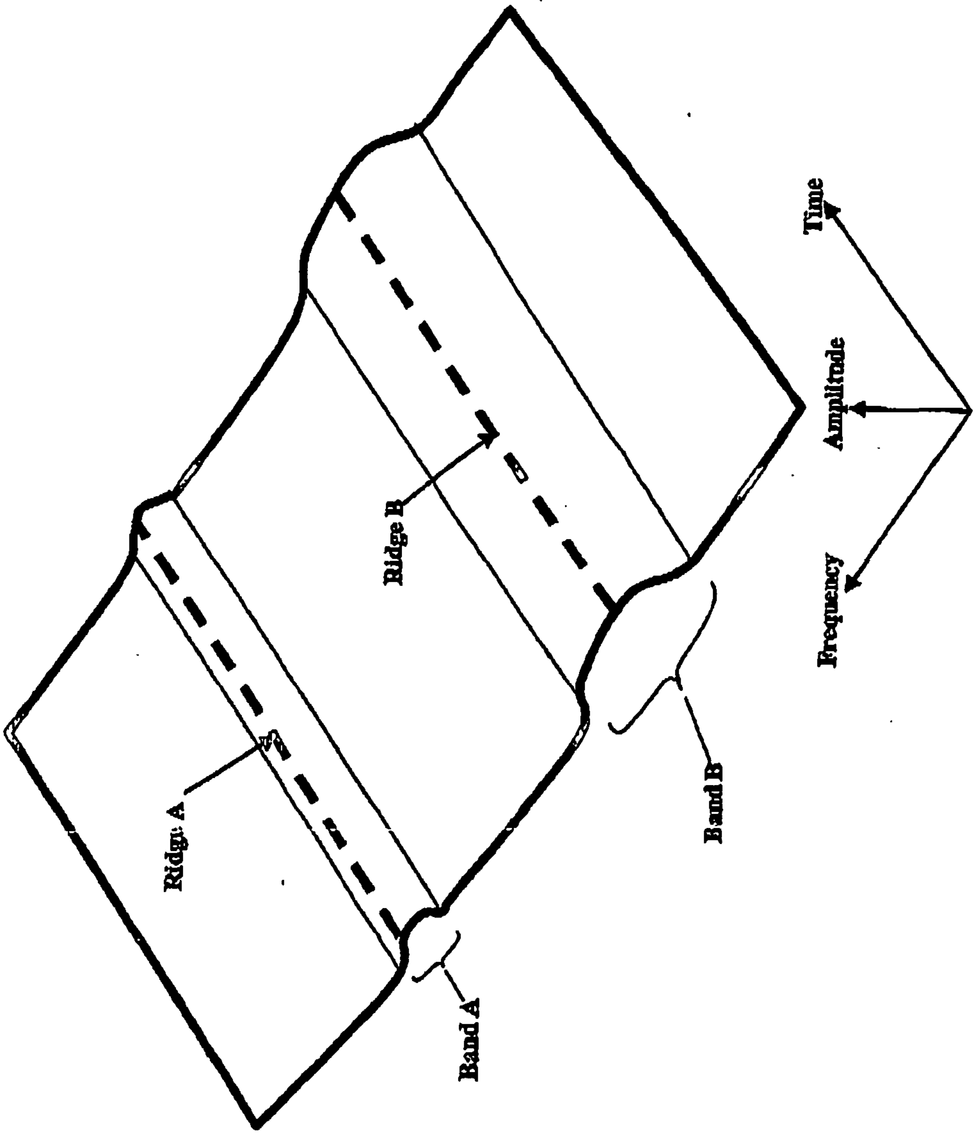


Figure 2

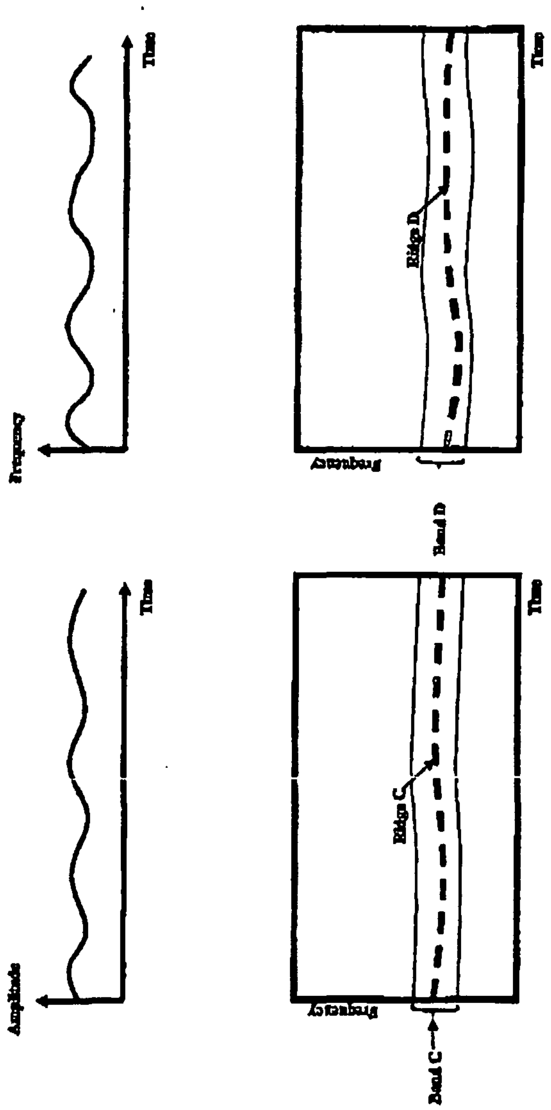


Figure 3

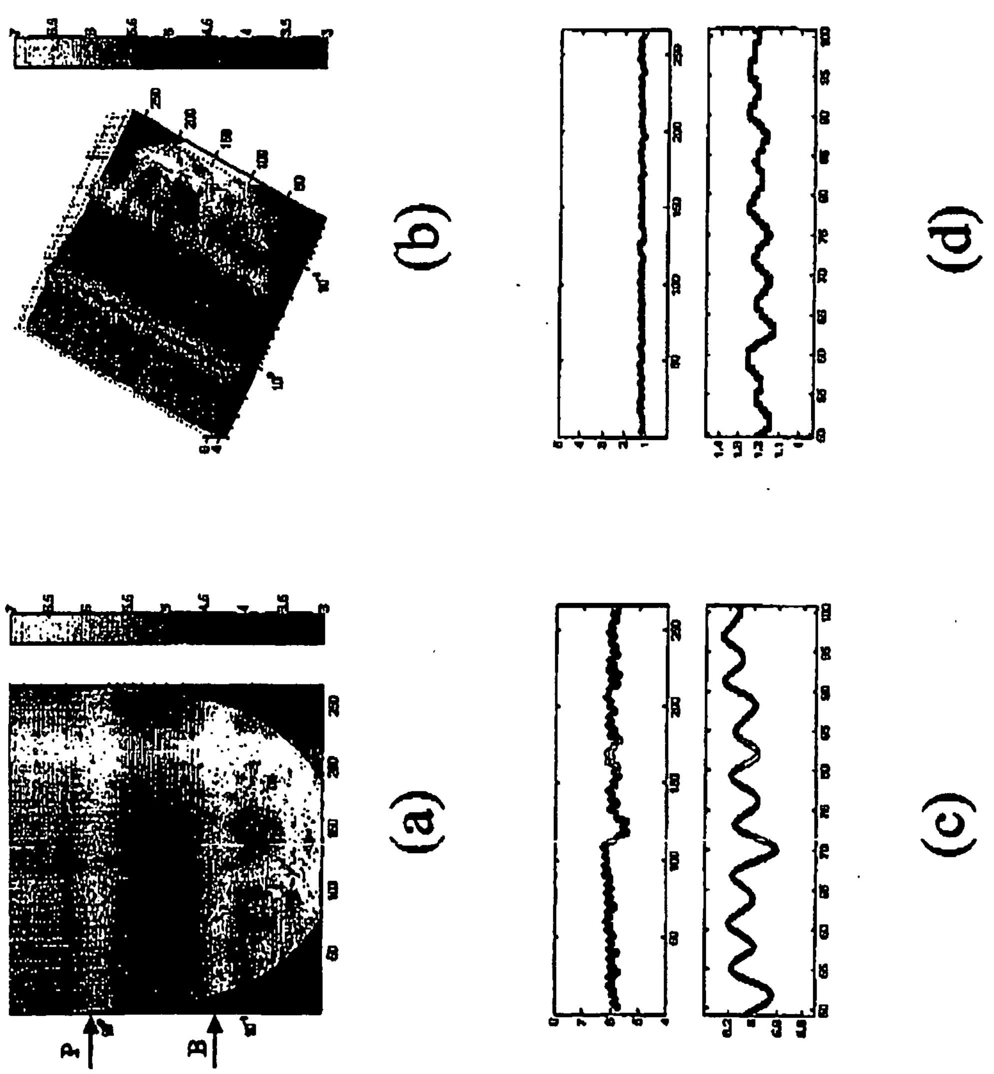


Figure 4

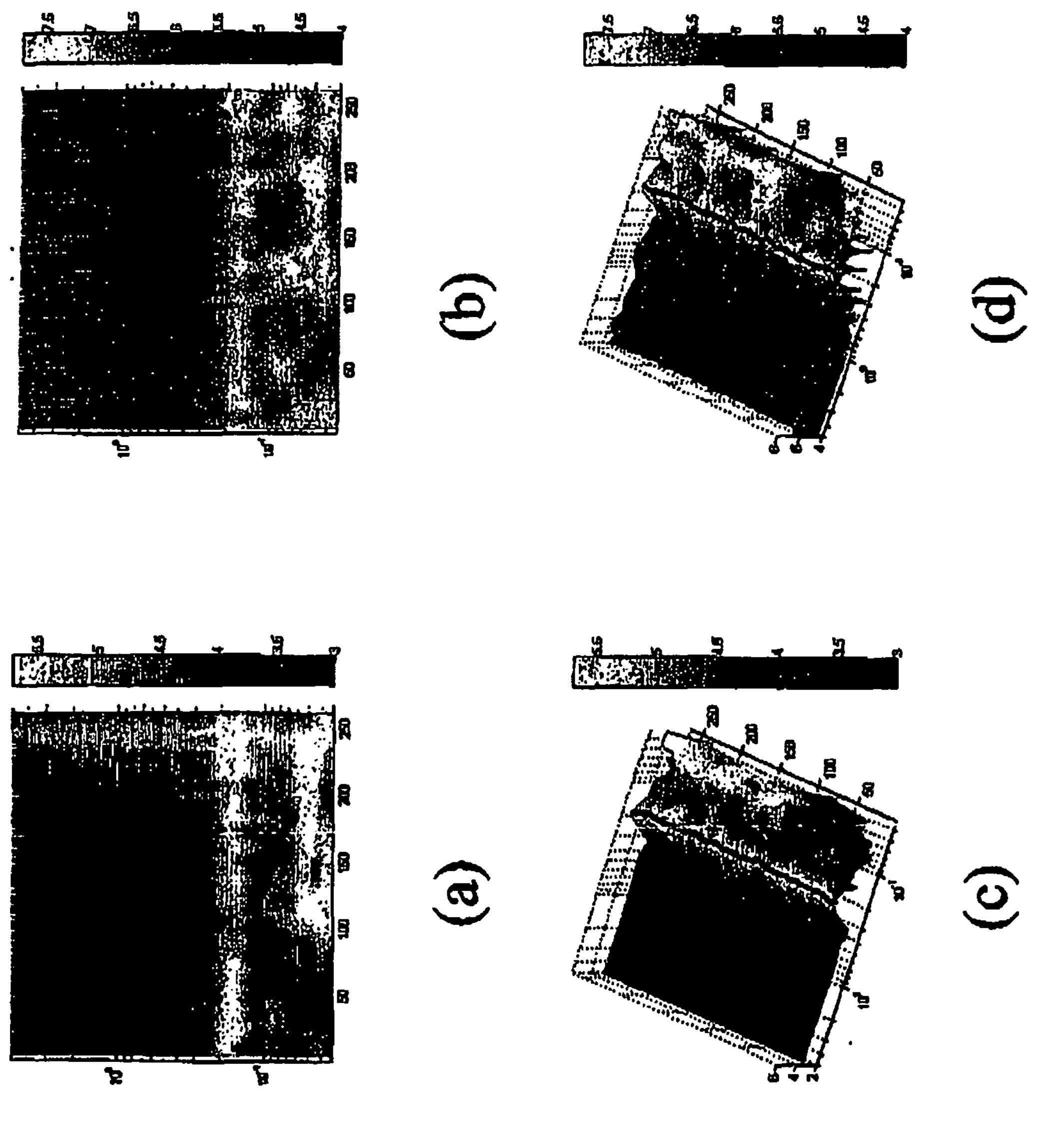


Figure 5

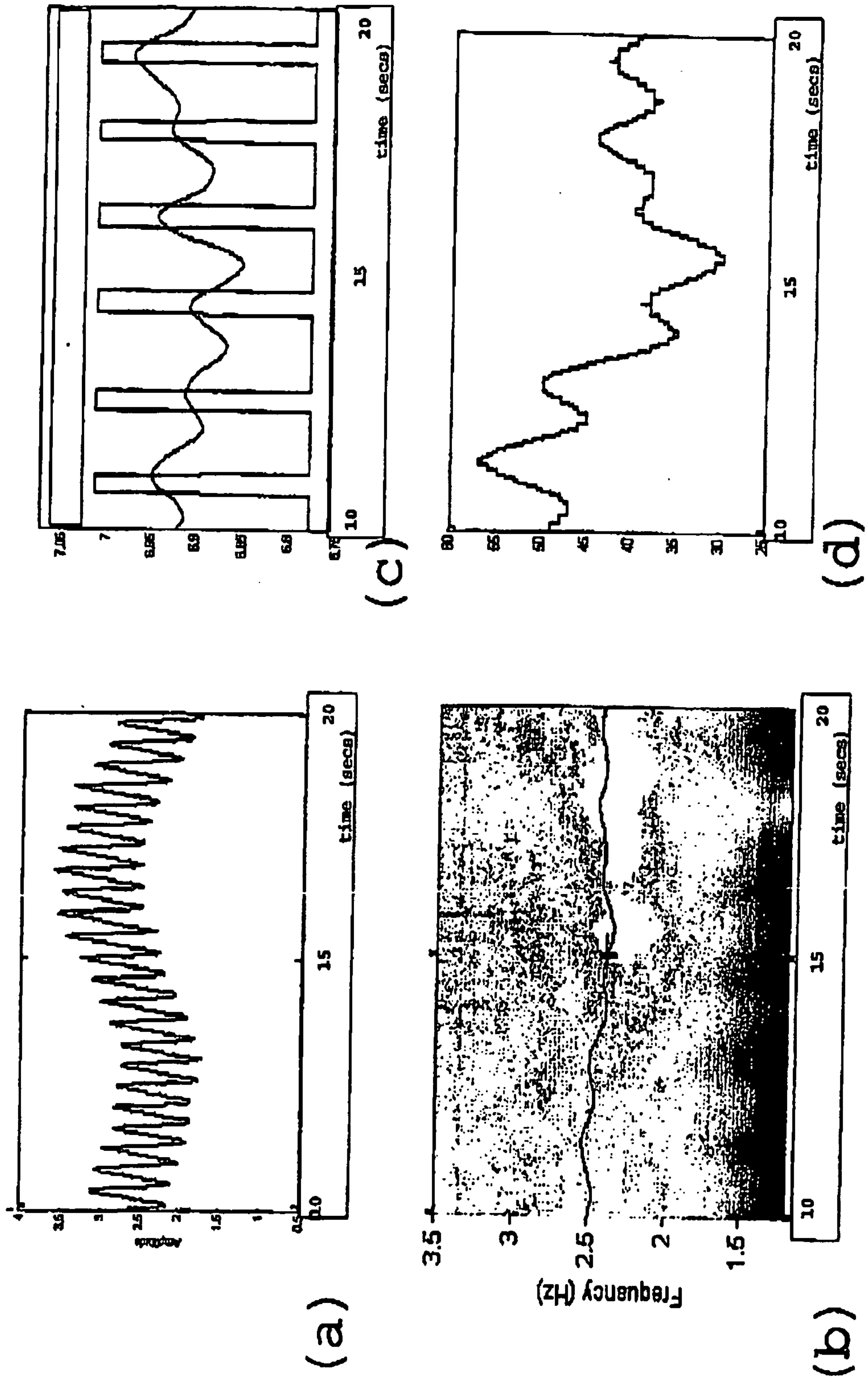


Figure 6

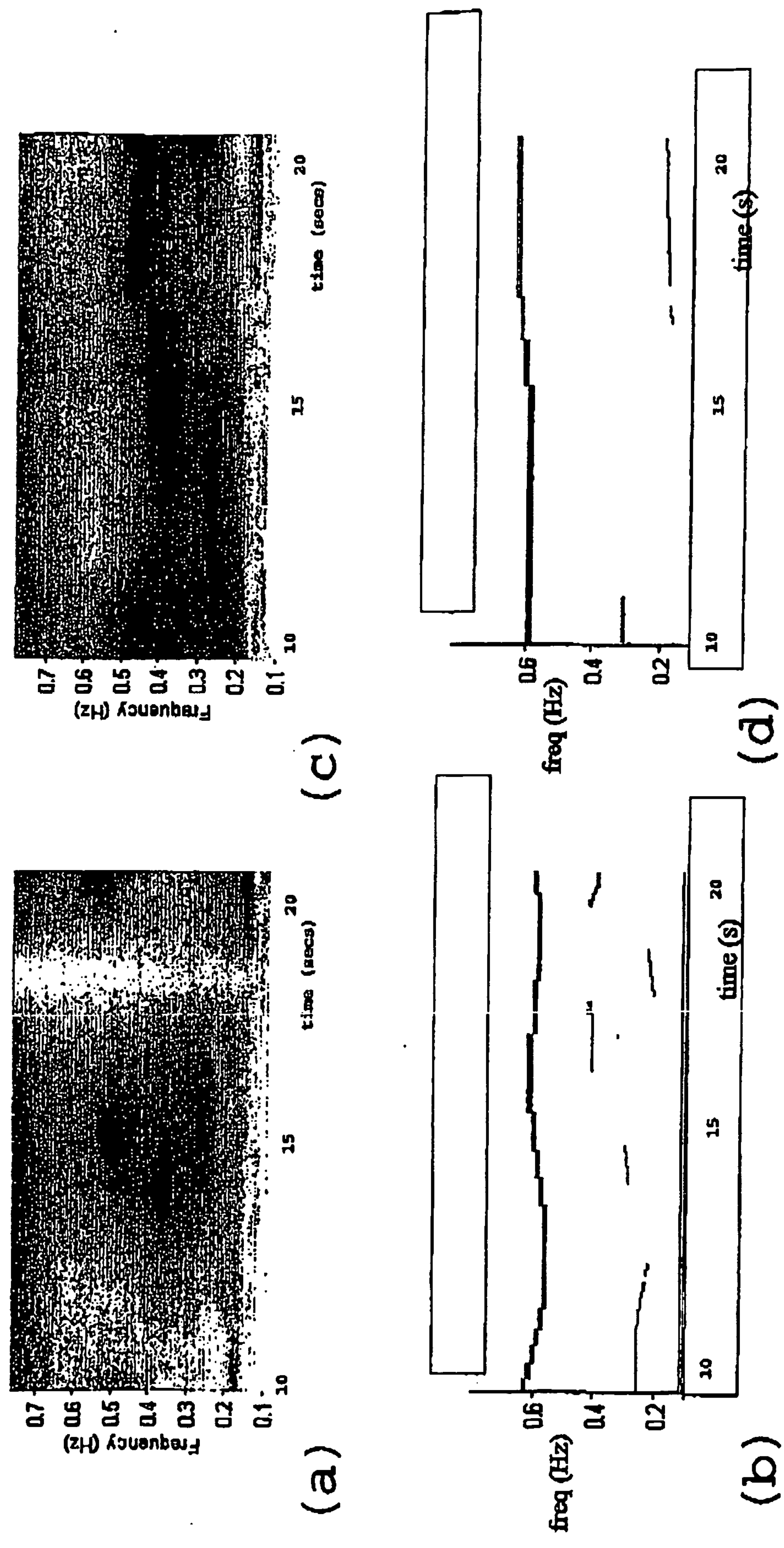

(a)
Frequency (Hz)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
10
15
20
time (secs)
(b)
freq (Hz)
0.6
0.4
0.2
10
15
20
time (s)
(c)
Frequency (Hz)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
10
15
20
time (secs)
(d)
freq (Hz)
0.6
0.4
0.2
10
15
20
time (s)

