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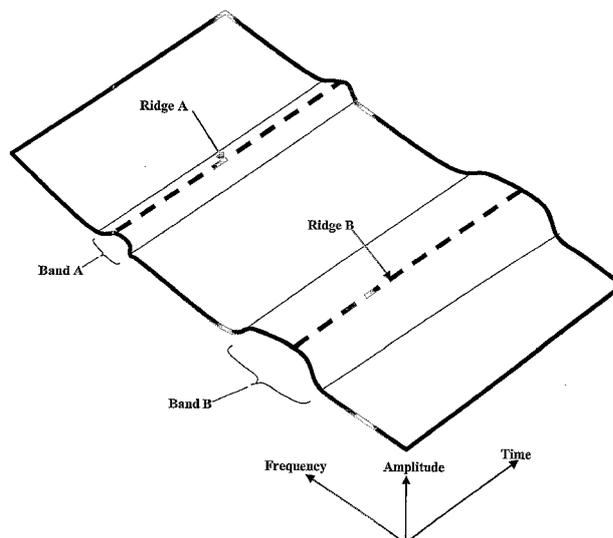
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[Continued on next page]

(54) Title: METHOD OF ANALYSING AND PROCESSING SIGNALS



(57) Abstract: A physiological measurement system is disclosed which can take a pulse oximetry signal such as a photoplethysmogram from a patient and then analyse the signal to measure physiological parameters including respiration, pulse, oxygen saturation and movement. The system can be used as a general monitor, or more specifically, to for infant or adult apnea, and to guard against sudden infant death syndrome. The system comprises a pulse oximeter which includes a light emitting device and a photodetector attachable to a subject to obtain a pulse oximetry signal; analogue to digital converter means arranged to convert said pulse oximetry signal into a digital pulse oximetry signal; signal processing means suitable to receive said digital pulse oximetry signal and arranged to decompose that signal by wavelet transform means; feature extraction means arranged to derive physiological information from the decomposed signal; an analyser component arranged to collect information from the feature extraction means; and data output means arranged in communication with the analyser component.

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1 **METHOD OF ANALYSING AND PROCESSING SIGNALS**

2

3 **1. Introduction: Problem Domain / Field of Invention**

4

5 The present invention relates to a method of
6 analysing and processing signals. More specifically
7 the invention relates to the analysis and processing
8 of photoplethysmogram (PPG) signals. The invention
9 uses wavelet transform methods to derive clinically
10 useful information from the PPG including
11 information regarding the respiration, pulse, oxygen
12 saturation, and patient movement. This information
13 may be used within a device to monitor the patient
14 within a range of environments including the
15 hospital and home environments. In one preferred
16 embodiment the device may be used to detect
17 irregularities in one or more of the derived
18 signals: respiration, pulse, oxygen saturation and
19 movement. The device allows output of this
20 information in a clinically useful form and
21 incorporates an alarm which is triggered when one or
22 a combination of signal irregularities are detected.

1 Of particular note is that the utility of current
2 pulse oximeter devices is greatly increased through
3 the provision of a robust measure of patient
4 respiration directly from the PPG signal.

5

6 **2. Background**

7

8 **2.1 Blood Oxygen Saturation and its Measurement**

9 Oximetry is an optical method for measuring oxygen
10 saturation in blood. Oximetry is based on the
11 ability of different forms of haemoglobin to absorb
12 light of different wavelengths. Oxygenated
13 haemoglobin (HbO₂) absorbs light in the red spectrum
14 and deoxygenated or reduced haemoglobin (RHb)
15 absorbs light in the near-infrared spectrum. When
16 red and infrared light is passed through a blood
17 vessel the transmission of each wavelength is
18 inversely proportional to the concentration of HbO₂
19 and RHb in the blood. Pulse oximeters can
20 differentiate the alternating light input from
21 arterial pulsing from the constant level
22 contribution of the veins and other non-pulsatile
23 elements. Only the alternating light input is
24 selected for analysis. Pulse oximetry has been shown
25 to be a highly accurate technique. Modern pulse
26 oximeter devices aim to measure the actual oxygen
27 saturation of the blood (SaO₂) by interrogating the
28 red and infrared PPG signals. This measurement is
29 denoted SpO₂. The aim of modern device manufacturers
30 is to achieve the best correlation between the pulse
31 oximeter measurement given by the device and the
32 actual blood oxygen saturation of the patient. It is

1 known to those skilled in the art that in current
2 devices a ratio derived from the photoplethysmogram
3 (PPG) signals acquired at the patients body is used
4 to determine the oxygen saturation measurement using
5 a look up table containing a plurality of
6 corresponding ratio and saturation values. Modern
7 pulse oximeter devices also measure patient heart
8 rate. Current devices do not provide a measure of
9 respiration directly from the PPG signal. Additional
10 expensive and obtrusive equipment is necessary to
11 obtain this measurement.

12

13 2.2 Time-Frequency Analysis in Wavelet Space

14 The wavelet transform of a signal $x(t)$ is defined as

15

$$16 \quad T(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t) \psi^* \left(\frac{t-b}{a} \right) dt \quad [1]$$

17

18 where $\psi^*(t)$ is the complex conjugate of the wavelet
19 function $\psi(t)$, a is the dilation parameter of the
20 wavelet and b is the location parameter of the
21 wavelet. The transform given by equation (1) can be
22 used to construct a representation of a signal on a
23 transform surface. The transform may be regarded as
24 a time-scale representation or a time-frequency
25 representation where the characteristic frequency
26 associated with the wavelet is inversely
27 proportional to the scale a . In the following
28 discussion 'time-scale' and 'time-frequency' may be
29 interchanged. The underlying mathematical detail
30 required for the implementation within a time-scale

1 or time-frequency framework can be found in the
2 general literature, e.g. the text by Addison (2002).

3
4 The energy density function of the wavelet
5 transform, the scalogram, is defined as

$$7 \quad S(a,b) = |T(a,b)|^2 \quad [2]$$

8
9 where '| |' is the modulus operator. The scalogram
10 may be rescaled for useful purpose. One common
11 rescaling is defined as

$$13 \quad S_R(a,b) = \frac{|T(a,b)|^2}{a} \quad [3]$$

14
15 and is useful for defining ridges in wavelet space
16 when, for example, the Morlet wavelet is used.
17 Ridges are defined as the locus of points of local
18 maxima in the plane. Any reasonable definition of a
19 ridge may be employed in the method. We also include
20 as a definition of a ridge herein paths displaced
21 from the locus of the local maxima. A ridge
22 associated with only the locus of points of local
23 maxima in the plane we label a 'maxima ridge'. For
24 practical implementation requiring fast numerical
25 computation the wavelet transform may be expressed
26 in Fourier space and the Fast Fourier Transform
27 (FFT) algorithm employed. However, for a real time
28 application the temporal domain convolution
29 expressed by equation (1) may be more appropriate.
30 In the discussion of the technology which follows
31 herein the 'scalogram' may be taken to include

1 all reasonable forms of rescaling including but not
2 limited to the original unscaled wavelet
3 representation, linear rescaling and any power of
4 the modulus of the wavelet transform may be used in
5 the definition.

6
7 As described above the time-scale representation of
8 equation (1) may be converted to a time-frequency
9 representation. To achieve this, we must convert
10 from the wavelet a scale (which can be interpreted
11 as a representative temporal period) to a
12 characteristic frequency of the wavelet function.
13 The characteristic frequency associated with a
14 wavelet of arbitrary a scale is given by

$$16 \quad f = \frac{f_c}{a} \quad [4]$$

17
18 where f_c , the characteristic frequency of the mother
19 wavelet (i.e. at $a=1$), becomes a scaling constant
20 and f is the representative or characteristic
21 frequency for the wavelet at arbitrary scale a .

22
23 Any suitable wavelet function may be used in the
24 method described herein. One of the most commonly
25 used complex wavelets, the Morlet wavelet, is
26 defined as:

$$28 \quad \psi(t) = \pi^{-1/4} \left(e^{i2\pi f_0 t} - e^{-(2\pi f_0)^2/2} \right) e^{-t^2/2} \quad [5]$$

29
30 where f_0 is the central frequency of the mother
31 wavelet. The second term in the brackets is known as

1 the correction term, as it corrects for the non-zero
2 mean of the complex sinusoid within the Gaussian
3 window. In practice it becomes negligible for values
4 of $f_0 \gg 0$ and can be ignored, in which case, the
5 Morlet wavelet can be written in a simpler form as
6

$$7 \quad \psi(t) = \frac{1}{\pi^{1/4}} e^{i2\pi f_0 t} e^{-t^2/2} \quad [6]$$

8
9 This wavelet is simply a complex wave within a
10 Gaussian envelope. We include both definitions of
11 the Morlet wavelet in our discussion here. However,
12 note that the function of equation (6) is not
13 strictly a wavelet as it has a non-zero mean, i.e.
14 the zero frequency term of its corresponding energy
15 spectrum is non-zero and hence it is inadmissible.
16 However, it will be recognised by those skilled in
17 the art that it can be used in practice with $f_0 \gg 0$
18 with minimal error and we include it and other
19 similar near wavelet functions in our definition of
20 a wavelet herein. A more detailed overview of the
21 underlying wavelet theory, including the definition
22 of a wavelet function, can be found in the general
23 literature, e.g. the text by Addison (2002). Herein
24 we show how wavelet transform features may be
25 extracted from the wavelet decomposition of pulse
26 oximeter signals and used to provide a range of
27 clinically useful information within a medical
28 device.

29

30

31 **3. Wavelet Feature Extraction**

1 In this section, methods are described for the
2 extraction and use of wavelet features from the PPG
3 signals for use in the provision of clinically
4 useful information. These are incorporated within a
5 medical device and the information is output in a
6 range of formats for use in the monitoring of the
7 patient. The device comprises four key components
8 for the utilization of the wavelet transform
9 information, these are the Pulse Component,
10 Respiration Monitoring Component, Oxygen Saturation
11 Component and the Movement Component. The underlying
12 theory pertaining to these components is detailed
13 below.

14

15 3.1 Pulse Component

16 Pertinent repeating features in the signal gives
17 rise to a time-frequency band in wavelet space or a
18 rescaled wavelet space. For example the pulse
19 component of a photoplethysmogram (PPG) signal
20 produces a dominant band in wavelet space at or
21 around the pulse frequency. Figure 1(a) and (b)
22 contains two views of a scalogram derived from a PPG
23 signal. The figures show an example of the band
24 caused by the pulse component in such a signal. The
25 pulse band is located between the dashed lines in
26 the plot of figure 1(a). The band is formed from a
27 series of dominant coalescing features across the
28 scalogram. This can be clearly seen as a raised band
29 across the transform surface in figure 1(b) located
30 within a region at just over 1Hz, i.e. 60 breaths
31 per minute. The maxima of this band with respect to
32 frequency is the ridge. The locus of the ridge is

1 shown as a black curve on top of the band in figure
2 1(b). By employing a suitable rescaling of the
3 scalogram, such as that given in equation 3, we can
4 relate the ridges found in wavelet space to the
5 instantaneous frequency of the signal. In this way
6 the pulse frequency (pulse rate) may be obtained
7 from the PPG signal. Instead of rescaling the
8 scalogram, a suitable predefined relationship
9 between the frequency obtained from the ridge on the
10 wavelet surface and the actual pulse frequency may
11 also be used to determine the pulse rate.

12

13 By mapping the time-frequency coordinates of the
14 pulse ridge onto the wavelet phase information
15 gained through the wavelet transform, individual
16 pulses may be captured. In this way both times
17 between individual pulses and the timing of
18 components within each pulse can be monitored and
19 used to detect heart beat anomalies, measure
20 arterial system compliance, etc. Alternative
21 definitions of a ridge may be employed. Alternative
22 relationships between the ridge and the pulse
23 frequency may be employed.

24

25 **3.2 Respiration Monitoring Component**

26 The respiration monitoring component uses wavelet
27 based methods for the monitoring of patient
28 respiration. This can include the measurement of
29 breathing rate and the identification of abnormal
30 breathing patterns including the cessation of
31 breathing. A key part of the respiration monitoring
32 component is the use of secondary wavelet feature

1 decoupling (SWFD) described below. The information
2 concerning respiration gained from the application
3 of SWFD can then be compared and/or combined with
4 respiration information from other methods to
5 provide a respiration measure output.

6
7 As stated above, pertinent repeating features in the
8 signal give rise to a time-frequency band in wavelet
9 space or a rescaled wavelet space. For a periodic
10 signal this band remains at a constant frequency
11 level in the time frequency plane. For many real
12 signals, especially biological signals, the band may
13 be non-stationary; varying in characteristic
14 frequency and/or amplitude over time. Figure 2 shows
15 a schematic of a wavelet transform of a signal
16 containing two pertinent components leading to two
17 bands in the transform space. These bands are
18 labeled band A and band B on the three-dimensional
19 (3-D) schematic of the wavelet surface. We define
20 the band ridge as the locus of the peak values of
21 these bands with respect to frequency. For the
22 purposes of the discussion of the method we assume
23 that band B contains the signal information of
24 interest. We will call this the 'primary band'. In
25 addition, we assume that the system from which the
26 signal originates, and from which the transform is
27 subsequently derived, exhibits some form of coupling
28 between the signal components in band A and band B.
29
30 When noise or other erroneous features are present
31 in the signal with similar spectral characteristics
32 of the features of band B then the information

1 within band B can become ambiguous, i.e. obscured,
2 fragmented or missing. In this case the ridge of
3 band A can be followed in wavelet space and
4 extracted either as an amplitude signal or a
5 frequency signal which we call the '*ridge amplitude*
6 *perturbation (RAP) signal*' and the '*ridge frequency*
7 *perturbation (RFP) signal*' respectively. The RAP and
8 RFP signals are extracted by projecting the ridge
9 onto the time-amplitude or time-frequency planes
10 respectively. The top plots of figure 3 shows a
11 schematic of the RAP and RFP signals associated with
12 ridge A in figure 2. Below these RAP and RFP signals
13 we can see schematics of a further wavelet
14 decomposition of these newly derived signals. This
15 secondary wavelet decomposition allows for
16 information in the spectral region of band B in
17 figure 2 to be made available as band C and band D.
18 The ridges of bands C and D can serve as
19 instantaneous time-frequency characteristic measures
20 of the signal components causing bands C and D. This
21 method, which we call Secondary Wavelet Feature
22 Decoupling (SWFD), therefore allows information
23 concerning the nature of the signal components
24 associated with the underlying physical process
25 causing the primary band B (figure 2) to be
26 extracted when band B itself is obscured in the
27 presence of noise or other erroneous signal
28 features.