Figure 7

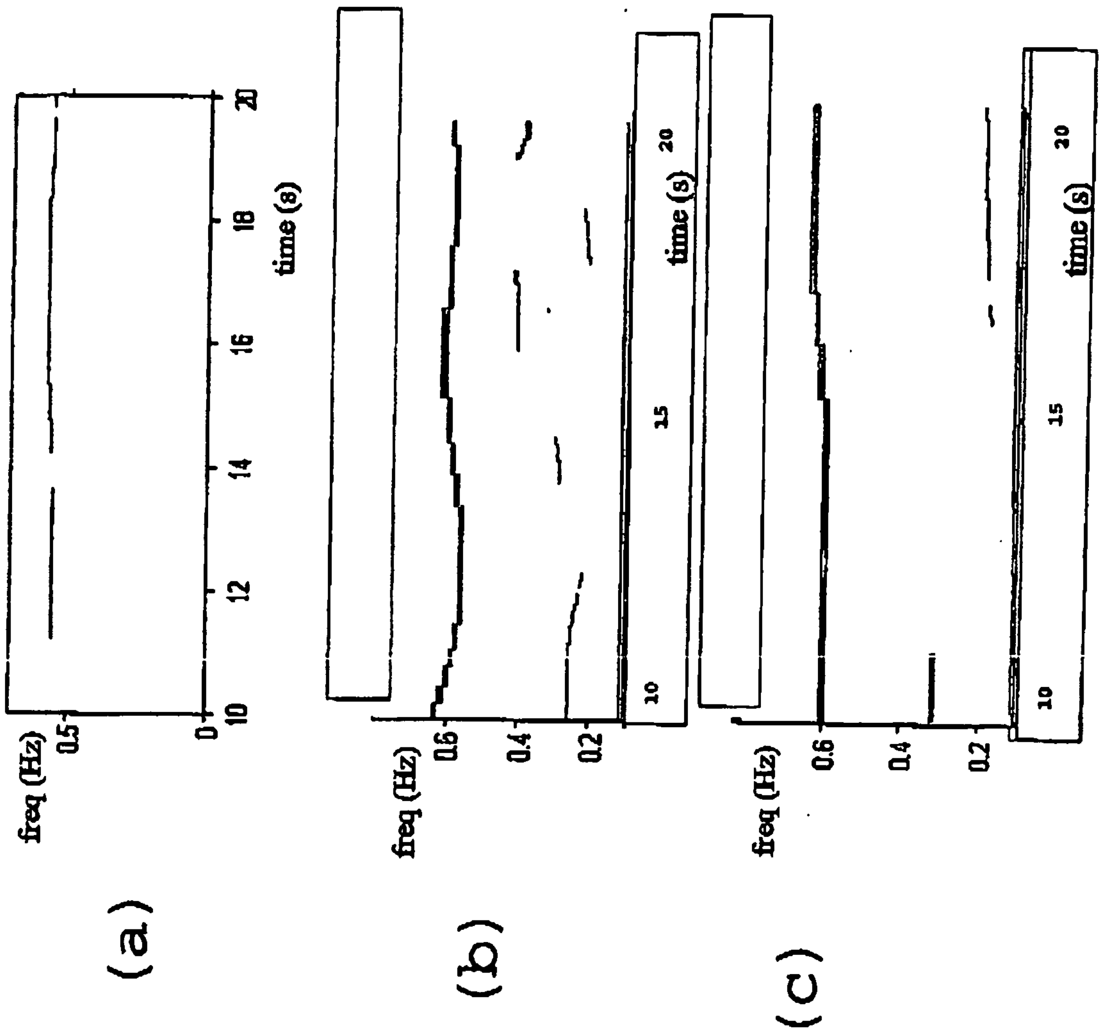

(a)
freq (Hz)
0.5
0
10
12
14
16
18
20
time (s)
(b)
freq (Hz)
0.6
0.4
0.2
10
15
20
time (s)
(c)
freq (Hz)
0.6
0.4
0.2
10
15
20
time (s)

Figure 8

(d)

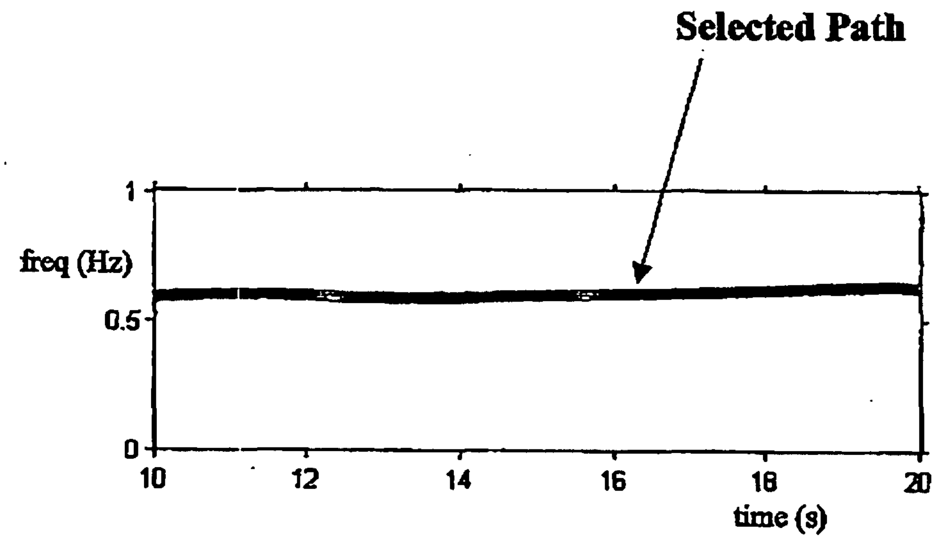


Figure 8 (continued)

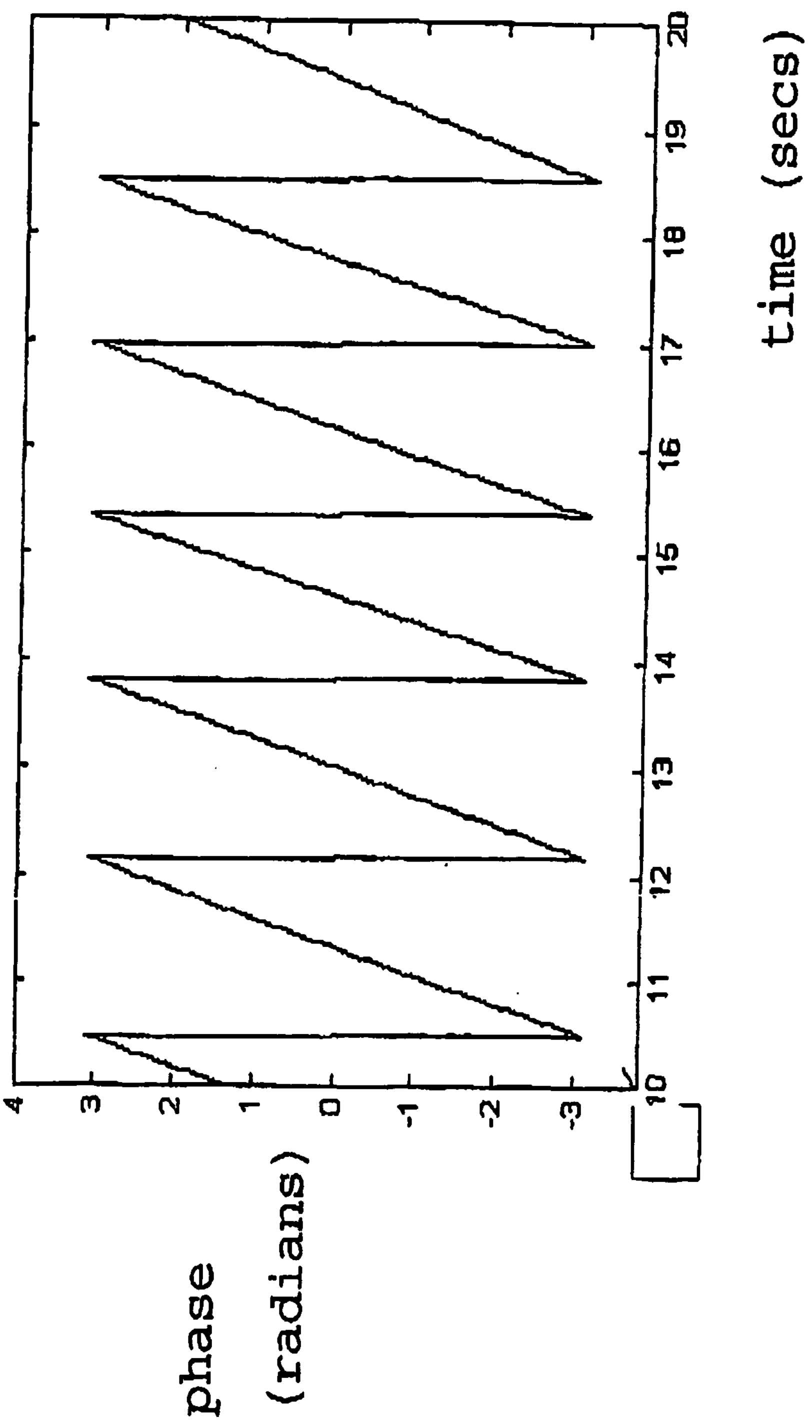

phase
(radians)
4
3
2
1
0
-1
-2
-3
10
11
12
13
14
15
16
17
18
19
20
time (secs)

Figure 9

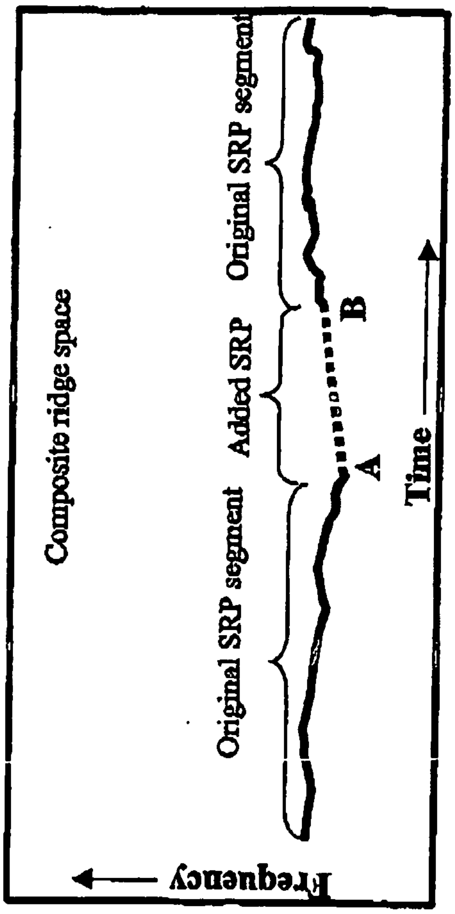

Composite ridge space
Original SRP segment
Added SRP
Original SRP segment
A
B
Time
Frequency

Figure 10

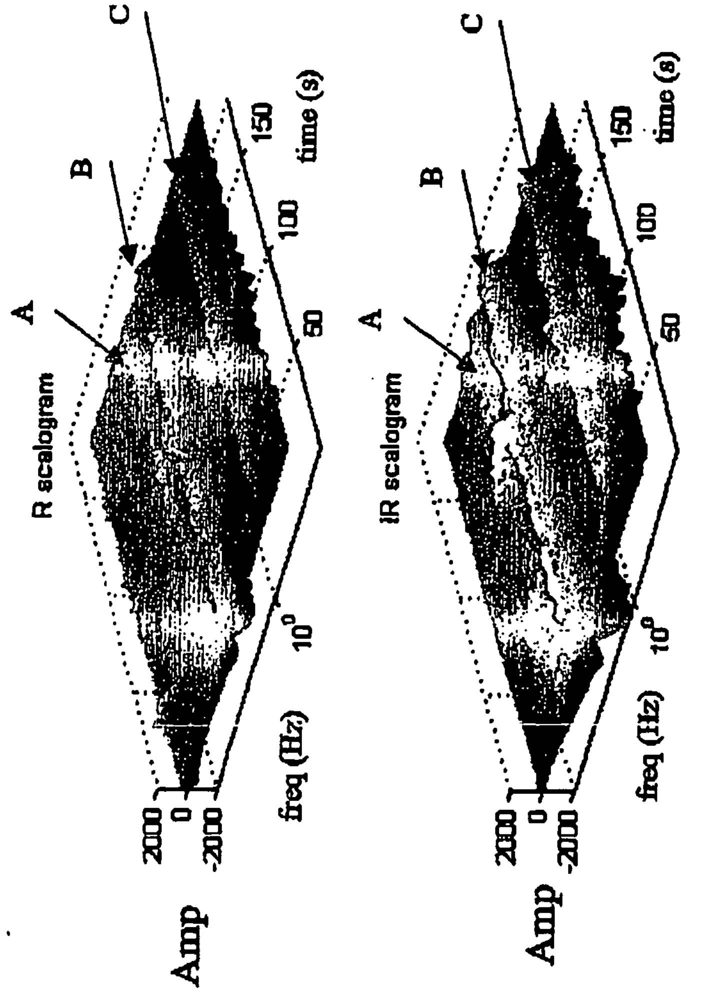

R scalogram
IR scalogram
A
B
C
Amp
2000
0
-2000
freq (Hz)
10^0
50
100
150
time (s)