29

30 An example of the SWFD method used on a PPG signal
31 to detect patient breathing from the ridge
32 associated with patient pulse is shown in figures 4

1 and 5. During the experiment from which the signal
2 was taken the patient was breathing regularly at
3 breaths of 6 seconds duration (= 0.167Hz).

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

30

31 Figure 4(c) contains the RAP signal derived from the
32 pulse ridge shown in figure 4(b) where the pulse

1 ridge is followed and its amplitude is plotted
2 against time. The top plot of figure 4(c) contains
3 the whole RAP signal. The lower plot of figure 4(c)
4 contains a blow up of the RAP signal over a 50
5 seconds interval. An obvious modulation with a
6 period of 6 seconds can be seen in this blow up. The
7 top plot of figure 4(d) contains the whole RFP
8 signal corresponding to the pulse ridge in figure
9 4(b). The lower plot of figure 4(d) contains a blow
10 up of the RFP signal over 50 seconds. Again an
11 obvious modulation (of 6 second period) can be seen
12 in this blow up.

13

14 A second wavelet transform was then performed on the
15 RAP and RFP signals. The resulting scalograms
16 corresponding to the RAP and RFP signals are shown
17 in figures 5a and 5b respectively and the 3-D plots
18 of these scalograms are shown in figures 5c and 5d
19 respectively. The breathing ridges derived from the
20 RAP and RFP scalograms are superimposed on the 3-D
21 scalograms. The RAP scalogram is the cleaner of the
22 two and can be seen not to contain interference from
23 the artefact feature 'F' found in the original
24 signal scalogram of figure 4(a). For this example
25 the RAP scalogram provides the best solution for the
26 removal of erroneous signal features and the
27 identification of the breathing band when compared
28 to the original scalogram and the RFP scalogram. In
29 practice all three scalograms are compared and the
30 optimal scalogram or combination of scalograms for
31 the extraction of the information required is
32 determined.

1
2 Through experimentation covering a variety of
3 patient groups (e.g. adult, child, neonate) we have
4 found that for certain signals the method can be
5 enhanced by incorporating paths displaced from the
6 band ridge in the SWFD method. In these cases the
7 RAP signals derived from the displaced path exhibits
8 much larger oscillations (compared to the low
9 frequency background waveform) than those of the
10 original ridge path. We find that this enhancement
11 allows us to better detect the breathing component
12 within the SWFD method. Hence we extend our
13 definition of a surface ridge as employed in the
14 method to include paths displaced from the locus of
15 the peak values, contours at a selected level of the
16 pulse band, and in general any reasonably
17 constructed path within the vicinity of the
18 pertinent feature under investigation, where the
19 vicinity is taken to be within the region of the
20 corresponding band.

21
22 From the above example it can be seen how a
23 secondary wavelet transform of wavelet transform
24 ridge information derived from the pulse band ridge
25 may be used to provide a clearer manifestation of
26 the breathing features in wavelet space from which
27 pertinent breathing information may be derived.

28
29 The SWFD method described above can form the basis
30 of completely new algorithms for incorporation
31 within devices which require the detection of
32 otherwise masked signal components. Herein, we show

1 the application of the method to the detection of
2 breathing features from within the
3 photoplethysmogram, although it will be recognised
4 by those skilled in the art that the method may be
5 applied to other problematic signals.

6

7 In practice, both the original direct observation of
8 the primary band and the indirect observation
9 through perturbations to the secondary band may be
10 employed simultaneously and the optimal time-
11 frequency information extracted.

12

13 Those skilled in the art will recognise that
14 modifications and improvements can be incorporated
15 within the methodology outlined herein without
16 departing from the scope of the invention.

17

18 Those skilled in the art will recognise that the
19 above methods may be performed using alternative
20 time-frequency representations of the signals where
21 the amplitude in the time-frequency transform space
22 can be related to the amplitude of pertinent
23 features within the signal. In addition the
24 decomposition of the original signal and the
25 subsequent decompositions of the RFP and RAP
26 scalograms may be performed, each with a different
27 time-frequency method. However, in the preferred
28 method the continuous wavelet transform is employed
29 in all decompositions, although different wavelet
30 functions may be employed in each of the wavelet
31 transforms employed in the method.

32

1 The preferred method detailed herein departs from
2 alternate methods to probe the time-frequency
3 information within wavelet space which follow paths
4 of constant frequency in wavelet space. The current
5 method involves following a selected path in wavelet
6 space from which new signals are derived. This
7 allows signal components with non-stationary
8 frequency characteristics to be followed and
9 analysed to provide information of other signal
10 components which may also exhibit non-stationary
11 behaviour.

12

13 It will be obvious to those skilled in the art that
14 the method relies on high resolution in wavelet
15 space hence the continuous wavelet transform is the
16 preferred method. (The time-frequency discretisation
17 employed by the discrete wavelet transform and the
18 stationary wavelet transform is, in general, too
19 coarse for the useful application of the method.)
20 The continuous wavelet transform is implemented in
21 the method through a fine discretisation in both
22 time and frequency.

23

24 Although the method herein has been described in the
25 context of the detection of breathing features from
26 the pulse band of the wavelet transform of the
27 photoplethysmogram, those skilled in the art will
28 recognise that the method has wide applicability to
29 other signals including, but not limited to: other
30 biosignals (e.g. the electrocardiogram,
31 electroencephalogram, electrogastrogram,
32 electromyogram, heart rate signals, pathological

1 sounds, and ultrasound), dynamic signals, non-
2 destructive testing signals, condition monitoring
3 signals, fluid signals, geophysical signals,
4 astronomical signals, electrical signals, financial
5 signals including financial indices, sound and
6 speech signals, chemical signals, and meteorological
7 signals including climate signals.

8

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

14

15 (a) A wavelet transform decomposition of the
16 signal is made.

17 (b) The transform surface is inspected in the
18 vicinity of the characteristic frequency of the
19 pertinent signal feature to detect the dominant
20 band (the primary band) associated with the
21 pertinent feature. This band is then
22 interrogated to reveal information
23 corresponding to the pertinent feature. This
24 interrogation may include ridge following
25 methods for identification of localised
26 frequencies in the time-frequency plane.

27 (c) A secondary band is then identified
28 outwith the region of the pertinent feature and
29 its ridge identified.

30 (d) The time-frequency and time-amplitude
31 locus of points on the secondary ridge are then
32 extracted. These new signals are denoted the

1 `ridge amplitude perturbation (RAP) signal' and
2 the `ridge frequency perturbation (RFP) signal'
3 respectively.

4 (e) A wavelet transformation of the RAP and
5 RFP signals is then carried out to give the RAP
6 and RFP scalograms respectively.

7 (f) These secondary scalograms are then
8 interrogated to reveal information in the
9 region of the primary band of the original
10 scalogram. This interrogation may include ridge
11 following methods for identification of
12 localised frequencies in the time-frequency
13 plane.

14 (g) The information gained from step (b) and
15 step (f) are then used to provide the optimal
16 signal information pertaining to the signal
17 feature or features under investigation.

18

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

22

23 In the context of breathing detection from the
24 photoplethysmogram the `primary band' referred to in
25 the above is the breathing band and the `secondary
26 band' is the pulse band. In the method one or more
27 or a combination of PPG signals may be employed.

28

29 In an alternative methodology once the RAP and RFP
30 signals have been abstracted in step (d) these are
31 then interrogated over short segments using an
32 alternative time-frequency or frequency based method

1 (e.g. using a standard FFT routine to find a
2 dominant peak associated with the primary band
3 signal) or another method of signal repetition
4 including, but not limited to, turning points of the
5 signal. This may be employed to speed up the
6 computation of the characteristic frequency of the
7 RAP and RFP scalogram bands or to enhance the
8 technique.

9
10 In step (d) above a combination of the RAP and RFP
11 signals may also be used to generate a
12 representative signal for secondary wavelet
13 decomposition.

14
15 Patient respiration information from the secondary
16 wavelet feature decoupling incorporating the RAP and
17 RFP signals is used directly to monitor patient
18 respiration. This can include the measurement of
19 breathing rate and the identification of abnormal
20 breathing patterns including the cessation of
21 breathing. Either the RAP-based SWFD or the RFP-
22 based SWFD information may be chosen for patient
23 respiration monitoring. Alternatively a combination
24 of both may be employed where the respiration
25 information derived from each method may be graded
26 quantitatively according to a confidence measure.

27
28 Further the respiration information gained from the
29 RAP-based SWFD and the RFP-based SWFD may be
30 compared to and/or combined with respiration
31 information gained from other methods to provide an
32 optimal output for respiration measures including

1 respiration rate, breath timings, breathing
2 anomalies, etc. These other methods may include that
3 described in International Patent Application No
4 PCT/GB02/02843 , "Wavelet-based Analysis of Pulse
5 Oximetry Signals" by Addison and Watson. The chosen
6 respiration measure for output will be extracted
7 using a polling mechanism based on a quantitative
8 measure of the quality of the respiration
9 information derived by each method.

10

11 Figures 6 to 10 illustrate the preferred embodiment
12 of the respiration monitoring methodology. The
13 wavelet transform of the PPG signal (figure 6(a)) is
14 computed. A plot of the resulting scalogram is shown
15 in figure 6(b). The 10 second PPG signal used in
16 this example was taken from a premature neonate. The
17 same methodology also works for adult and child
18 PPGs. The pulse ridge is shown plotted as a black
19 path across the scalogram in figure 6(b) at around
20 2.5Hz - typical for these young patients. The RAP
21 and RFP signals are then derived from the pulse
22 ridge of the wavelet transform. The RAP and RFP
23 signals are shown respectively in figure 6(c) and
24 figure 6(d). Also shown in figure 6(c) is the
25 patient switch signal which shows inspiration and
26 expiration of the patient as a high /low amplitude
27 square wave trace. The switch signal was activated
28 by an observer monitoring the movement of the chest
29 wall of the neonate during the experiment. The
30 turning points in the RAP and RFP signals may be
31 used as an initial detection mechanism for
32 individual breaths. The RFP and RAP signals are

1 assessed for quality using a confidence measure.
2 This measure may be based on any reasonable measure
3 including but not limited to the entropy of the
4 signals. The signal with the highest confidence is
5 used to extract information on individual breaths
6 and a breathing rate using the average duration of a
7 number of recently detected breaths. A second
8 wavelet transform is performed on both signals. The
9 result of a second wavelet transform on the RAP
10 signal of figure 6(c) is shown in figure 7(a) and
11 the ridges of this transform surface are extracted
12 as shown in figure 7(b). The result of a second
13 wavelet transform on the RFP signal of figure 6(d)
14 is shown in figure 7(c) and the ridges of this
15 transform surface are extracted as shown in figure
16 7(d).

17
18 The extracted ridges from the RFP and RAP signal
19 transforms and the ridges found in the original
20 transform in the region of respiration, shown in
21 figures 8(a), (b) and (c) respectively, are then
22 analysed to determine a composite path which we call
23 the 'selected respiration path' SRP. The analysis
24 may include, but is not limited to, the intensities
25 and locations of the ridges. The SRP represents the
26 most likely breathing components. The SRP derived
27 from the extracted ridges shown in figures 8(a), (b)
28 and (c) is shown in figure 8(d). The SRP will
29 normally be determined within an initial pre-
30 determined "latch-on" time window and reassessed
31 within an updated time window. The ridge selection
32 procedure used to derive the SRP is based upon a

1 decision tree implementing a weighted branching
2 dependent upon, but not limited to, the following
3 local (i.e. relationship between ridge components
4 within a particular ridge set) and global (i.e. the
5 inter-relationship between ridge components across
6 ridge sets) criteria: start and end position,
7 length, average and peak strengths, various spatial
8 (i.e. movement range over the time-frequency
9 surface) statistical parameters including variance
10 and entropy, and a measurement of relative
11 switchback positions (i.e. degree of overlap with
12 other ridges). These criteria are based on results
13 of our in house experimentation across a range of
14 patient categories: adult, child and neonate.

15

16 A confidence metric for the accuracy of the SWFD
17 ridge obtained from the RAP signal can also be
18 acquired by comparing the resultant SWFD ridge
19 intensities derived from the RAP signal of the band
20 maxima ridge and ridges off-set from it. When
21 compared to RAP-SWFD derived from the band maxima
22 ridge, the off-ridge transform's ridges associated
23 with respiration have been observed to increase (to
24 a maximum) in intensity as the displacement of the
25 off-ridge from the maxima ridge is increased. Those
26 ridges associated with other features, however,
27 remain relatively static in amplitudes. In this way,
28 by interrogating the ridge amplitudes of a plurality
29 of RAP signals derived from the band maxima offsets,
30 the ridge or ridges associated with respiration can
31 be identified through a significant change in
32 amplitude relative to others.

1
2 The selected ridge path (SRP) is then used to
3 provide an overall confidence as to breathing rate
4 and/or provide individual breath monitoring and/or
5 prediction. By superimposing the SRP shown in figure
6 8(d) onto the phase information derived from the
7 original transform the phase along the SRP can be
8 determined as shown in figure 9. In this way
9 individual breaths may be identified through the
10 behaviour of the phase cycling. This phase
11 information along the SRP path may used to derive a
12 breathing signal either by displaying the phase
13 information as shown in figure 9 or by taking the
14 cosine, or similar function, of the phase
15 information to produce a sinusoidal waveform, or by
16 some other method to provide a waveform of choice
17 for visual display of the breathing signal. In an
18 alternative embodiment the phase information from
19 one of the secondary transforms or a combination of
20 the phase information from all transforms may be
21 used in the method. In addition, the phase
22 information used may be processed to remove
23 erroneous phase information for example caused by
24 movement artifact.

25
26 Parts of the SPR may contain missing segments caused
27 by, for example, signal artefact. In these regions
28 the SRP may be inferred using the last available
29 path point and the next available path point as
30 shown schematically in figure 10. In the preferred
31 embodiment this is carried out using a linear fit
32 between the points. However, other methods may also

1 be used without departing from the scope of the
2 invention.

3

4 **3.3 Oxygen Saturation Measurement**

5 The amplitude of signal features scale with their
6 wavelet transform representation. Thus by dividing
7 components of the wavelet transform of the red PPG
8 signal by those of the infrared PPG signal we obtain
9 new wavelet-based representations which contain
10 useful information on the signal ratios for use in
11 the determination of oxygen saturation. If a complex
12 wavelet function is used this information may be
13 extracted using a suitable path defined on the ratio
14 of the moduli of the transforms or using a Lissajous
15 plot from the real or imaginary parts of the
16 transforms. If a wavelet function containing only a
17 real part is employed then this information should
18 be extracted using a Lissajous plot derived from the
19 transforms. Two complimentary methods for the
20 extraction of the wavelet-based ratio information
21 required for the determination of oxygen saturation
22 are given below.

23

24 Figure 11 shows the three dimensional plots of the
25 real-parts of the wavelet transforms of the
26 simultaneously collected red and infrared PPG
27 signals. A complex Morlet wavelet was used in the
28 transform. The dominant nature of the pulse band and
29 breathing band regions is evident in the figure.
30 These are marked 'B' and 'C' respectively in the
31 figure. A secondary band containing pulse components
32 can also be seen in the figure (marked 'A'). This

1 band is associated with the double humped morphology
2 of the PPG waveform. In the new wavelet-based
3 Lissajous method a number of frequency levels are
4 selected within a moving window. The moving window
5 is shown schematically on the plot in figure 12.
6 (Here we use a 4.56 second window for the purpose of
7 illustration although alternative window lengths may
8 be used as required.) The oscillatory nature of the
9 pulse band and breathing band regions is evident in
10 the plot. The wavelet transform values along each of
11 these frequency levels for the red and infrared
12 signals are plotted against each other to give a
13 Wavelet-Based Lissajous (WBL) plot. This results in
14 a multitude of WBL plots, one for each frequency
15 level selected. In the method, the selected
16 frequency levels lie in the range of expected pulse
17 frequencies which is, for the purposes of
18 illustration, herein defined as between 0.67 and
19 3.33 Hz. This range may be altered to reflect the
20 application. The multitude of WBL plots may be
21 displayed together to form a 3-D Lissajous figure,
22 as shown in figure 13(a).

23

24 Note that, in the example shown here, a complex
25 wavelet function was used and hence both real or
26 both imaginary values of the transform can be
27 utilized in the method. Further, information from
28 the real WBL plots and imaginary WBL plots may be
29 combined to provide an optimal solution. If a real-
30 only wavelet function is used (i.e. a wavelet
31 function containing only a real part and no

1 imaginary part) then only one set of transforms
2 (real) are available to use.

3

4 Each Lissajous plot making up the 3-D Lissajous
5 figure is then probed to find its spread both along
6 its principle axis and that axis orthogonal to it.
7 To do this, any reasonable measure of spread may be
8 used. Here we employ the standard deviation (SD).
9 Figure 13(b) shows an end on view of the 3-D
10 Lissajous of figure 13(a). The region of the 3-D
11 Lissajous figures 13(a) and 13(b) in the vicinity of
12 the pulse frequency is marked by the letter 'B' in
13 the figures and higher frequencies are marked by the
14 letter 'A'. Figure 14 contains plots of the standard
15 deviation of data spread along the principle axis
16 (top plot) and minor axis (middle plot), and the
17 ratio of the standard deviations (lower plot) for
18 each Lissajous component making up the 3-D Lissajous
19 plot in figure 13(a). In the preferred embodiment
20 the Lissajous component with the maximum spread is
21 used in the determination of the oxygen saturation.
22 The location of this component is marked by the
23 arrow in the top plot of figure 14. This component,
24 with the maximum spread along the major principle
25 axis, is plotted in figure 13(c): the representative
26 slope of which is computed and used to determine the
27 local oxygen saturation value using a predefined
28 look-up table. This maximum spread is usually found
29 at or near the pulse frequency. A check is also made
30 on the SD ratios: defined as the SD of spread along
31 the major axis divided by the SD of spread along the
32 minor axis. A low SD ratio implies good correlation

1 between the two signals. The SD ratio for the
2 component with maximum spread is indicated by the
3 arrow in the lower plot of figure 14. We can see for
4 this case that a relatively low SD ratio occurs at
5 this location. The SD ratio check may be used to
6 pick a more appropriate wavelet-based Lissajous plot
7 and can form part of a noise identification and/or
8 reduction algorithm. Alternate methods of picking an
9 optimal wavelet-based Lissajous may also be employed
10 as appropriate. During periods of excessive noise,
11 the Lissajous components can become spread out in
12 shape, and in some cases the direction of the major
13 and minor principle axis can significantly change
14 from that of the relatively noise free portions of
15 the signals. A check can therefore be made to
16 determine if this has occurred by retaining a recent
17 history of the selected Lissajous components. This
18 can further be used as a confidence check on the
19 selected Lissajous figure used in the determination
20 of oxygen saturation.

21

22 Note that the ratio of the amplitudes of the
23 independent wavelet signals making up the selected
24 Lissajous component may also be used to determine
25 the oxygen saturation. Note also that the inverse
26 transform of these wavelet signals may be used in
27 the method to determine oxygen saturation. The
28 method described can be used to extract the
29 pertinent ratio information from wavelet transforms
30 computed using either complex or real-only wavelet
31 functions.

32

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

12

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

27

28

$$29 \quad R_{WT} = \frac{|T(a,b)_R|}{|T(a,b)_{IR}|}$$

[7]

30

31

1 where where the subscripts R and IR identify the red
2 and infrared signals respectively. The wavelet ratio
3 surface derived from the two scalograms in figure 16
4 is shown schematically in figure 17. Note that as
5 described previously in our definition of scalogram
6 we include all reasonable forms of rescaling
7 including the original unscaled wavelet
8 representation, linear rescaling and any power of
9 the modulus of the wavelet transform may be used in
10 the definition. As the amplitude of the wavelet
11 components scale with the amplitude of the signal
12 components then for regions of the surface not
13 affected by erroneous signal components the wavelet
14 ratio surface will contain values which can be used
15 to determine the oxygen saturation using a pre-
16 defined look-up table.

17

18 As can be seen in figure 17, the time frequency
19 wavelet ratio surface along, and in close proximity
20 to, the projection of the pulse ridge path P onto
21 the wavelet ratio surface are stable and hence may
22 be used in the robust determination of the oxygen
23 saturation. In the preferred embodiment the values
24 obtained along the projection of P onto R_{WT} are used
25 to determine oxygen saturation via a pre-defined
26 look-up table which correlates R_{WT} to oxygen
27 saturation.

28

29 A 2-D or 3-D view of the R_{WT} plot may be computed and
30 displayed in real time to provide a visual
31 indication of the quality of the ratio of ratios

1 obtained by the method, and hence the quality of the
2 measurement of oxygen saturation.

3

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

17

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

29

30 It will be recognized by those skilled in the art
31 that, in an alternative embodiment, the pulse band
32 ridge path P can also be projected onto the real or

1 imaginary transform components. From the values of
2 the transform components along this path over a
3 selected time interval a Lissajous figure may be
4 obtained and used in the determination of oxygen
5 saturation. It will also be recognized by those
6 skilled in the art that, in an alternative
7 embodiment, alternative paths may be projected onto
8 the wavelet ratio surface and used for the
9 determination of oxygen saturation. For example in
10 regions where the pulse band exhibits noise causing
11 the path of the ridge maxima to move far from the
12 actual pulse frequency a method for detecting such
13 noisy events and holding the path to the most
14 appropriate recent pulse frequency may be used until
15 the event has passed or until a preset period of
16 time whereby an alarm is triggered.

17
18 The 3-D Lissajous and wavelet ratio surface
19 methodologies for the determination of oxygen
20 saturation, as described above, can form the basis
21 of an algorithm for incorporation within pulse
22 oximeter devices. Furthermore the ability of the
23 methodologies to restrict themselves to the optimal
24 wavelet transform values by picking the optimal
25 Lissajous or following the pulse band respectively,
26 allows for erroneous signal elements to be discarded
27 automatically; so leading to a more robust algorithm
28 for the determination of oxygen saturation.

29
30 Note that in both new methods the inverse transform
31 of the selected wavelet values may also be used as
32 they too scale with the signal features.

1

2 In the preferred embodiment, both the 3-D Lissajous
3 and wavelet ratio surface methods are employed
4 simultaneously and the optimal measured saturation
5 value determined. It is obvious from the above
6 description that the initial inputted signals and
7 wavelet transformation of these signals form common
8 elements to both methods.

9

10 Those skilled in the art will recognise that
11 modifications and improvements can be incorporated
12 to the methodology outlined herein without departing
13 from the scope of the invention.

14

15 Those skilled in the art will recognise that the
16 above methods may be performed using alternative
17 time-frequency representations of the signals where
18 the amplitude in the time-frequency transform space
19 can be related to the amplitude of pertinent
20 features within the signal. However, in the
21 preferred method the continuous wavelet transform is
22 employed.

23

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

30 (a) provide, using information derived from the
31 signal wavelet transforms (i.e. from the original
32 transform, the rescaled wavelet transforms, the

1 ratio of derived wavelet transforms, the
2 scalograms, wavelet ridges, etc.) a method for
3 measuring oxygen saturation.

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

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

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

27

28 3.4 The Monitoring of Patient Movement

29 Current devices are configured to remove detrimental
30 movement artifact from the signal in order to clean
31 it prior to determination of the clinical parameter
32 of interest, e.g. the pulse rate or oxygen

1 saturation. However, the method described herein as
2 embodied within a device monitors general patient
3 movement, including large scale body movements,
4 respiration and the beating heart. In this way the
5 absence of patient movement and/or irregularity of
6 movement can be detected and an alarm triggered.

7
8 Patient movement results in PPG signal artifact. The
9 manifestation of this artifact can be observed in
10 the wavelet transform of the signal. An example of a
11 movement artifact in the scalogram is shown in
12 figure 20(a). The PPG signal from which the wavelet
13 plot was derived was acquired from a premature baby
14 a few weeks after birth. The location of the
15 movement artifact is marked by the arrow in the
16 plot. The breathing band ridge has been superimposed
17 on the wavelet plot (marked R in the figure). The
18 pulse band is marked P in the figure. Notice that
19 the artifact causes a drop-out in the detected
20 breathing ridge (i.e. a missing fragment), and also
21 cuts through the pulse band where it can cause
22 similar drop outs to occur in the detection of the
23 pulse ridge. It has been the focus of pulse oximeter
24 device manufacturers to remove as much of the
25 movement artifact component from the signal while
26 leaving the information necessary to obtain accurate
27 oxygen saturation and pulse rate measurements. In a
28 preferred embodiment of the methods described herein
29 we extract a movement component from the PPG signals
30 for use in the monitoring of patient movement and,
31 in particular, for the monitoring of the movement of
32 infants.

1
2 A three-dimensional view of the scalogram of figure
3 20(a) is plotted in figure 20(b). Here we see the
4 dominance of the movement artifact feature in
5 wavelet space. By identifying such features we can
6 monitor patient movement. It is common for young
7 babies to exhibit very variable respiration patterns
8 and to cease breathing for short periods of time,
9 especially when making a movement of the body. Hence
10 inspecting the derived movement signal when an
11 irregular respiration signal occurs, including
12 cessation of breathing, gives a further measure of
13 patient status.

14
15 The modulus maxima of the wavelet surface is the
16 loci of the maxima of the wavelet surface with
17 respect to time. Figure 21(a) plots the modulus
18 maxima lines associated with figure 20(a). Figure
19 21(b) shows a three-dimensional view of the
20 transform surface with the modulus maxima lines
21 superimposed. Figure 22(a) shows an end view of the
22 maxima lines (without the surface shown)
23 corresponding to those shown in figures 21(a) and
24 21(b). We can see from the end view that the modulus
25 maxima line corresponding to the movement artifact
26 has a significantly different morphology to the
27 other maxima lines: it covers a large frequency
28 range and contains significantly more energy than
29 the other maxima, especially at low frequencies. By
30 setting amplitude threshold criteria at a frequency
31 or range of frequencies we can differentiate the
32 modulus maxima of the artifact from other features.