Figure 11

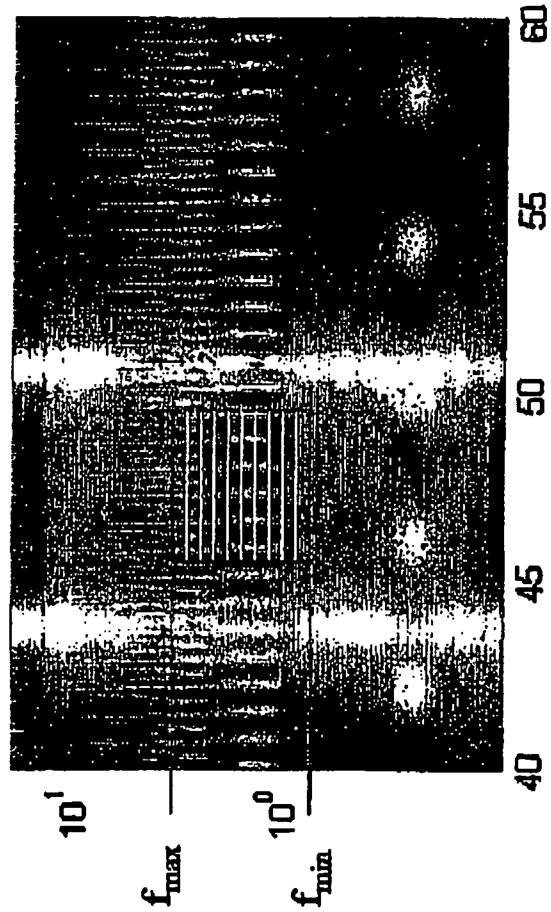


Figure 12

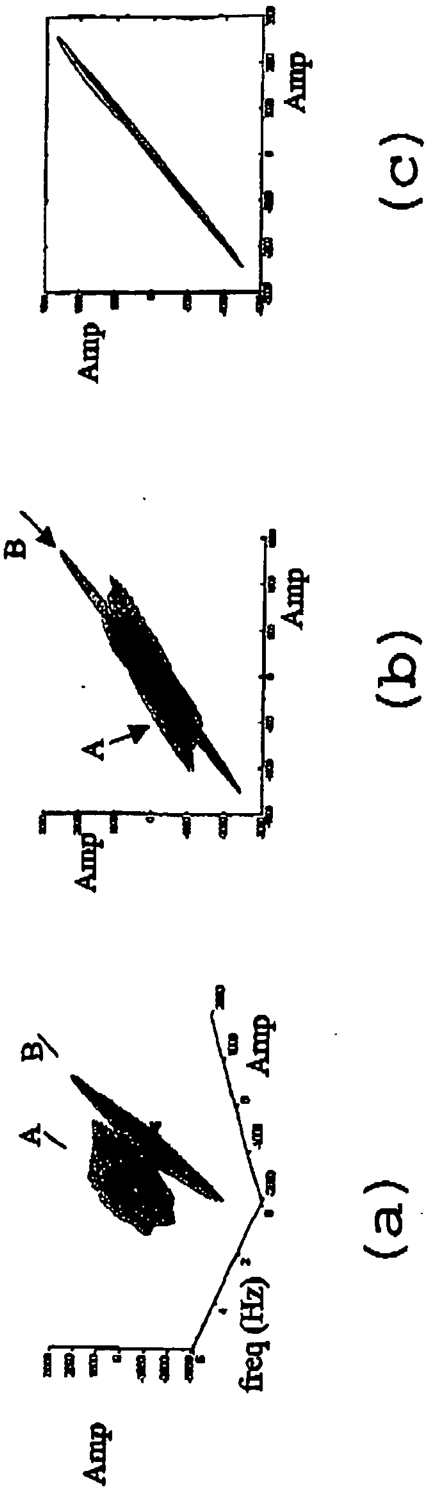


Figure 13

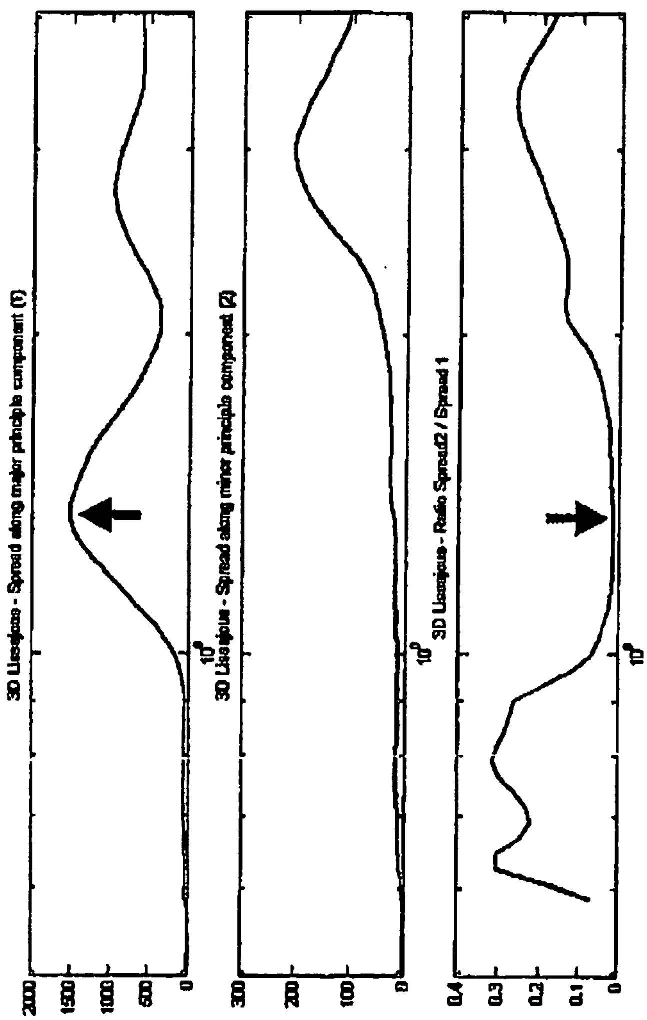

3D Lissajous - Spread along major principle component (1)
2000
1500
1000
500
0
10^0
3D Lissajous - Spread along minor principle component (2)
300
200
100
0
10^0
3D Lissajous - Ratio Spread2 / Spread 1
0.4
0.3
0.2
0.1
0
10^0

Figure 14

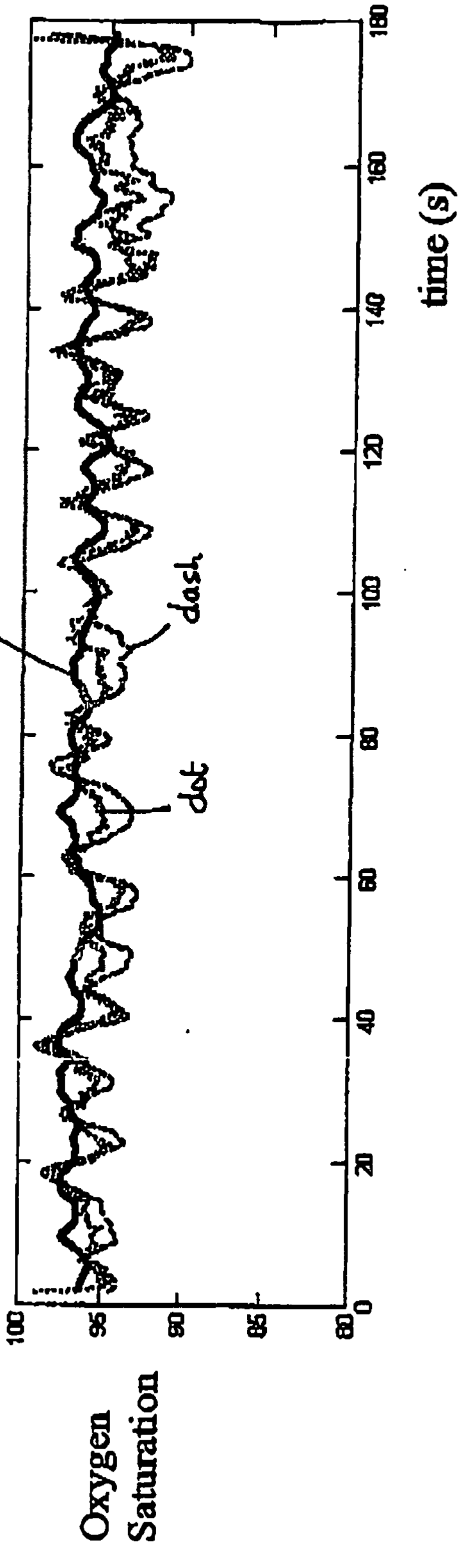

solid
dash
dot
Oxygen Saturation
100
95
90
85
80
0
20
40
60
80
100
120
140
160
180
time (s)