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

17
18 A region in the time frequency plane within the
19 support of the wavelet is then deemed to contain
20 artifact. The support of the wavelet is taken as a
21 predefined measure of temporal 'width' of the
22 wavelet. For wavelets with theoretical infinite
23 width, such as the Morlet wavelet, the width is
24 defined in terms of the standard deviation of
25 temporal spread: for example we use three times the
26 standard deviation of spread each side from the
27 wavelet centre. Thus a cone of influence of the
28 artifact may be defined in the transform plane.

29
30 Using the above method we can monitor patient
31 movement by detecting modulus maxima corresponding
32 to movement artifact. This information can be used

1 to monitor patient movement and/or to provide a
2 measure of confidence on the derived values of other
3 measurements (e.g. oxygen saturation, pulse and
4 respiration). These measurements may, for example be
5 held at a previous value until the detected movement
6 event has passed.

7
8 Other artefact may exist in the signal which may
9 originate from the drive and control electronics
10 including, but not limited to, automatic gain
11 adjustments. The occurrence of this type of artifact
12 will be known and can be accounted for in the signal
13 and hence differentiated from movement artifact.
14

1 **4. Device Configuration and Usage**

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

7

8 In one embodiment the device would be used to
9 continually monitor one or more of these signals.

10

11 In another embodiment the device would be used to
12 monitor one or more of these signals intermittently.

13

14 **4.1 Device Configuration**

15 Detailed block diagrams of the device are provided
16 in figures 23,24, 25 and 26.

17

18 The following is with reference to figure 23. In the
19 present invention signals are acquired at the
20 patient's body 10. These are sent for digitization
21 11. The links between components of the system may
22 be fixed physical or wireless links, for example
23 radiofrequency links. In particular, either or both
24 of the links between 10 and 11 or 11 and 12, or the
25 links between the analyser component and a visual
26 display may a wireless link enabled by a
27 radiofrequency transmitter. The digitised cardiac
28 signals 11 are sent to 12 where in the preferred
29 embodiment the natural logarithm of the signals are
30 computed. These are then sent to 13 where the
31 wavelet transforms of the signals are performed. The
32 components of the wavelet transformed signals,

1 including modulus, phase, real part, imaginary part
2 are then sent to 14 where the pulse ridge is
3 identified. The information from 13 and 14 is then
4 used in the extraction of patient pulse information
5 15, oxygen saturation 16, patient movement
6 information 17 and respiration information 18. The
7 information regarding oxygen saturation, pulse,
8 respiration and patient movement is all sent to the
9 Analyser component 19 where it is collected and
10 collated ready for outputting at 20. The oxygen
11 saturation, respiration, pulse rate and movement
12 information is output from the device 20 through a
13 number of methods, which may include a printout, a
14 display screen or other visual device, an audible
15 tone, and electronically via a fixed or remote link.
16 The output information may be sent to a location
17 remote from the patient, for example sent via
18 telephone lines, satellite communication methods, or
19 other methods. Further, real-time wavelet-based
20 visualisations of the signal (including the original
21 transform and/or the wavelet ratio surface with
22 projected pulse ridge path) may be displayed on the
23 device 20. These visualisations will highlight
24 salient information concerning the quality of the
25 outputted measurements. Additional useful
26 information regarding movement artefact and
27 breathing information may be apparent from such a
28 real time display.

29

30 The workings of components 15, 16, 17 and 18 shown
31 in figure 23 are described below in more detail.

32

1 Pulse Component 15: With reference to figure 23,
2 pulse information including pulse rate and pulse
3 irregularities are derived at 15 using the
4 instantaneous frequency of the pulse band ridge
5 determined at 14. The instantaneous frequency may
6 correspond directly with the instantaneous ridge
7 frequency or require a mapping from the
8 instantaneous ridge frequency and the true
9 respiration rate. Further the method allows for a
10 smoothing of this value over a fixed time interval.
11 Further the method allows for erroneous values of
12 the pulse rate derived in this way to be excluded
13 from the outputted values. This component 15 may
14 also be used to measure inter-beat intervals and
15 pertinent pulse wave timings. The pulse information
16 determined at 15 is then sent to the Analyser
17 Component 19.

18

19 The Oxygen Saturation Component 16: The following is
20 with reference to figures 23 and 24. The oxygen
21 saturation component 16 shown in figure 23 comprises
22 the subcomponents 31, 32, 33, 34, 35, 36 and 37 as
23 shown in figure 24. The wavelet transform
24 information and pulse ridge information from 14 is
25 input into this module at the feature sorter 31
26 which sends the relevant information to the
27 Lissajous computation unit (components 32, 33 and
28 34) and the pulse ridge computational unit
29 (components 35 and 36). A predetermined number of
30 wavelet-based Lissajous are computed over the pulse
31 region 32. An automated procedure is employed for
32 the determination of the optimal Lissajous for use

1 in the oxygen saturation calculation 33. In the
2 preferred embodiment this would be achieved by
3 comparing the standard deviations of the data spread
4 along of the principle axes of the Lissajous plot.
5 The slope of the principle axis is then used to
6 determine the oxygen saturation using a suitable
7 look-up table which correlates the slope to oxygen
8 saturation 34. The oxygen saturation determined at
9 34 is denoted 'Oxygen Saturation Determination (1)'.
10

11 The information regarding the wavelet transforms of
12 the PPG signals and the path of the pulse ridge is
13 collected at the feature sorter 31 used to compute
14 the wavelet ratio surface 35. The wavelet ratio
15 corresponding to the pulse path is determined by
16 projecting the pulse path onto the wavelet ratio
17 surface. This ratio is then used to determine the
18 oxygen saturation using a look-up table which
19 correlates the wavelet ratio to oxygen saturation
20 36. The oxygen saturation determined at 36 is
21 denoted 'Oxygen Saturation Determination (2)'. The
22 two oxygen saturation values (1) and (2) are then
23 used to determine the most appropriate value of
24 oxygen saturation 37. This value is then sent to the
25 Analyzer Component 19.

26

27 Movement Component 17: The following is with
28 reference to figures 23 and 26. The Movement
29 component 17 of figure 23 comprises the
30 subcomponents 51, 52, 53, 54, 55 as shown in figure
31 26. The wavelet transform information and pulse
32 ridge information is sent from 14 to the modulus

1 maxima component 51 where the modulus maxima of the
2 wavelet surfaces are computed. The modulus maxima
3 information is then sent to be analysed for movement
4 artifact. The modulus maxima information is sent to
5 the components 52, 53 and 54. These are described as
6 follows. The Threshold component 52 detects maxima
7 above a preset threshold and within a preset
8 frequency range which are then defined as movement
9 artifact. The Pulse Check component 53 checks the
10 maxima corresponding to the pulse band to see if
11 anomalously large excursion from the local mean
12 level has occurred. If so movement artifact is
13 detected. The Respiration Check component 54 checks
14 the maxima in the vicinity of the selected
15 respiration path SRP obtained from 18 to determine
16 if anomalously large excursion from the local mean
17 level has occurred. If so movement artifact is
18 detected. The information from components 52, 53 and
19 54 are then collected and collated at the Movement
20 Signal component 55 where a movement signal is
21 generated. This is then sent to the Analyser
22 Component 19.

23

24 Respiration Component 18: The following is with
25 reference to figures 23 and 25. The respiration
26 component 17 of figure 23 comprises the
27 subcomponents 61, 62, 63 and 64 as shown in figure
28 25. The wavelet transform and pulse ridge
29 information from 14 are input into this module at
30 component 61 which uses the information to derive
31 the ridge amplitude perturbation (RAP) signal and
32 the ridge frequency perturbation (RFP) signals. The

1 RAP and RFP signals are derived using the path
2 defined by the projection of the maxima of the pulse
3 band or a locus of points displaced from this maxima
4 path. A secondary wavelet transform is performed on
5 these signals 62 and then passed to the respiration
6 detection component 63 where the respiration ridges
7 are detected for the wavelet transforms of the RFP
8 and RAP signals. These are then used within an
9 algorithm which decides the selected respiration
10 path (SRP). This algorithm may also incorporate
11 respiration information using complementary methods
12 64. Note that in the method the original transform
13 obtained at 13 and the secondary transform 62 may be
14 computed using different wavelet functions. The
15 respiration information is then sent to the Analyzer
16 Component 19 and also to the Movement component 17.

17
18 The Analyser Component 19: With reference to Fig.
19 23, the Analyzer Component collects the information
20 from the pulse component 15, Oxygen Saturation
21 Component 16, Movement Component 17 and Respiration
22 Component 18. During periods of detected motion or
23 other signal artifact the analyzer makes a decision
24 to hold the most appropriate recent values of these
25 signals until the artifact event passes or until
26 predetermined interval has passed at which point an
27 alarm signal sent to the device output 20. Further
28 the analyzer checks the incoming signals for
29 anomalous behaviour including, but not limited to:
30 low and or high pulse rates, pulse irregularities,
31 low and high breathing rates, breathing
32 irregularities, low and high oxygen saturation

1 rates, movement irregularities including excessive
2 movement and absence of movement. Detected anomalous
3 behaviour or combination of behaviours will trigger
4 an alarm signal sent to the device output 20.

5

6 **4.2 Physical Attachment of Probes and Transmission** 7 **of PPG Signals**

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

19

20 In one preferred embodiment for use with neonates a
21 foot/ankle mounted device such as a cuff is employed
22 as depicted schematically in figure 27. The cuff is
23 used to house the probe electronics, radio frequency
24 transmitter modules and battery. Figure 27(a) shows
25 the patients lower leg 80 and foot with the
26 preferred embodiment of the cuff 83 attached to the
27 foot. The patients heel 81 and toes 82 protrude from
28 the cuff. Figure 27(b) shows two views, one from
29 each side of the foot showing the cuff with
30 compartments for housing the electronic equipment
31 required for signal acquisition and transmission.
32 The PPG signals may be taken directly through the

1 foot using Light Emitting Diodes (LEDs) 86 and
2 photodetector 88 located as shown or, in an
3 alternative embodiment, they may be taken at the toe
4 using a short length of cable attaching the pulse
5 oximeter probe to the electronics contained in the
6 cuff. In a further alternative embodiment
7 reflectance mode photoplethysmography may be
8 employed. In a further alternative embodiment more
9 suitable for adult monitoring the electronic
10 equipment is packaged within a soft housing which is
11 wrapped and secured around the wrist as shown in
12 figure 28. The electronic components for receiving
13 processing and transmitting the PPGs are housed in a
14 unit 90 secured by a band 91 to the patients wrist.
15 The PPG signals are acquired at a site local to the
16 wrist band. For example from a finger 93 via a lead
17 92 from the wrist unit 90, or at the site of the
18 wrist band and housing using, for example,
19 reflectance mode photoplethysmography. In yet
20 another alternative embodiment, the signal from the
21 pulse oximeter probe would be sent to the monitor
22 device using a physical lead instead of the wireless
23 method described here.

24

25 Light transmitters other than LEDs may be used in
26 the device without departing from the scope of the
27 invention.

28

29 In an alternative embodiment, the digitised signal
30 from 11 may input directly to the wavelet transform
31 component 13 without taking the natural logarithm.

32

1 In an alternative embodiment, more than two
2 wavelengths or combination of more than two
3 wavelengths of light may be employed in the Oximetry
4 method.

5

6

7

8

9

10 **4.3 Use of the Device**

11

12 **4.3.1 General Use**

13 The device may be used for general patient
14 monitoring in the hospital, home, ambulatory or
15 other environment. For example in a preferred
16 embodiment for a device for use within a hospital
17 setting it may be used to continually or
18 intermittently monitor patient respiration together
19 with oxygen saturation and pulse rate.

20

21 **4.3.2 Embodiment as an Apnea Monitor**

22 In another preferred embodiment of the device it
23 would be used as an apnea monitor. Apnea is the
24 cessation of breathing usually occurring during
25 sleep. There is increasing awareness of this sleep
26 disorder as the cause of a number of serious medical
27 conditions in adults and infants. Separate areas of
28 use are envisaged for the device as an apnea
29 monitor. Examples of this use include, but are not
30 limited to: (1) adult monitoring, where it can be
31 used as a *home screening diagnostic tool* for
32 potential apnea patients and (2) infant monitoring,

1 where it can be used as either an *in hospital* or
2 *home monitoring tool* to alert the child's carer to
3 this potentially fatal respiration irregularity.

4
5 Apnea monitors monitor heart and respiratory signals
6 to detect apnea episodes - usually defined as
7 cessation of breathing for >20 seconds. Apnea is
8 associated with slowing of the pulse (bradycardia)
9 or bluish discoloration of the skin due to lack of
10 oxygenated haemoglobin (cyanosis). Long term effects
11 of apnea in adults are quite serious and have been
12 reported to include: heavy snoring, weariness and
13 obsessive drive to fall asleep, reduced physical and
14 mental fitness, strokes, nervousness, fall in
15 concentration and headaches, psychic symptoms up to
16 depressions, sexual dysfunctions, impotence,
17 dizziness and nightly perspiration. In babies apnea
18 may lead to death if suitable resuscitation measures
19 are not taken.