Figure 15

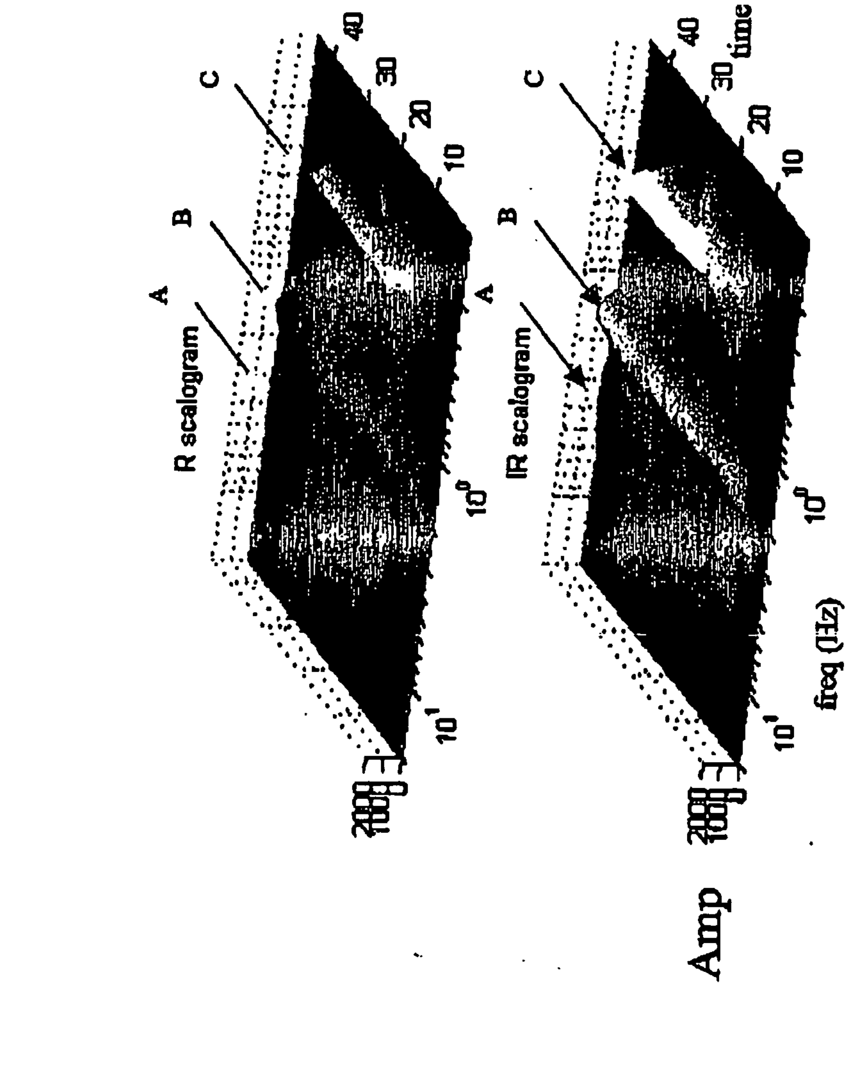


Figure 16

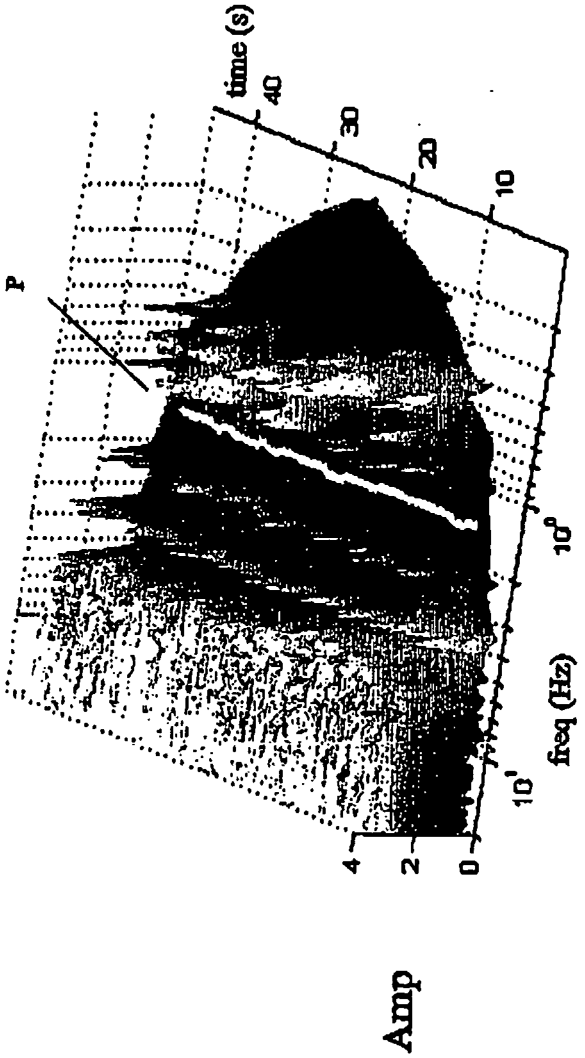


Figure 17

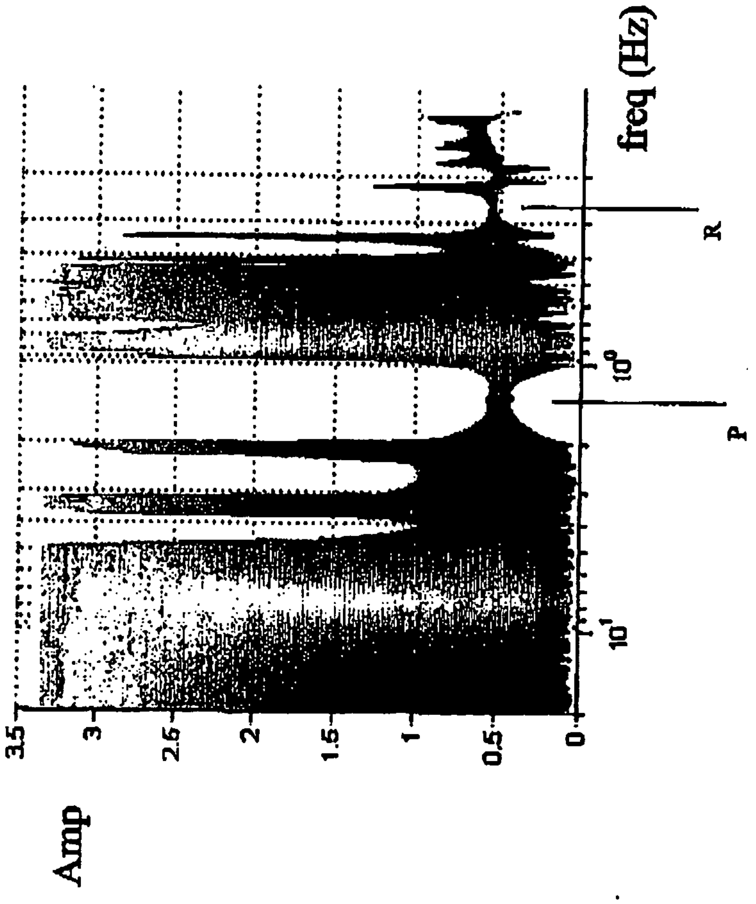
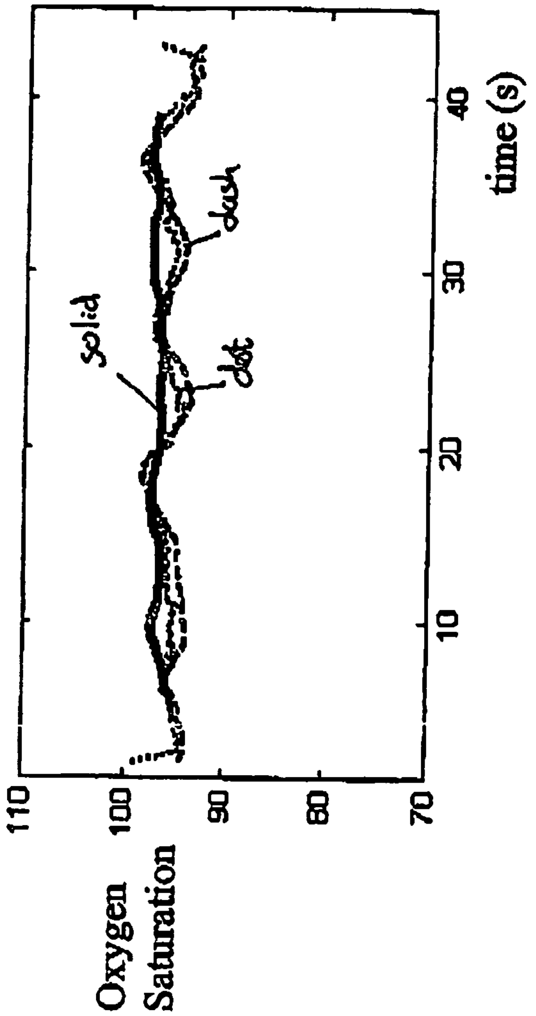
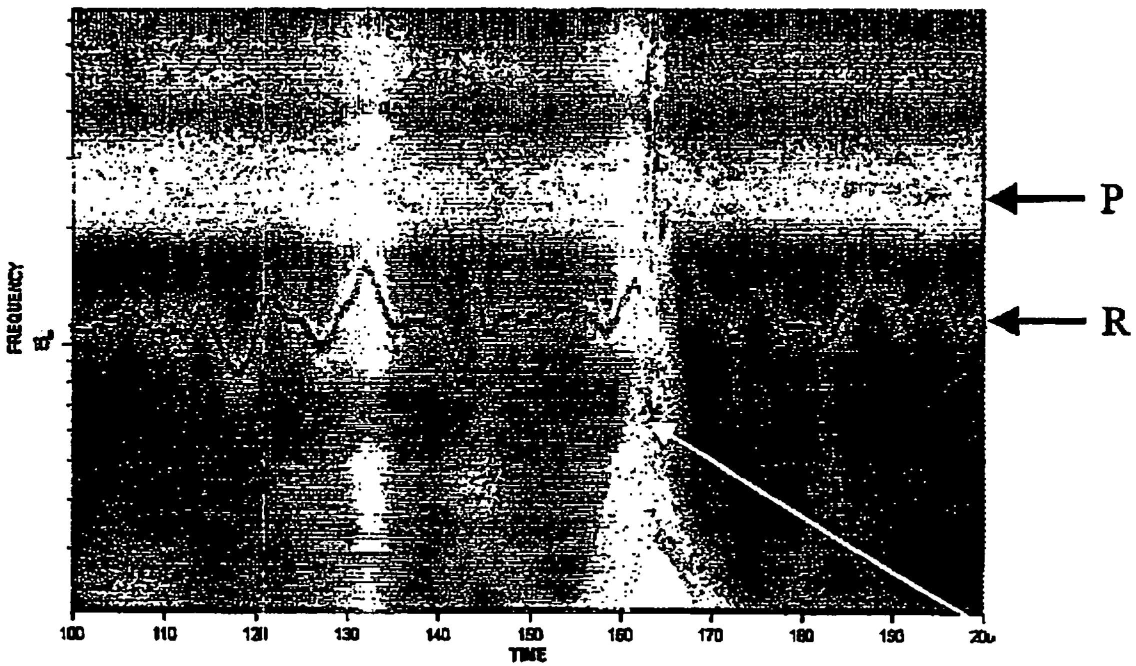


Figure 18



Oxygen Saturation
110
100
90
80
70
10
20
30
40
time (s)
solid
dot
dash

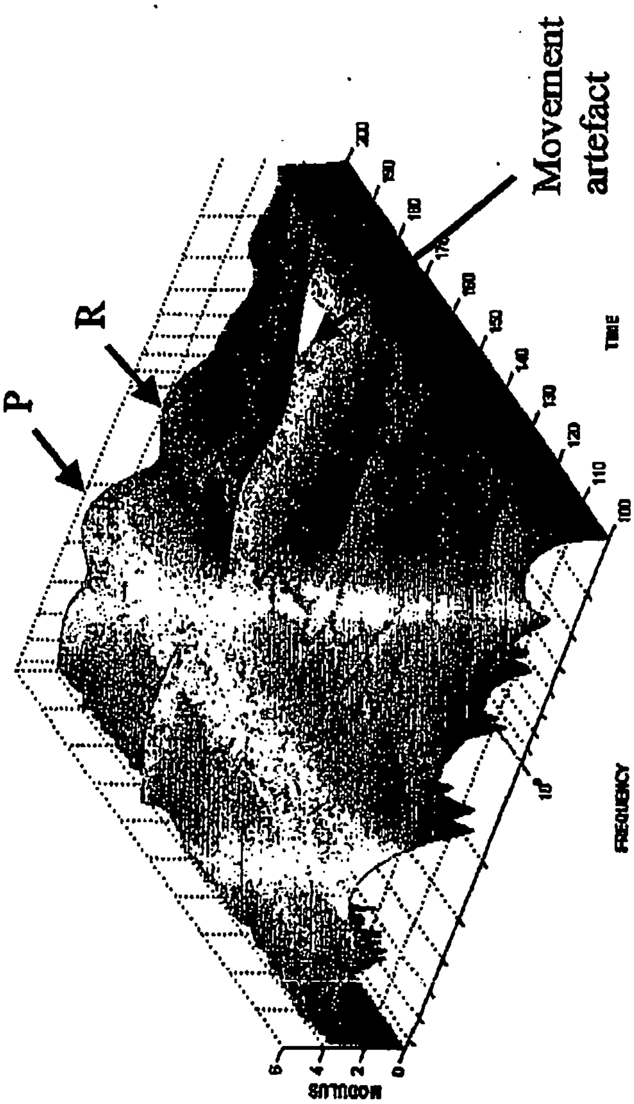
Figure 19



(a)

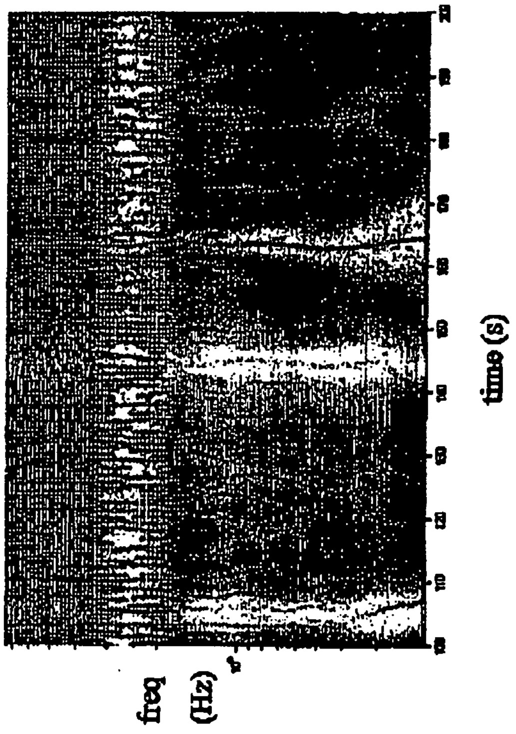
Movement artefact

Figure 20



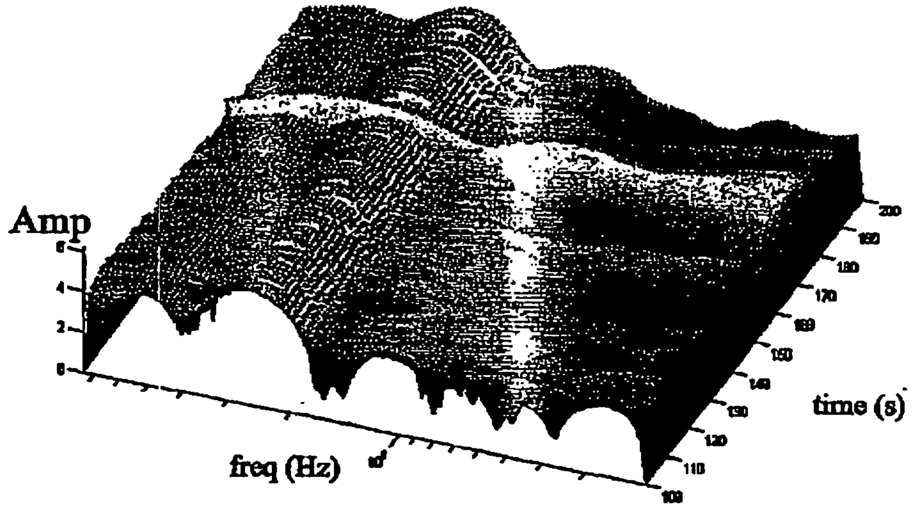
(b)

Figure 20 (continued)



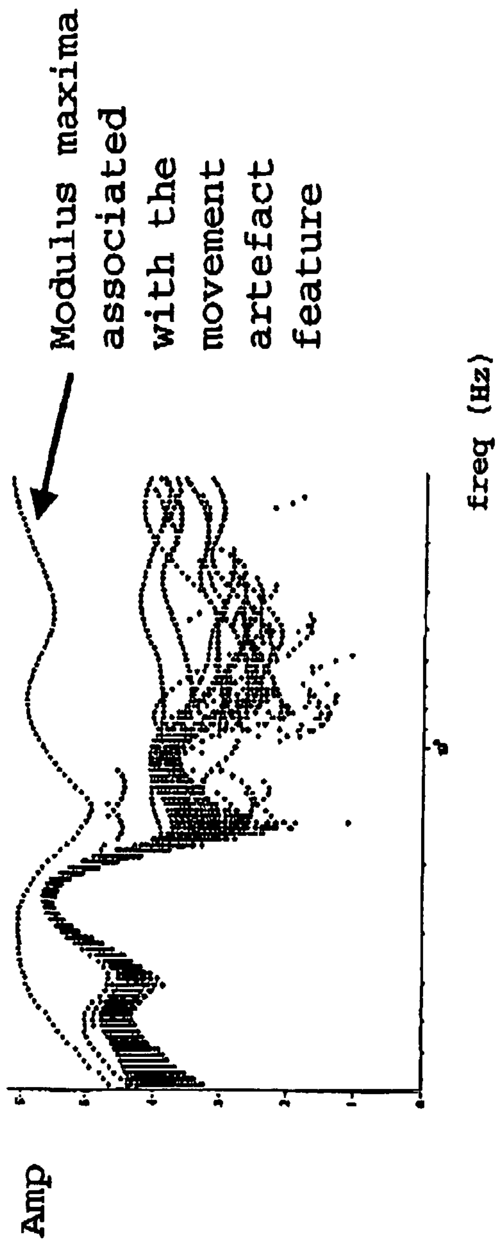
(a)

Figure 21



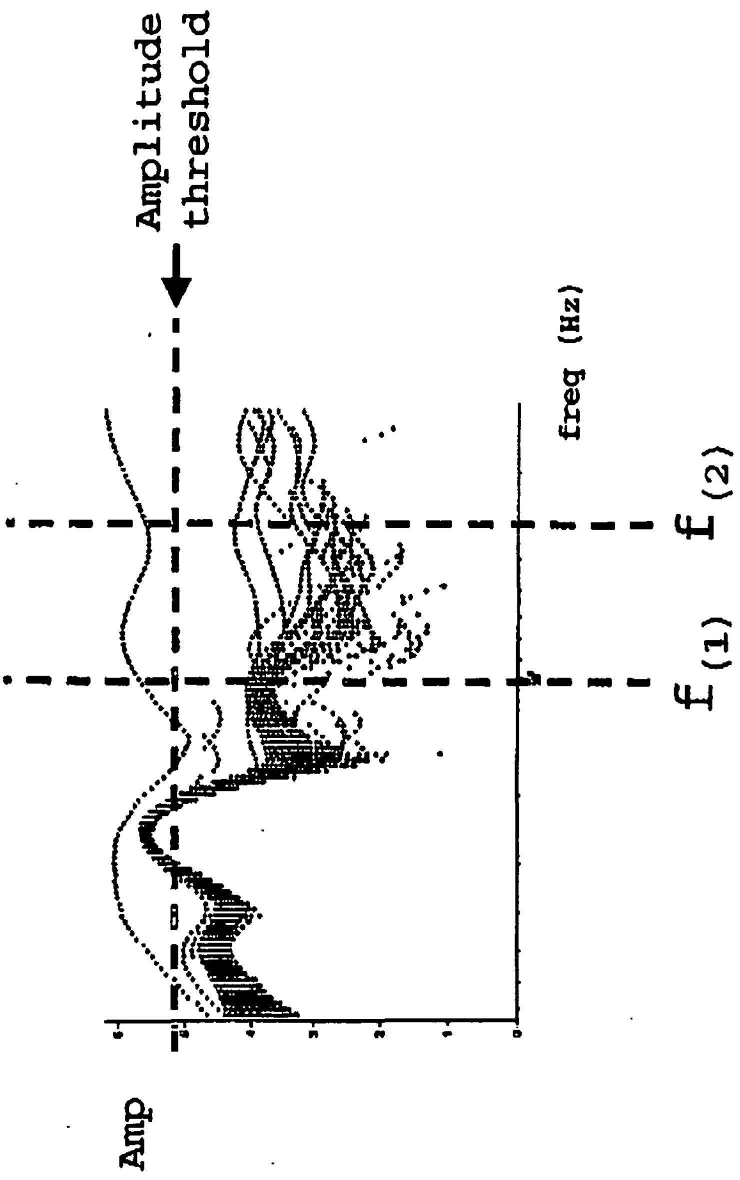
(b)

Figure 21 (continued)


Modulus maxima
associated
with the
movement
artefact
feature
freq (Hz)
Amp

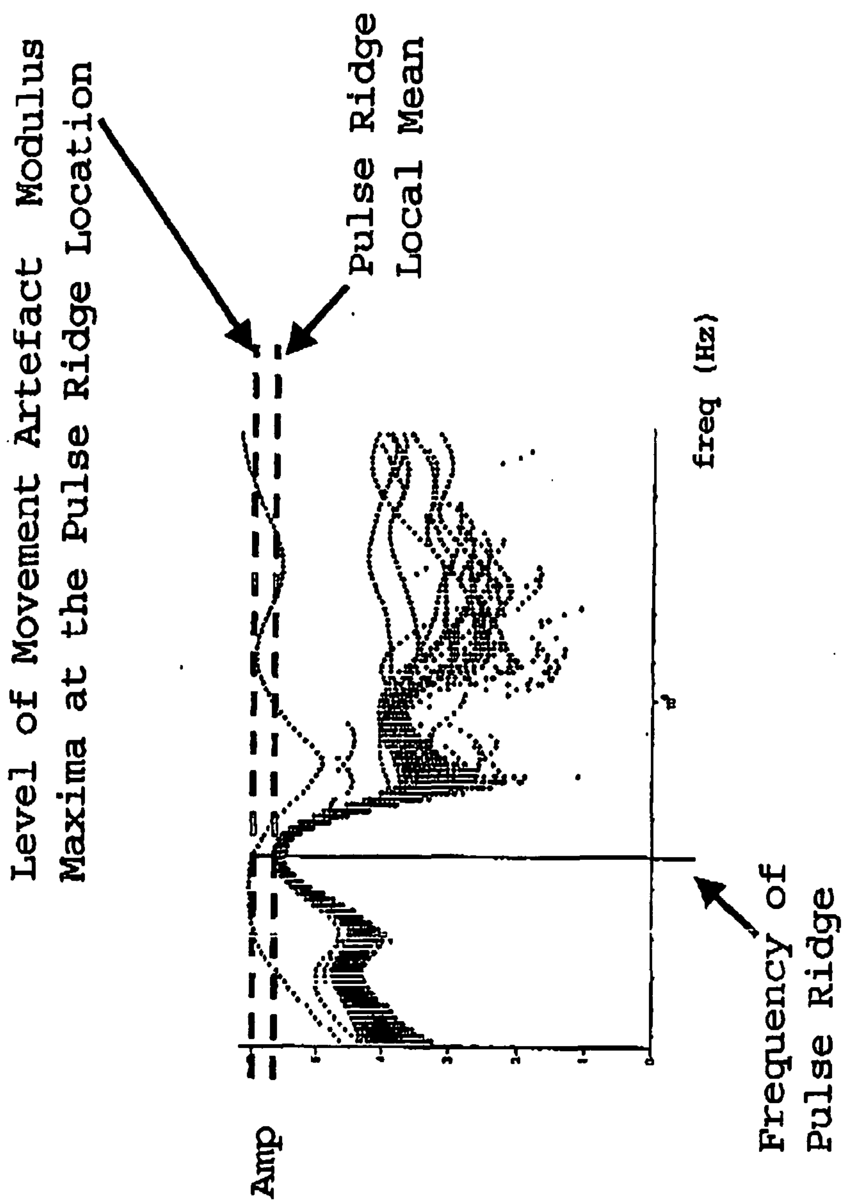
(a)

Figure 22



(b)

Figure 22


Level of Movement Artefact Modulus
Maxima at the Pulse Ridge Location
Pulse Ridge
Local Mean
Amp
freq (Hz)
Frequency of
Pulse Ridge

(C)