20
21 As it measures respiration and movement directly
22 from the pulse oximeter signal (in addition to
23 oxygen saturation and pulse), the device can be
24 fitted remote from the head; e.g. the foot or arm of
25 the patient. This has the advantage over current
26 devices which comprise of probes located on the
27 patients head and face to measure breathing at the
28 patients nose and/or mouth. As such they are
29 uncomfortable for adult patients and are quite
30 impractical for fitting to babies for the obvious
31 reason of causing a potential choking hazard. The
32 preferred embodiment of our invention allows the PPG

1 signal collected at the patient to be sent via a
2 wireless link to a remotely located device.

3

4 In summary, embodied as an apnea monitor, the device
5 provides a method for the acquisition analysis and
6 interpretation of pulse oximeter signals to provide
7 clinically useful information on patient pulse rate,
8 oxygen saturation, respiration and movement. From a
9 combination of some or all of this information
10 clinical decisions can be made with regard to the
11 patient's health. The patient respiration
12 information is used to monitor the patient in order
13 to compute a respiration rate and to detect
14 breathing abnormalities, for example: apnea events,
15 cessation in breathing, sharp intakes of breaths,
16 coughing, excessively fast breathing, excessively
17 slow breathing, etc. Information derived from one or
18 more of the respiration, movement, oxygen saturation
19 and pulse measurements may be used to trigger an
20 alarm to call for medical help or to initiate an
21 automated process for the administration of a
22 therapeutic intervention. A method may be employed
23 for the archiving of the derived signals during the
24 analysis period of the patient which may be used at
25 a later date for analysis by the clinician.

26

27 The device may be used to monitor the patient both
28 during sleep and when awake.

29

30 The device may be used to detect the onset of sudden
31 infant death syndrome SIDS by detecting and
32 analysing abnormalities in the measurement of one or

1 more of the following: oxygen saturation,
2 respiration, movement and pulse.

3

4 **4.3.3 Alarm**

5 As described above, it is envisaged that the
6 gathered information is used to trigger an alarm at
7 the bedside and/or at a remote nursing station. This
8 alarm would be graded according to a classification
9 of patient information. For example a reduction in
10 oxygen saturation below a predefined threshold with
11 associated loss or irregularity of patient movement,
12 irregularity of pulse rate and loss or irregularity
13 of patient respiration could trigger the highest
14 level of alarm, whereas a reduction of oxygen
15 saturation below a predefined threshold with a
16 normal level of patient movement and/or a regular
17 respiration pattern could trigger a lower level of
18 alarm.

1 **5 . Brief Description of Drawings**

2 **Figure 1(a):** A wavelet transform surface showing the
3 pulse band (located between the dashed lines). (High
4 to Low energy is graded from white to black in the
5 grey scale plot.)

6 **Figure 1(b):** Three-dimensional view of the wavelet
7 transform surface of figure 1(a) showing the maxima
8 of the pulse band with respect to frequency (the
9 ridge) superimposed as a black path across the band
10 maxima. (High to Low energy is graded from white to
11 black in the grey scale plot.)

12 **Figure 2:** 3-D Schematic of a wavelet transform
13 surface containing two bands. The locus of the local
14 maxima on the bands (the 'ridges') are shown by
15 dashed lines.

16 **Figure 3:** Schematics of the RAP (top left) and RFP
17 (top right) signals derived from ridge A in figure 1
18 together with their corresponding wavelet transforms
19 shown below each (in 2D).

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

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

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

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

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

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

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

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

20 **Figure 6(a):** PPG Signal

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

24 **Figure 6(c):** RAP signal derived from ridge in (b)
25 with breathing switch (square waveform)
26 superimposed.

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

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

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

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

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

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

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

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

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

17 **Figure 9:** Transform Phase along the SRP

18 **Figure 10:** Filling in missing segments of the SRP

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

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

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

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

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

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

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

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

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

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

14 **Figure 19:** Computed Oxygen Saturation curves. Dotted
15 line: Oxygen Saturation from Traditional Signal
16 Amplitude Method; Dashed Line: Oxygen Saturation
17 from Traditional Signal Lissajous Method; Solid
18 Line: Oxygen Saturation from Traditional Wavelet-
19 Ratio Surface Method

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

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

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

30 **Figure 21(b):** Three-dimensional view of figure
31 21(a). Low to high energy is depicted from black to
32 white in the greyscale plot.

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

3 **Figure 22(b):** Amplitude threshold method of
4 identifying modulus maxima associated with movement
5 artefact

6 **Figure 22(c):** Pulse ridge-based method of
7 identifying modulus maxima associated with movement
8 artefact

9 **Figure 22(d):** Respiration ridge-based method of
10 identifying modulus maxima associated with movement
11 artefact

12 **Figure 23:** Block diagram of device configuration

13 **Figure 24:** Block diagram of subcomponents of oxygen
14 saturation component (16) shown in figure 23

15 **Figure 25:** Block diagram of subcomponents of
16 respiration component (18) shown in figure 23

17 **Figure 26:** Block diagram of subcomponents of
18 movement component (17) shown in figure 23

19 **Figure 27(a):** Schematic of foot cuff mounting: soft
20 housing surrounding foot used to hold monitoring
21 apparatus.

22 80 patient leg; 81 patient heel; 82 patient toes; 83
23 soft housing surrounding foot

24 **Figure 27(b):** View from both sides of the envisaged
25 device: preferred embodiment for neonatal monitor.
26 84 connection cabling; 85 RF components attached to
27 housing; 86 LEDs; 87 pulse oximeter components
28 attached to housing; 88 photodetector. (Note LEDs
29 and photodetector may also be located on toe using
30 short cable length from cuff.)

1 **Figure 28:** Schematic of wrist cuff mounting: 90
2 electronic component housing; 91 wrist band; 92
3 connector cable; 93 finger probe
4

5 **6. General**

6 The invention has been described and shown with
7 specific reference to specific embodiments. However
8 it will be understood by those skilled in the art
9 that changes to the form and details of the
10 disclosed embodiments may be made without departing
11 from the spirit and scope of the invention. For
12 example signal transforms other than the wavelet
13 transform may be used. Other variations may include
14 using a multiplexed arrangement which alternates
15 measurements for pulse, oxygen saturation,
16 respiration and movement artefact using variations
17 of the acquisition equipment and transmission
18 electronics. These variations may include but are
19 not limited to the use of more than two wavelengths
20 of light and variable power and/or variable duty
21 cycle to the light transmitters.

22

23 **7. Reference**

24 Addison P.S., '*The Illustrated Wavelet Transform*
25 *Handbook*', Institute of Physics Publishing, 2002,
26 Bristol, UK.

27

1 CLAIMS

2

3 1. A method of measuring physiological parameters,
4 comprising:

5 using a signal acquisition means to obtain a
6 pulse oximetry signal;

7 decomposing the pulse oximetry signal by
8 wavelet transform analysis;

9 identifying a primary band and a secondary band
10 on a transform surface constructed by the wavelet
11 transform analysis; and

12 interpreting the secondary band to reveal
13 information pertaining to the physiological
14 parameters causing the primary band.

15

16 2. The method of claim 1, wherein the step of
17 deriving information from the secondary band
18 comprises:

19 defining a selected path along the secondary
20 band;

21 extracting a time-frequency locus of points on
22 the selected path;

23 extracting a time-amplitude locus of points on
24 the selected path; and

25 decomposing the time-frequency and time-
26 amplitude loci by wavelet transform analysis.

27

28 3. The method of claim 1 or claim 2, wherein the
29 selected path is in the vicinity of a ridge.

30

31 4. The method of claim 3, wherein the selected
32 path is a ridge.

1

2 5. The method of any preceding claim, wherein the
3 pulse oximetry signal is a photoplethysmogram (PPG).

4

5 6. The method of any preceding claim, wherein the
6 wavelet transform analysis employs a continuous
7 wavelet transform.

8

9 7. The method of any preceding claim, further
10 comprising the steps of;

11 defining a second selected path along the
12 primary band;

13 deriving primary band information from the
14 second selected path;

15 comparing the primary band information with the
16 information derived from the secondary band; and

17 choosing the optimum data set from the
18 information, said optimum data set being the data
19 set that most accurately represents the
20 physiological parameters causing the primary band.

21

22 8. The method of claim 7 when dependent from any
23 of claims 2-6, wherein the optimum data set is
24 chosen from the group comprising information derived
25 from the primary band, information derived from the
26 decomposed time-frequency locus, and the information
27 derived from the time-amplitude locus.

28

29 9. The method of any preceding claim, wherein the
30 primary band is a breathing band and the secondary
31 band is a pulse band.

32

1 10. The method of any preceding claim, in which the
2 derived information is patient respiration
3 information.

4

5 11. The method of claim 10, wherein the information
6 is used to determine the respiration rate of a
7 patient.

8

9 12. The method of claim 10 or claim 11, wherein the
10 information is used to identify individual breaths
11 of the patient.

12

13 13. The method of any of claims 10-12, used to
14 reveal breathing irregularities.

15

16 14. A physiological measurement system comprising:
17 a signal acquisition means which includes a
18 light emitting device and a photodetector attachable
19 to a subject to obtain a pulse oximetry signal;
20 analogue to digital converter means arranged to
21 convert said pulse oximetry signal into a digital
22 pulse oximetry signal;

23 signal processing means suitable to receive
24 said digital pulse oximetry signal and arranged to
25 decompose that signal by wavelet transform means;

26 a respiration component arranged to identify a
27 primary band and a secondary band on a transform
28 surface constructed by the wavelet transform
29 analysis; and to interpret the secondary band to
30 reveal information pertaining to the physiological
31 parameters causing the primary band.

32

1 15. The system of claim 14, in which the signal
2 processing means and respiration component are
3 arranged to process the pulse oximetry signal by the
4 method of any of claims 2-13.

5
6 16. The system of claim 14 or claim 15, further
7 comprising an analyser component arranged to collect
8 information from the respiration component, and a
9 device output arranged in communication with the
10 analyser component.

11
12 17. The system of claim 16 wherein the analyser
13 component is arranged to generate an alarm signal
14 upon detection of a predetermined set of conditions.

15
16 18. The system of claim 17, wherein the
17 predetermined set of conditions includes the
18 existence of a respiration artefact for at least a
19 given time.

20
21 19. The system of any of claims 16-18, wherein the
22 device output comprises visual display means
23 operable to display the pulse oximetry signal and
24 information derived therefrom in real time; and
25 alarm means operable to receive the alarm signal
26 from the analyser component and to generate an
27 alarm.

28
29 20. A method of measuring physiological parameters,
30 comprising:

31 using a signal acquisition means to obtain a
32 red pulse oximetry signal in the red light spectrum

1 and an infra-red pulse oximetry signal in the infra-
2 red spectrum;

3 decomposing each pulse oximetry signal by
4 wavelet transform analysis; and

5 combining the decomposed signals to obtain a
6 measure of a physiological parameter.

7

8 21. The method of claim 20, wherein the step of
9 combining the decomposed signals to obtain a measure
10 of a physiological parameter comprises;

11 for each decomposed signal, selecting a
12 plurality of frequencies and a first set time
13 period; and

14 plotting the transform values over the set time
15 period at each frequency of the decomposed red pulse
16 oximetry signal against those of the decomposed
17 infra-red pulse oximetry signal as a plurality of
18 Lissajous figures.

19

20 22. The method of claim 21, wherein the Lissajous
21 figures are three-dimensional.

22

23 23. The method of claim 21 or claim 22, further
24 comprising plotting Lissajous figures for the
25 selected frequencies over a second set time period,
26 the start of which is later than the start of the
27 first set time period.

28

29 24. The method of claim 23, wherein a plurality of
30 successive later time periods are selected such that
31 a frequency window moves across the time-frequency
32 plane of each decomposed signal.

1

2 25. The method of any of claims 21-24 further
3 comprising the steps of analysing a characteristic
4 parameter of each Lissajous figure; using the value
5 of the characteristic parameter to select a
6 Lissajous figure from the plurality of Lissajous
7 figures; and

8 using the selected Lissajous figure to
9 determine a physiological parameter.

10

11 26. The method of claim 25, wherein the
12 characteristic parameter of a Lissajous figure is
13 derived from its spread along its principle
14 components, and wherein the selected Lissajous
15 figure is the one having the maximum spread.

16

17 27. The method of claim 26, wherein the spread of a
18 Lissajous figure is represented by the standard
19 deviation along the principle component or
20 components.

21

22 28. The method of claim 27, wherein the ratio of
23 standard deviations along two orthogonal principle
24 components is calculated to give a further aid to
25 the selection of the Lissajous figure for use in
26 determining the physiological parameter.

27

28 29. The method of any of claims 21-28, wherein the
29 slope of the selected Lissajous figure is used as a
30 measure of the patient oxygen saturation.

31

1 30. The method of claim 29, wherein a predefined
2 look-up table is used to deduce the relationship
3 between the slope and the oxygen saturation.
4

5 31. The method of claim 20, wherein the step of
6 combining the decomposed signals to obtain a measure
7 of a physiological parameter comprises the steps of:
8 constructing a wavelet ratio surface based
9 on the ratio of one of the decomposed signals to the
10 other of the decomposed signals; and
11 deriving one or more physiological parameters
12 from the wavelet ratio surface.
13

14 32. The method of claim 31, wherein the step of
15 deriving one or more physiological parameters from
16 the wavelet ratio surface comprises the steps of:
17 selecting a region of the wavelet ratio surface
18 for use in determining the physiological parameter.
19

20 33. The method of claim 32, wherein the selected
21 region is derived from a path in the wavelet ratio
22 surface formed from a collection of points in the
23 vicinity of the maxima of a pulse band.
24

25 34. The method of claim 33, wherein the selected
26 region is derived from a path in the wavelet ratio
27 surface formed from a collection of points
28 corresponding to the maxima of a pulse band.
29

30 35. The method of claim 33 or claim 34, further
31 comprising the step of inspecting a predefined look-

1 up table to determine the correlation between the
2 path and the oxygen saturation.