Figure 22

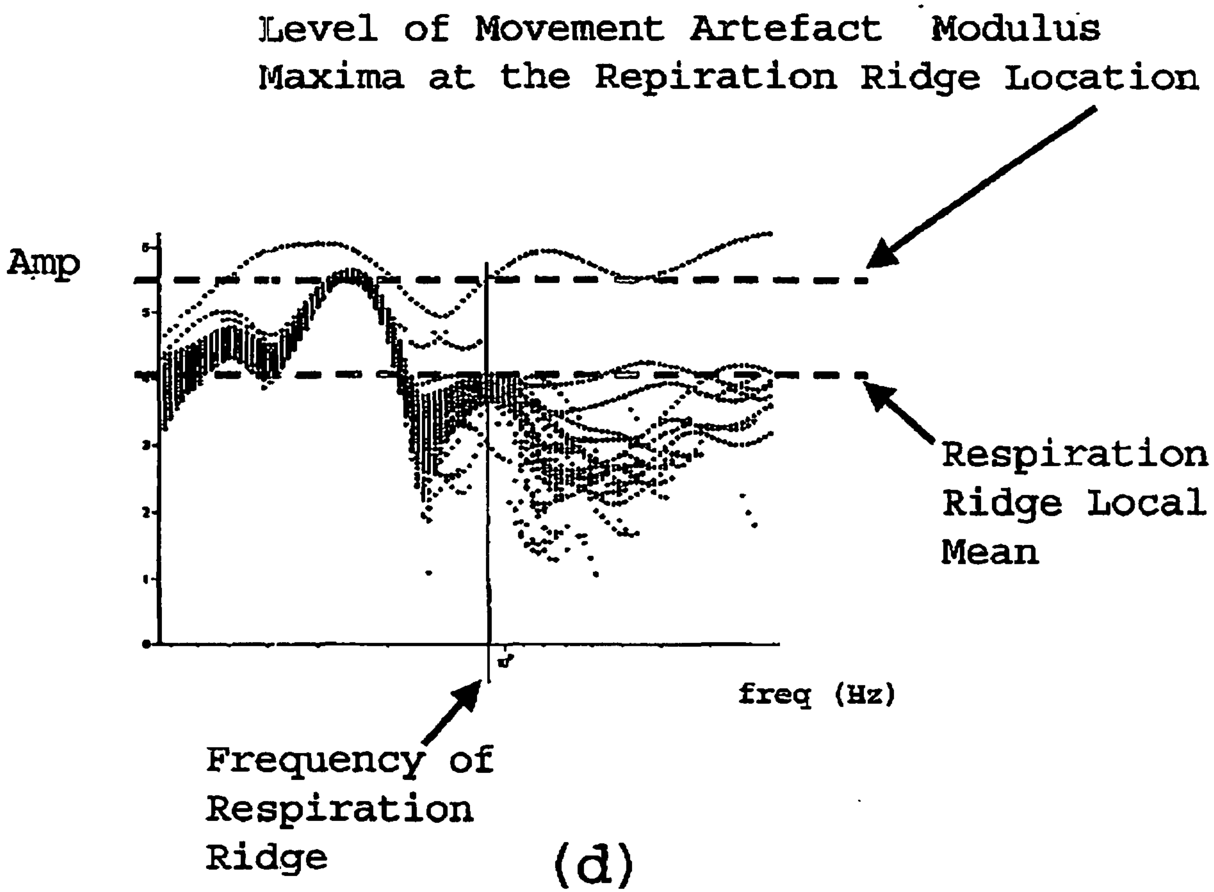

Level of Movement Artefact Modulus
Maxima at the Repiration Ridge Location
Amp
Respiration
Ridge Local
Mean
freq (Hz)
Frequency of
Respiration
Ridge
(d)

Figure 22

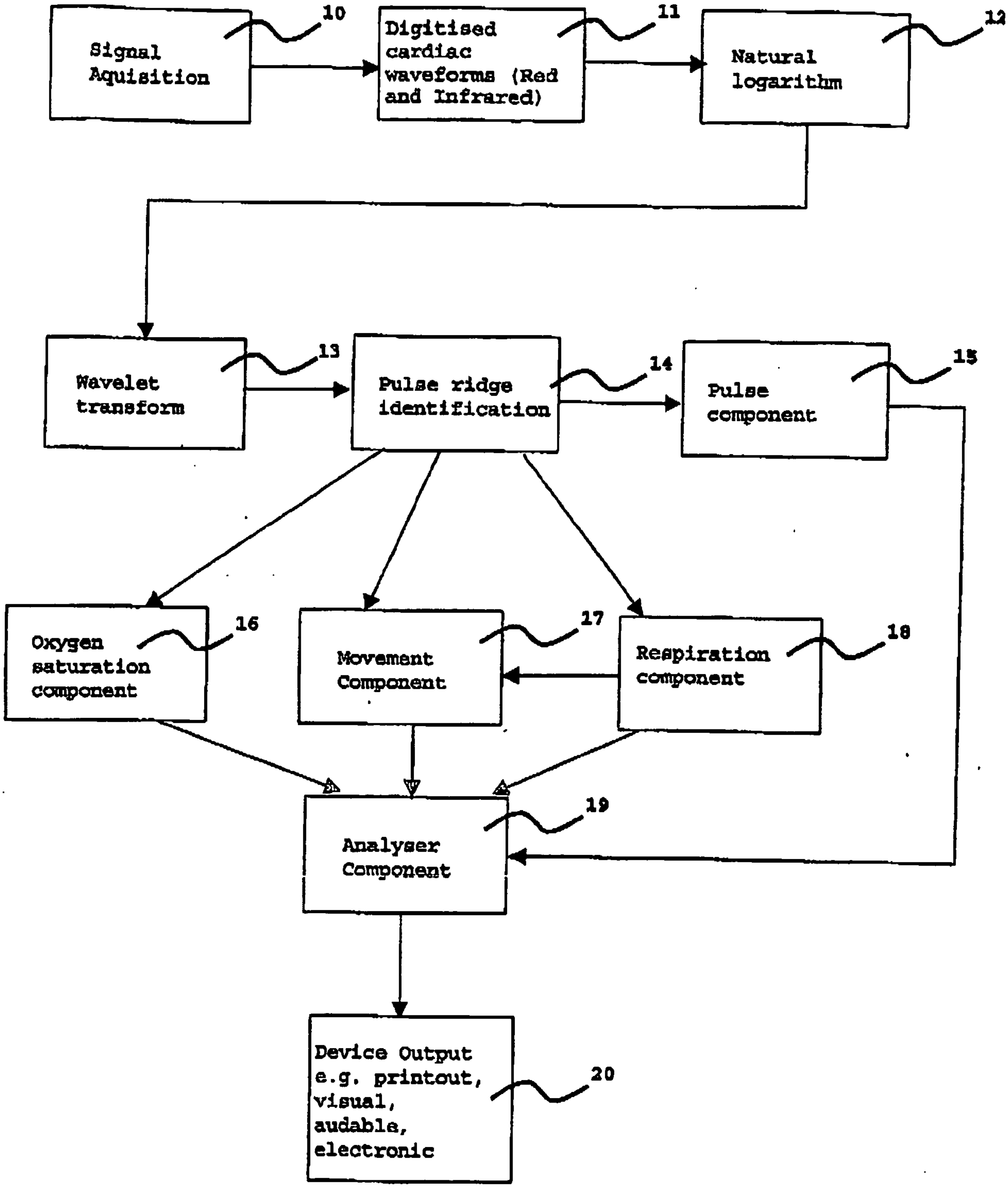

Signal Aquisition
10
Digitised cardiac waveforms (Red and Infrared)
11
Natural logarithm
12
Wavelet transform
13
Pulse ridge identification
14
Pulse component
15
Oxygen saturation component
16
Movement Component
17
Respiration component
18
Analyser Component
19
Device Output e.g. printout, visual, audable, electronic
20

Figure 23

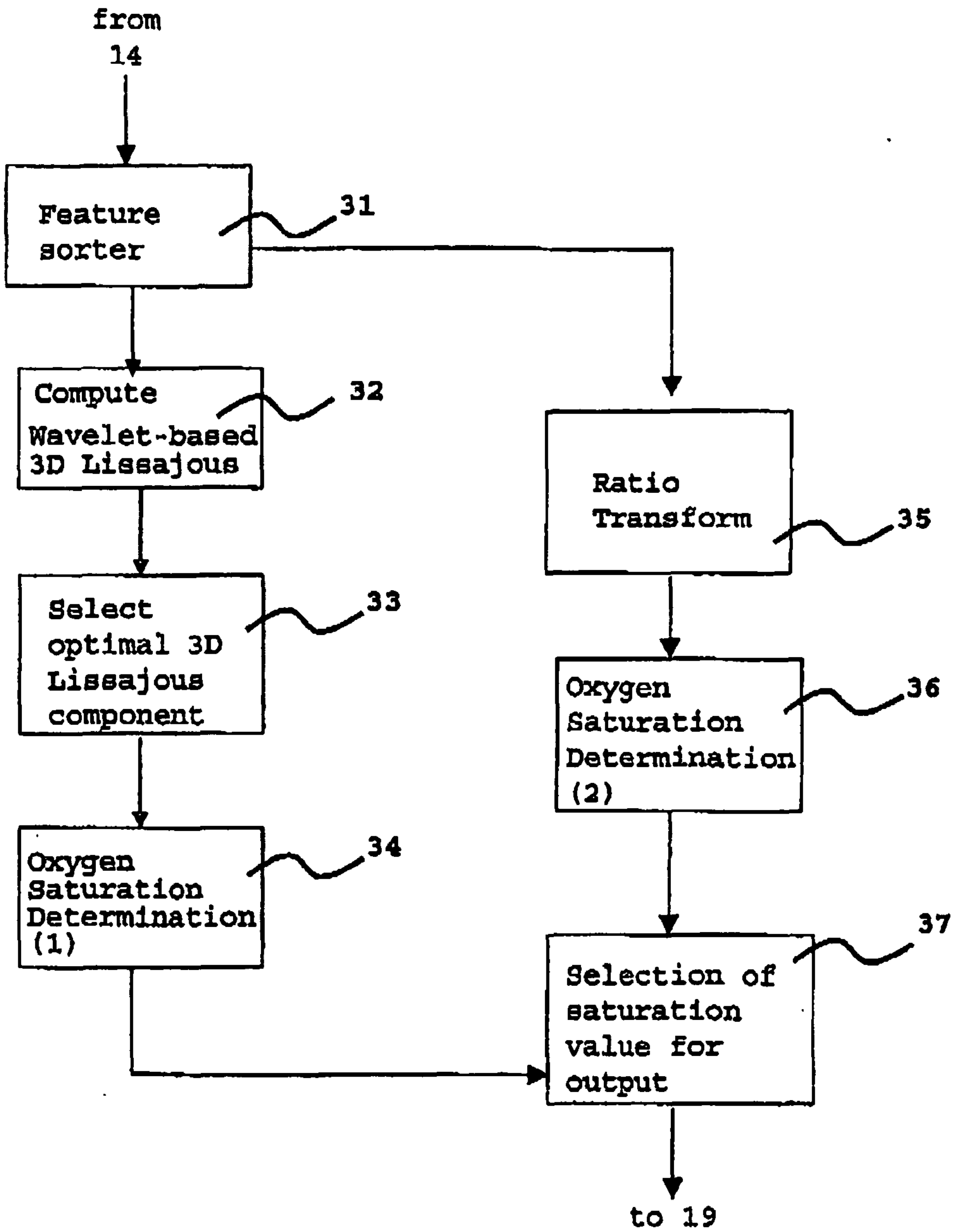

from
14
Feature sorter
31
Compute Wavelet-based 3D Lissajous
32
Select optimal 3D Lissajous component
33
Oxygen Saturation Determination (1)
34
Ratio Transform
35
Oxygen Saturation Determination (2)
36
Selection of saturation value for output
37
to 19