3

4 36. The method of any of claims 31-35, further
5 comprising the step of, when a local disturbance
6 occurs in the pulse band maxima, holding the
7 previously determined oxygen saturation value for a
8 specified duration or until the local disturbance
9 ceases.

10

11 37. The method of any of claims 20-36, wherein the
12 pulse oximetry signal is a photoplethysmogram (PPG)
13 signal.

14

15 38. The method of any of claims 20-37, wherein the
16 wavelet transform analysis employs a continuous
17 wavelet transform.

18

19 39. A physiological measurement system comprising:
20 a signal acquisition means which includes a
21 light emitting device and a photodetector attachable
22 to a subject to obtain a red pulse oximetry signal
23 in the red light spectrum and an infra-red pulse
24 oximetry signal in the infra-red spectrum;

25 analogue to digital converter means arranged to
26 convert said pulse oximetry signals into digital
27 pulse oximetry signals;

28 signal processing means suitable to receive
29 said digital pulse oximetry signals and arranged to
30 decompose those signals by wavelet transform means;
31 and

1 an oxygen saturation component arranged to
2 combine the decomposed signals to obtain a measure
3 of a physiological parameter.

4

5 40. The system of claim 39, wherein the oxygen
6 saturation component comprises a Lissajous
7 computation unit arranged to receive the decomposed
8 signals from the signal processing means, and, for
9 each decomposed signal, to:

10 select a plurality of frequencies and a first
11 set time period; and

12 plot the transform values over the first set
13 time period at each frequency of the decomposed red
14 pulse oximetry signal against those of the
15 decomposed infra-red pulse oximetry signal as a
16 plurality of Lissajous figures.

17

18 41. The system of claim 40, in which the signal
19 processing means and the Lissajous computation unit
20 are arranged to perform the method of any of claims
21 21-30.

22

23 42. The system of claim 39, wherein the oxygen
24 saturation component comprises a pulse ridge
25 computational unit arranged to:

26 receive the decomposed signals from the signal
27 processing means;

28 to construct a wavelet ratio surface based on
29 the ratio of one of the decomposed signals to the
30 other of the decomposed signals; and

31 to derive one or more physiological parameters
32 from the wavelet ratio surface.

1

2 43. The system of claim 42, in which the signal
3 processing means and the pulse ridge computational
4 unit are arranged to perform the method of any of
5 claims 31-38.

6

7 44. The system of claim 39, wherein the oxygen
8 saturation unit comprises the Lissajous computation
9 unit of claim 40 and the pulse ridge computational
10 unit of claim 42, said system further comprising a
11 signal sorting component arranged to receive a
12 signal from the signal processing means and to
13 allocate that signal to both the Lissajous
14 computation unit and the pulse ridge computational
15 unit.

16

17 45. The system of claim 44, further comprising
18 comparison means arranged to receive a signal from
19 each of the Lissajous computation unit and the pulse
20 ridge computational unit and to select a signal to
21 be representative of the physiological parameter.

22

23 46. The system of claim 45, in which the signal
24 processing means and the oxygen saturation component
25 are arranged to perform the method of any of claims
26 20-38.

27

28 47. The system of any of claims 39-46, further
29 comprising an analyser component arranged to collect
30 information from the respiration component, and a
31 device output arranged in communication with the
32 analyser component.

1

2 48. The system of claim 47 wherein the analyser
3 component is arranged to generate an alarm signal
4 upon detection of a predetermined set of conditions.

5

6 49. The system of claim 48, wherein the
7 predetermined set of conditions includes the
8 existence of an abnormal oxygen saturation for at
9 least a given time.

10

11 50. The system of any of claims 47-49, wherein the
12 device output comprises visual display means
13 operable to display the pulse oximetry signal and
14 information derived therefrom in real time; and
15 alarm means operable to receive the alarm signal
16 from the analyser component and to generate an
17 alarm.

18

19 51. A method of measuring a movement artefact
20 occurring in a pulse oximetry signal, comprising:
21 using a signal acquisition means to obtain a
22 pulse oximetry signal;
23 decomposing the pulse oximetry signal by
24 wavelet transform analysis;
25 finding the modulus maxima of a transform
26 surface constructed by the wavelet transform
27 analysis;
28 determining a set of modulus maxima that lie
29 within a predetermined amplitude threshold; and
30 associating this set of modulus maxima with the
31 movement artefact.

32

1 52. The method of claim 51, wherein the
2 predetermined threshold is defined as a given
3 quantitative excursion of the modulus maxima from a
4 localised mean value of a pulse ridge, said
5 excursion being encountered as the ridge is
6 followed.

7

8 53. The method of claim 51, wherein the
9 predetermined threshold is defined as a given
10 quantitative excursion of the modulus maxima from a
11 localised mean value of a breathing ridge, said
12 excursion being encountered as the ridge is
13 followed.

14

15 54. The method of any of claims 51-53, wherein the
16 amplitude threshold is defined over a specific
17 frequency range.

18

19 55. A movement measurement system comprising:
20 a signal acquisition means which includes a
21 light emitting device and a photodetector attachable
22 to a subject to obtain pulse oximetry signal;
23 analogue to digital converter means arranged to
24 convert said pulse oximetry signals into digital
25 pulse oximetry signals;
26 signal processing means suitable to receive
27 said digital pulse oximetry signals and arranged to
28 decompose those signals by wavelet transform means;
29 and
30 movement measurement means arranged to receive
31 the decomposed signal; find the modulus maxima of a
32 transform surface constructed by the wavelet

1 transform analysis; determine a set of modulus
2 maxima that lie within a predetermined amplitude
3 threshold; and associate this set of modulus maxima
4 with a movement artefact in the decomposed signal.

5
6 56. The system of claim 55, wherein the movement
7 measurement means further comprises pulse check
8 means arranged to determine if the set of modulus
9 maxima that lie within the predetermined amplitude
10 threshold represents an excursion from a pulse band.

11
12 57. The system of claim 55 or claim 56, wherein the
13 movement measurement means further comprises
14 respiration check means arranged to determine if the
15 set of modulus maxima that lie within the
16 predetermined amplitude threshold represents an
17 excursion from a breathing band.

18
19 58. The system of any of claims 55-57, further
20 comprising an analyser component arranged to collect
21 information from the movement measurement means, and
22 a device output arranged in communication with the
23 analyser component.

24
25 59. The system of claim 58 wherein the analyser
26 component is arranged to generate an alarm signal
27 upon detection of a predetermined set of conditions.

28
29 60. The system of claim 59, wherein the
30 predetermined set of conditions includes the
31 existence of excessive or erratic movement, or the
32 lack of movement, for at least a given time.

1

2 61. The system of any of claims 58-60, wherein the
3 device output comprises visual display means
4 operable to display the pulse oximetry signal and
5 information derived therefrom in real time; and
6 alarm means operable to receive the alarm signal
7 from the analyser component and to generate an
8 alarm.

9

10 62. A method of measuring physiological parameters,
11 comprising:

12 using a signal acquisition means to obtain a
13 pulse oximetry signal;

14 decomposing the pulse oximetry signal by
15 wavelet transform analysis; and

16 identifying a dominant band in a transform
17 surface constructed by the wavelet transform
18 analysis, the band being associated with pulse
19 components in the pulse oximetry signal.

20

21 63. The method of claim 62, further comprising the
22 step of deriving a selected time-frequency path
23 along the dominant band.

24

25 64. The method of claim 63, wherein the selected
26 time-frequency path is the ridge of the band.

27

28 65. The method of any of claims 62-64, wherein the
29 measured physiological parameter is a pulse rate.

30

31 66. The method of any of claims 63-65, further
32 comprising the step of using transform information

1 along the selected path to provide information on
2 the times between individual pulses.

3

4 67. The method of claim 66, further comprising the
5 step of using transform information along the
6 selected path to provide information on the timings
7 of features within the pulse.

8

9 68. The method of claim 67, further comprising the
10 step of using the information on the timings of
11 features within the pulse as a measure of arterial
12 compliance.

13

14 69. The method of any of claims 62-68, wherein the
15 pulse oximetry signal is a photoplethysmogram (PPG).

16

17 70. A physiological measurement system comprising:
18 a signal acquisition means which includes a
19 light emitting device and a photodetector attachable
20 to a subject to obtain a pulse oximetry signal;
21 analogue to digital converter means arranged to
22 convert said pulse oximetry signal into a digital
23 pulse oximetry signal;

24 signal processing means suitable to receive
25 said digital pulse oximetry signal and arranged to
26 decompose that signal by wavelet transform means;
27 and

28 a pulse component arranged to identify a
29 dominant band in a transform surface constructed by
30 the wavelet transform analysis, said band being
31 associated with pulse components in the pulse
32 oximetry signal.

1

2 71. The system of claim 70, arranged to process the
3 pulse oximetry signal by the method of any of claims
4 58-65.

5

6 72. The system of claim 70 or claim 71, further
7 comprising an analyser component arranged to collect
8 information from the pulse component, and a device
9 output arranged in communication with the analyser
10 component.

11

12 73. The system of claim 72 wherein the analyser
13 component is arranged to generate an alarm signal
14 upon detection of a predetermined set of conditions.

15

16 74. The system of claim 73, wherein the
17 predetermined set of conditions includes the
18 existence of a pulse abnormality for at least a
19 given time.

20

21 75. The system of any of claims 72-74, wherein the
22 device output comprises visual display means
23 operable to display the pulse oximetry signal and
24 information derived therefrom in real time; and
25 alarm means operable to receive the alarm signal
26 from the analyser component and to generate an
27 alarm.

28

29 76. A physiological measurement system comprising:
30 a signal acquisition means which includes a
31 light emitting device and a photodetector attachable
32 to a subject to obtain a pulse oximetry signal;

1 analogue to digital converter means arranged to
2 convert said pulse oximetry signal into a digital
3 pulse oximetry signal;

4 signal processing means suitable to receive
5 said digital pulse oximetry signal and arranged to
6 decompose that signal by wavelet transform means;

7 feature extraction means arranged to derive
8 physiological information from the decomposed
9 signal;

10 an analyser component arranged to collect
11 information from the feature extraction means; and

12 data output means arranged in communication
13 with the analyser component.

14

15 77. The system of claim 76, wherein the feature
16 extraction means comprises one or more of:

17 (a) a respiration component arranged to
18 identify a primary band and a secondary band on a
19 transform surface constructed by the wavelet
20 transform analysis; and to interpret the secondary
21 band to reveal information pertaining to the
22 physiological parameters causing the primary band;

23 (b) an oxygen saturation component arranged to
24 combine the decomposed signals to obtain a measure
25 of a physiological parameter;

26 (c) movement measurement means arranged to
27 receive the decomposed signal, find the modulus
28 maxima of a transform surface constructed by the
29 wavelet transform analysis; determine a set of
30 modulus maxima that lie within a predetermined
31 amplitude threshold; and associate this set of

1 modulus maxima with a movement artefact in the
2 decomposed signal; and

3 (d) a pulse component arranged to identify a
4 dominant band in a transform surface constructed by
5 the wavelet transform analysis associated with pulse
6 components in the pulse oximetry signal.

7

8 78. The system of claim 77, wherein the respiration
9 component is arranged to process the pulse oximetry
10 signal by the method of any of claims 1-13.

11

12 79. The system of claim 77, wherein the oxygen
13 saturation component is arranged to process the
14 pulse oximetry signal by the method of any of claims
15 20-38.

16

17 80. The system of claim 77, wherein the movement
18 measurement means is arranged to process the pulse
19 oximetry signal by the method of any of claims 51-
20 54.

21

22 81. The system of claim 80, wherein the output from
23 a respiration component is used as an input of the
24 movement measurement means.

25

26 82. The system of claim 77, wherein the pulse
27 component is arranged to process the pulse oximetry
28 signal by the method of any of claims 62-69.

29

30 83. The system of any of claims 76-82, wherein the
31 analyser component is arranged to generate an alarm
32 signal upon detection of a predetermined set of

1 conditions exhibited by the information collected
2 from the feature extraction means.

3

4 84. The system of claim 83, further comprising
5 alarm means arranged to receive the alarm signal and
6 to generate an alarm.

7

8 85. The system of any of claims 76-84, wherein the
9 data output means comprises visual display means
10 operable to display the pulse oximetry signal and
11 information derived therefrom in real time.

12

13 86. The system of any of claims 76-85, wherein any
14 one or more of the analogue to digital converter
15 means, signal processing means, feature extraction
16 means, analyser component, and data output means are
17 arranged to receive and/or transmit signals via a
18 wireless communications link.

19

20 87. The system of any of claims 76-85, wherein the
21 signal acquisition means is arranged to transmit
22 signals via a wireless communications link.

23

24 88. The system of claim 87, wherein the signal
25 acquisition means is arranged to transmit signals to
26 the analogue to digital converter means via a
27 wireless communications link.

28

29 89. The system of any of claims 86-88, wherein the
30 analogue to digital converter means is arranged to
31 transmit signals to the signal processing means via
32 a wireless communications link.

1

2 90. The system of any of claims 86-89, wherein the
3 analyser component is arranged to transmit signals
4 to the data output means via a wireless
5 communications link.