Figure 24

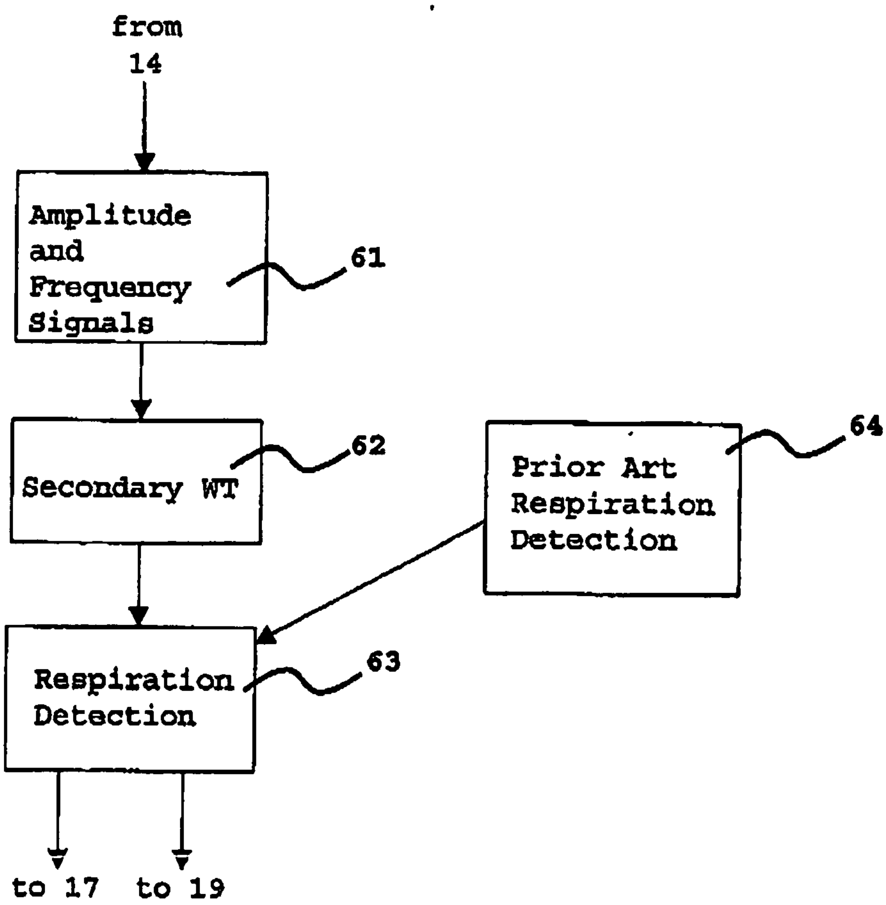

from
14
Amplitude and Frequency Signals
61
Secondary WT
62
Prior Art Respiration Detection
64
Respiration Detection
63
to 17
to 19

Figure 25

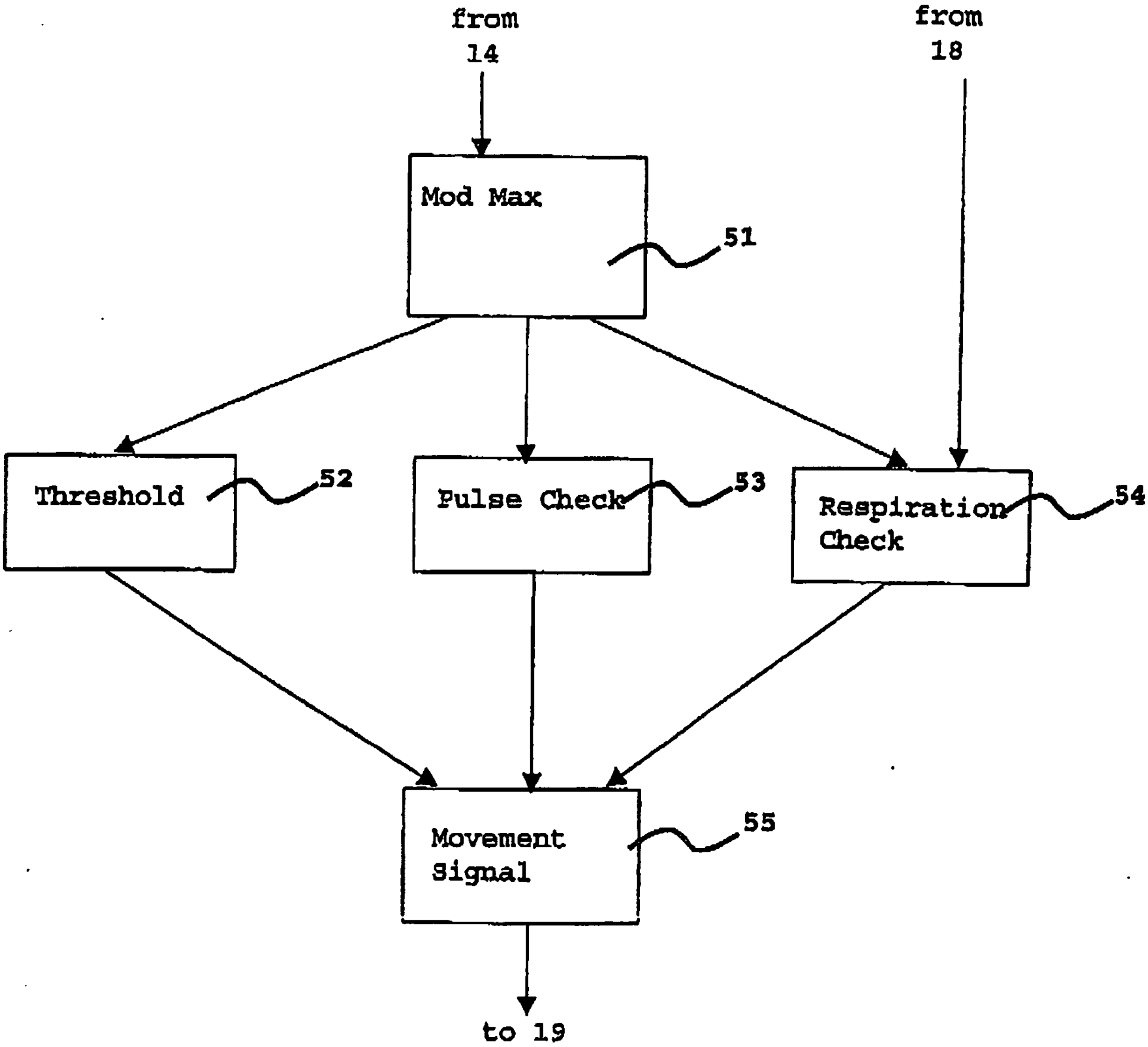
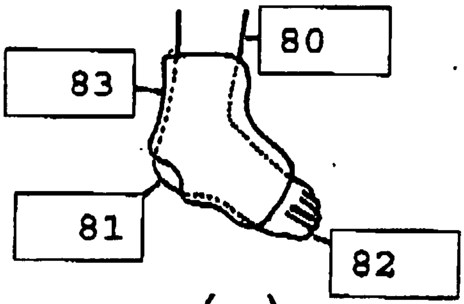
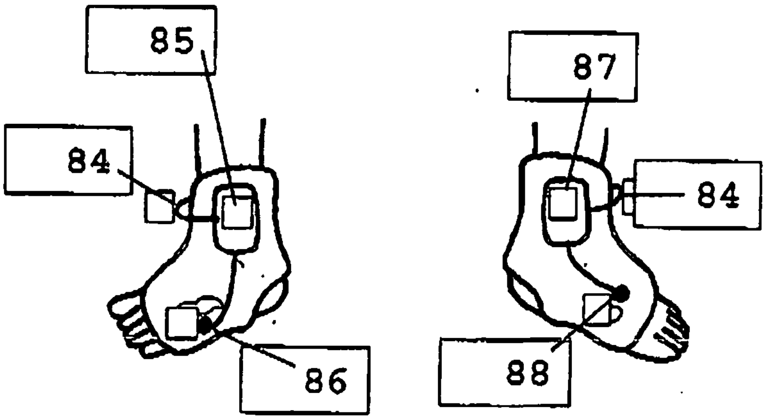

from
14
from
18
Mod Max
51
Threshold
52
Pulse Check
53
Respiration
Check
54
Movement
Signal
55
to 19

Figure 26



(a)



(b)

Figure 27

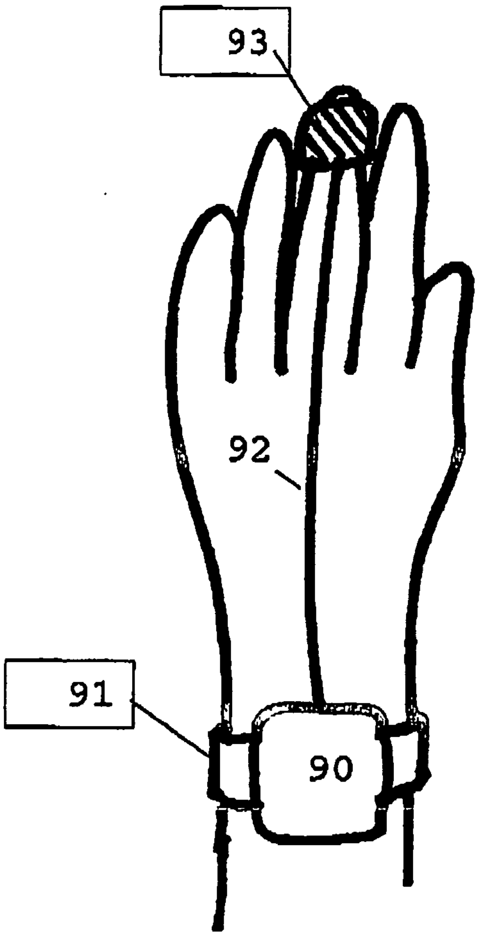


Figure 28

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

- GB 0202843 W, Addison and Watson **[0033]**
- WO 03000125 A **[0033]**

Non-patent literature cited in the description

- **ADDISON P.S.** The Illustrated Wavelet Transform Handbook. Institute of Physics Publishing, 2002 **[0090]**

专利名称(译)	用小波变换分析分析和处理光电容积脉搏波信号		
公开(公告)号	[EP2428159B1](#)	公开(公告)日	2016-04-20
申请号	EP2011006415	申请日	2004-02-27
[标]申请(专利权)人(译)	NELLCOR PURITAN BENNETT爱尔兰		
申请(专利权)人(译)	NELLCOR PURITAN BENNETT爱尔兰		
当前申请(专利权)人(译)	NELLCOR PURITAN BENNETT爱尔兰		
[标]发明人	ADDISON PAUL STANLEY WATSON JAMES NICHOLAS		
发明人	ADDISON, PAUL STANLEY WATSON, JAMES NICHOLAS		
IPC分类号	A61B5/024 A61B5/1455 G01N21/31 A61B5/11 A61B5/00 G06K9/00 G06F17/14 A61B5/08		
CPC分类号	A61B5/726 A61B5/0002 A61B5/0082 A61B5/02416 A61B5/02438 A61B5/0816 A61B5/14551 A61B5/14552 A61B5/4818 A61B5/6826 A61B5/6829 A61B5/6838 A61B5/6896 A61B5/7207 A61B5/7214 A61B5/7278 A61B5/7282 A61B5/742 A61B2503/06 G01N21/3151		
优先权	2003005168 2003-03-07 GB 2003004413 2003-02-27 GB 2004003066 2004-02-12 GB		
其他公开文献	EP2428159A3 EP2428159A2		
外部链接	Espacenet		

摘要(译)

一种测量生理参数的方法，包括：使用信号获取装置获得脉搏血氧测量信号;通过小波变换分析分解脉搏血氧饱和度信号;识别由小波变换分析构造的变换表面上的主带和次带;并解释次要频带以揭示与引起主要频带的生理参数有关的信息。