6

7 91. The system of any of claims 86-90, wherein the
8 wireless communications link is a radiofrequency
9 (RF) link.

10

11 92. The system of any of claims 85-91, wherein any
12 one or more of the signal acquisition means,
13 analogue to digital converter means, signal
14 processing means, feature extraction means, analyser
15 component, and data output means are embodied in a
16 form suitable to be worn on the body of a patient.

17

18 93. The system of claim 92, wherein any one or more
19 of the signal acquisition means, analogue to digital
20 converter means, signal processing means, feature
21 extraction means, analyser component, and data
22 output means are embodied in a cuff for attachment
23 to a patient's ankle.

24

25 94. The system of claim 92, wherein any one or more
26 of the signal acquisition means, analogue to digital
27 converter means, signal processing means, feature
28 extraction means, analyser component, and data
29 output means are embodied in a wrist band and
30 thimble for attachment to a patient's wrist and
31 finger respectively.

32

1 95. The system of any of claims 76-94, embodied in
2 a format suitable for home use.

3

4 96. The system of any of claims 77-95, where one or
5 more of the respiration component, oxygen saturation
6 component, movement measurement means and pulse
7 component are used as an apnea monitor.

8

9 97. The system of any of claims 77-95, where one or
10 more of the respiration component, oxygen saturation
11 component, movement measurement means and pulse
12 component are used as a monitor for sudden infant
13 death syndrome.

14

15 98. A method of measuring a characteristic
16 parameter, comprising:

17 obtaining a signal which varies according to a
18 set of parameters including the characteristic
19 parameter;

20 decomposing the signal by wavelet transform
21 analysis;

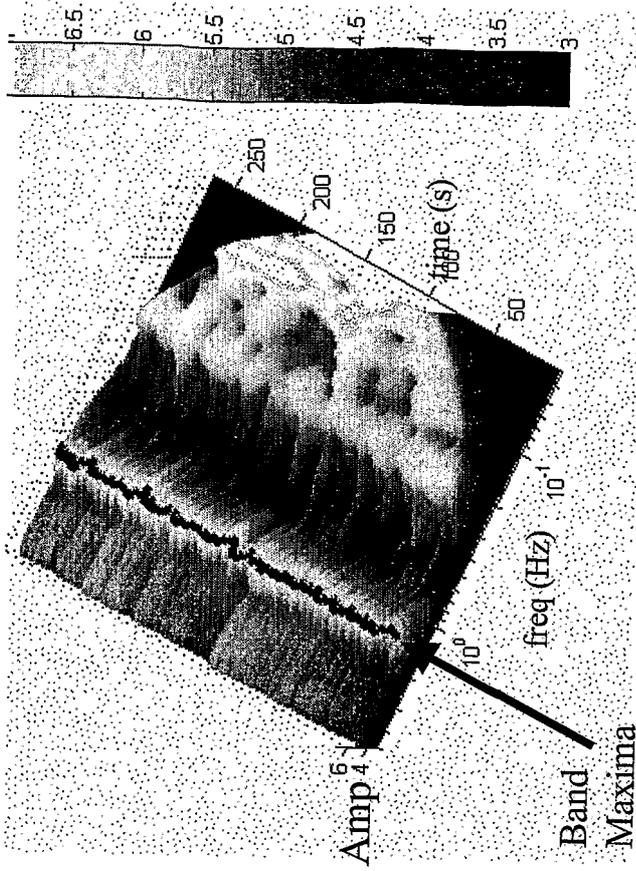
22 identifying a primary band representative of
23 the characteristic parameter, and a secondary band
24 representative of a secondary parameter, on a
25 transform surface constructed by the wavelet
26 transform analysis; and

27 interpreting the secondary band to reveal
28 information pertaining to the parameters causing the
29 primary band.

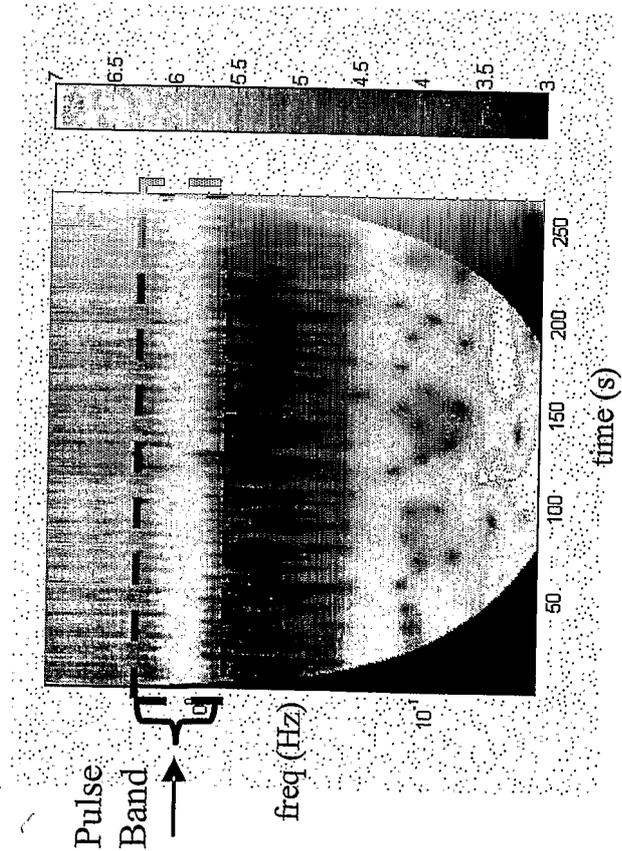
30

31 99. The method of claim 98, wherein the signal is
32 one of the group of signals comprising an

1 electrocardiogram, electroencephalogram,
2 electrogastrogram or electromyogram, heart rate
3 signals, pathological sounds, and ultrasound,
4 dynamic signals, non-destructive testing signals,
5 condition monitoring signals, fluid signals,
6 geophysical signals, astronomical signals,
7 electrical signals, financial signals including
8 financial indices, sound and speech signals,
9 chemical signals, and meteorological signals
10 including climate signals.
11
12 100. The method of claim 97 or claim 98, as applied
13 in conjunction with any of claims 1-96.
14



(a)



(b)

Figure 1

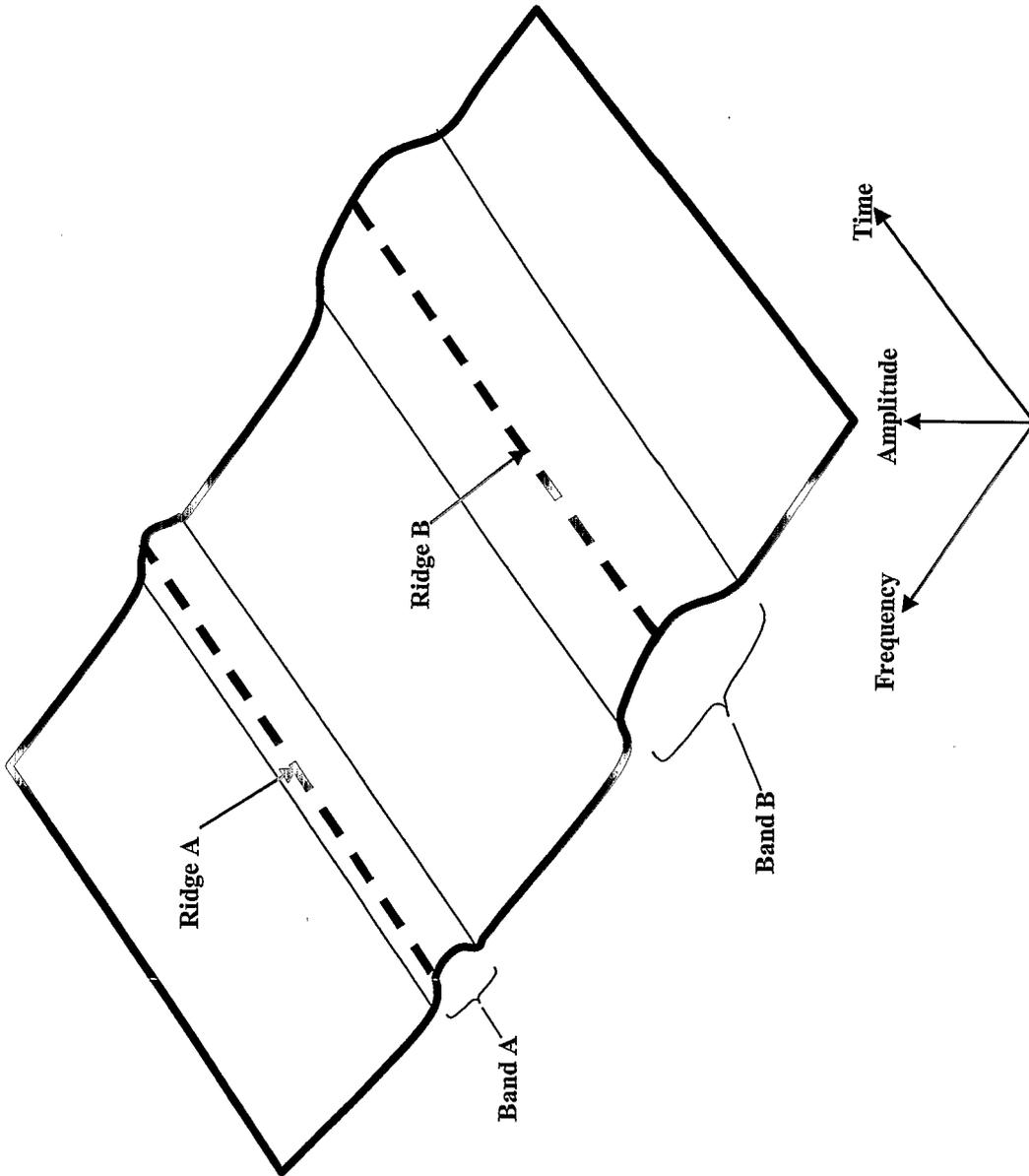


Figure 2

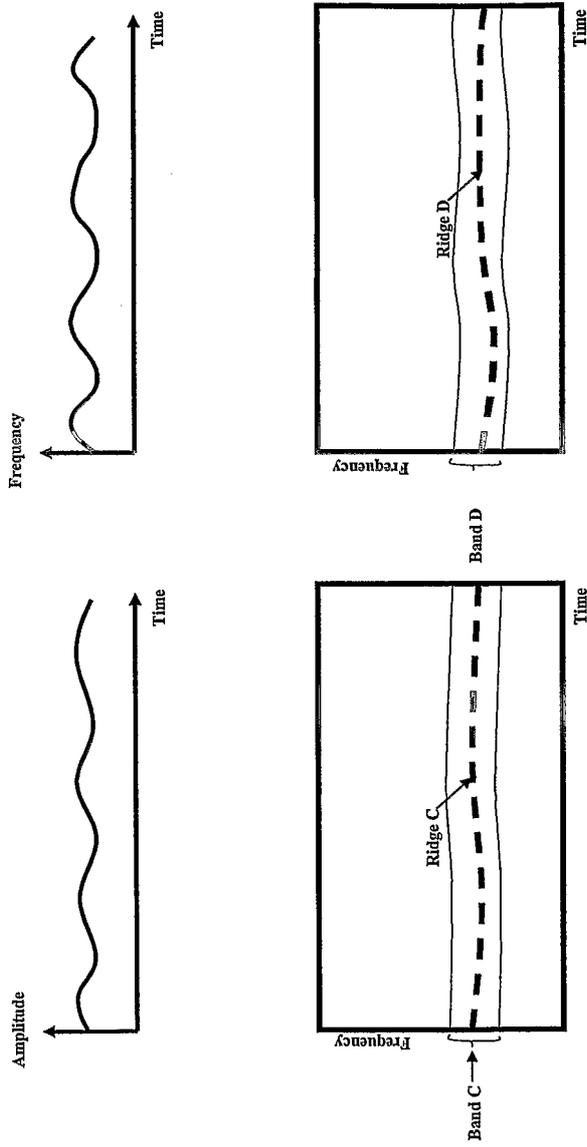
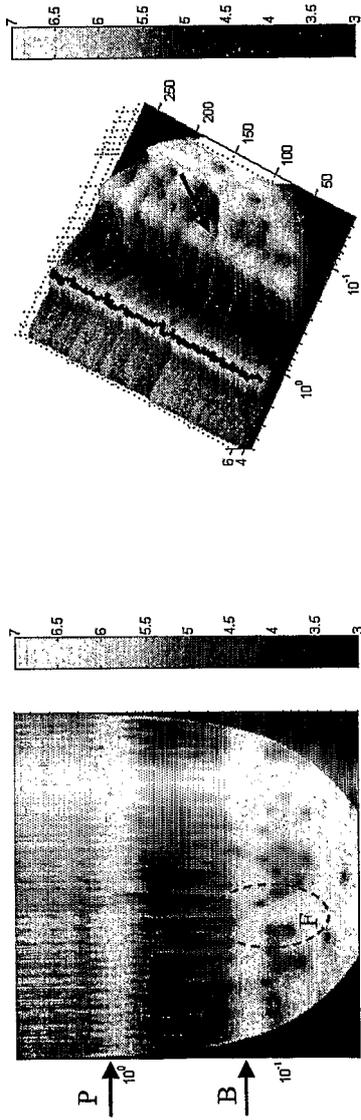
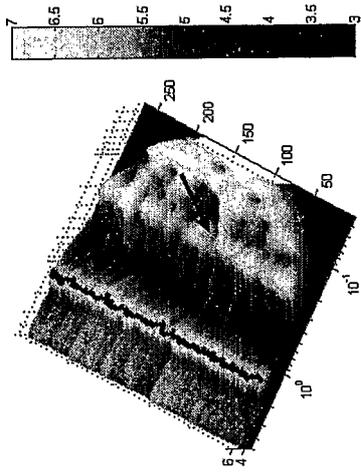


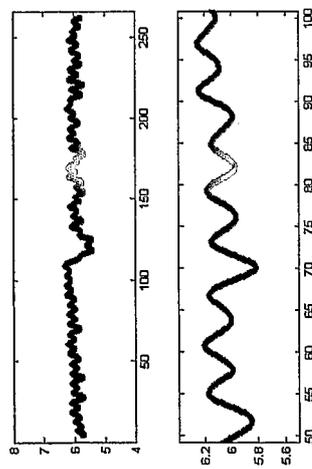
Figure 3



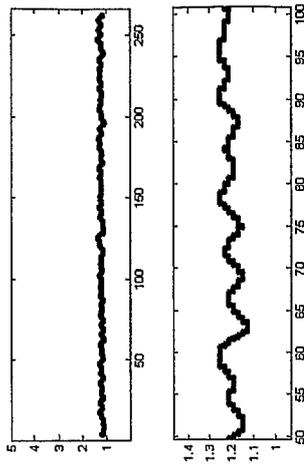
(a)



(b)

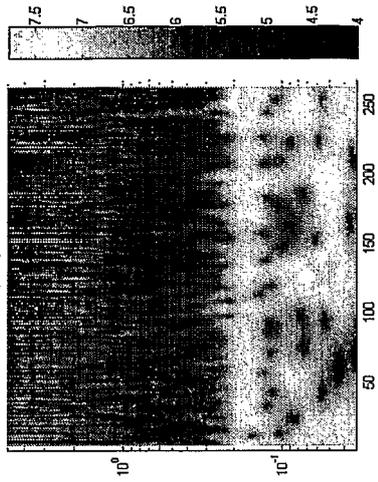


(c)

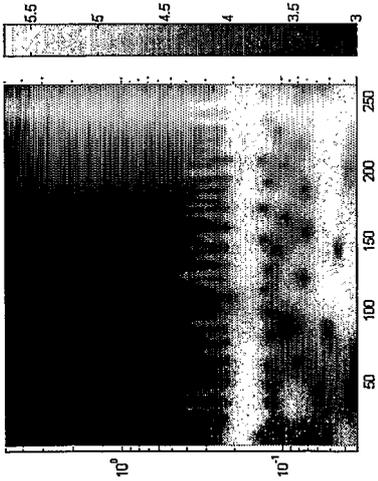


(d)

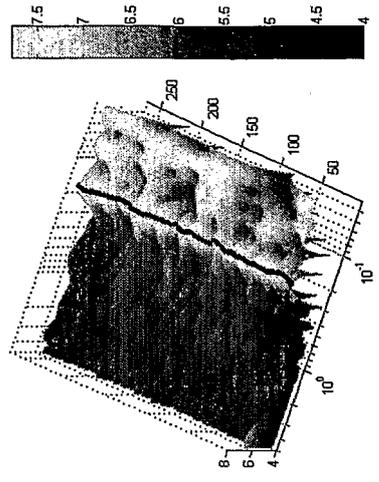
Figure 4



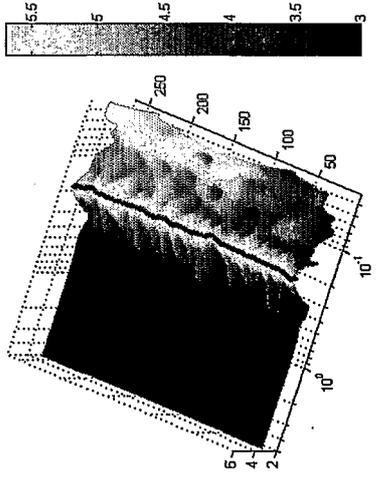
(a)



(b)



(c)



(d)

Figure 5

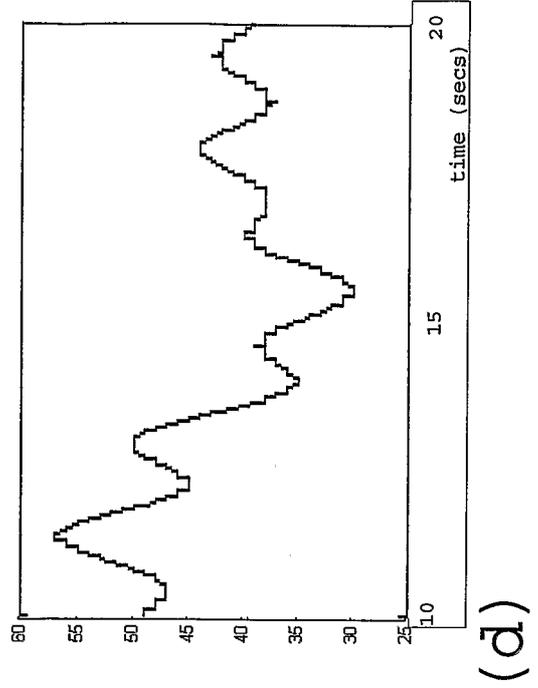
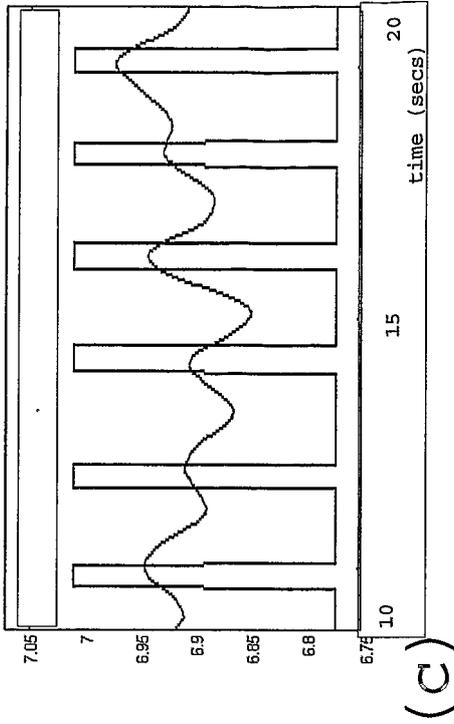
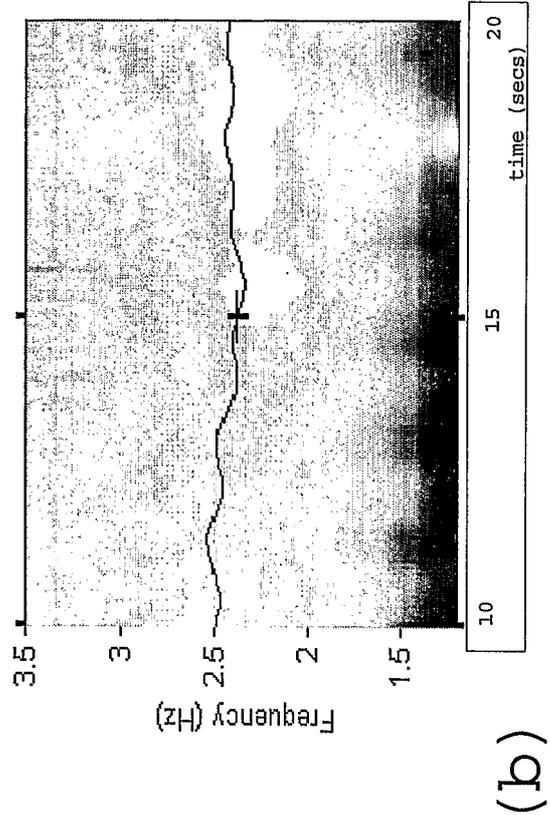
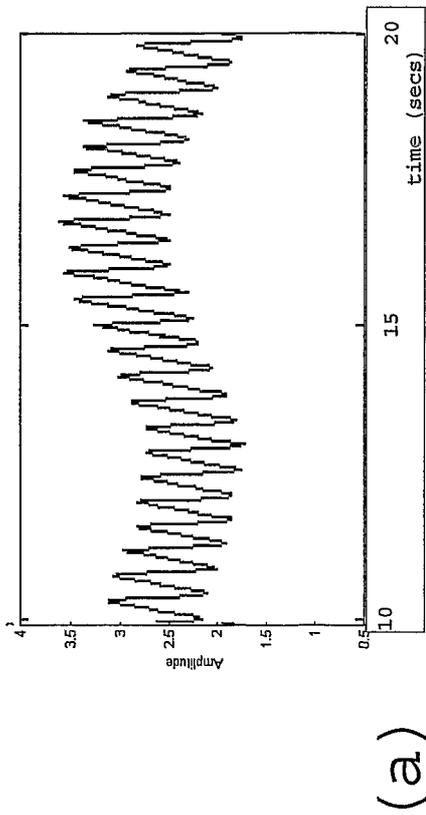
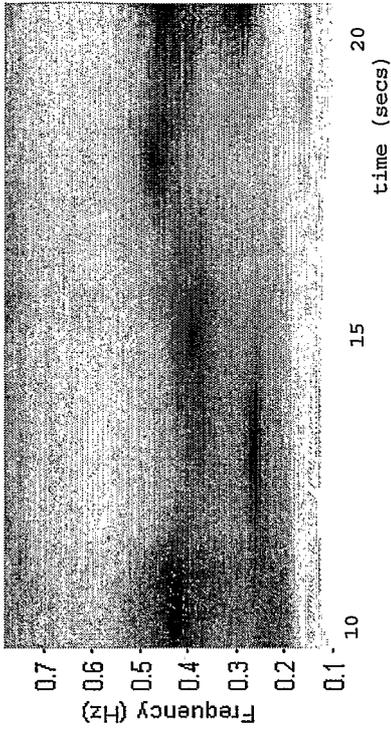
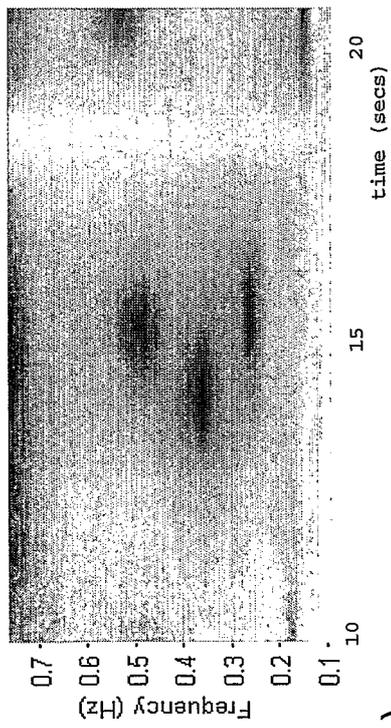


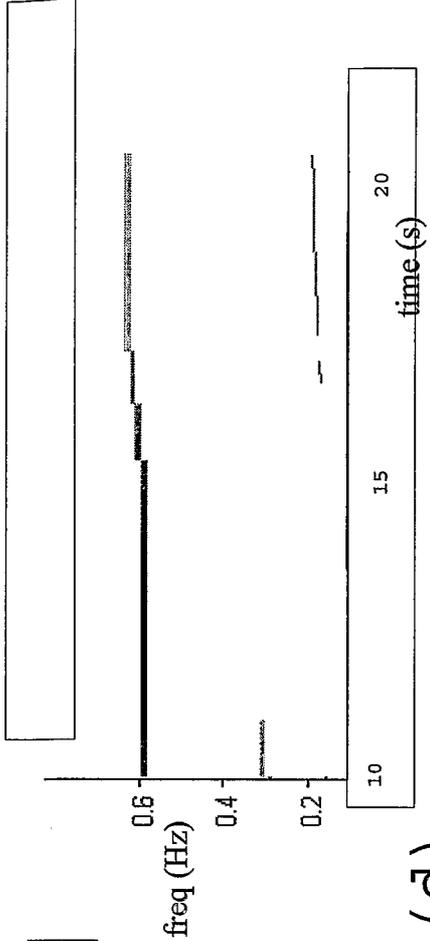
Figure 6



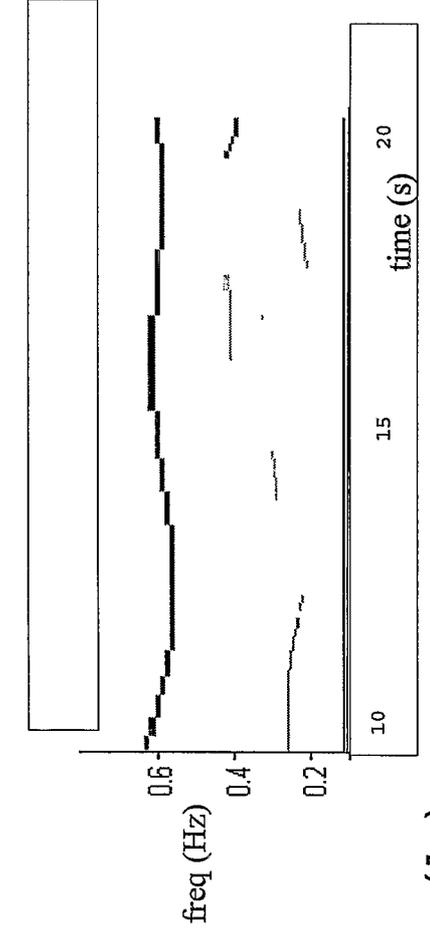
(a)



(b)

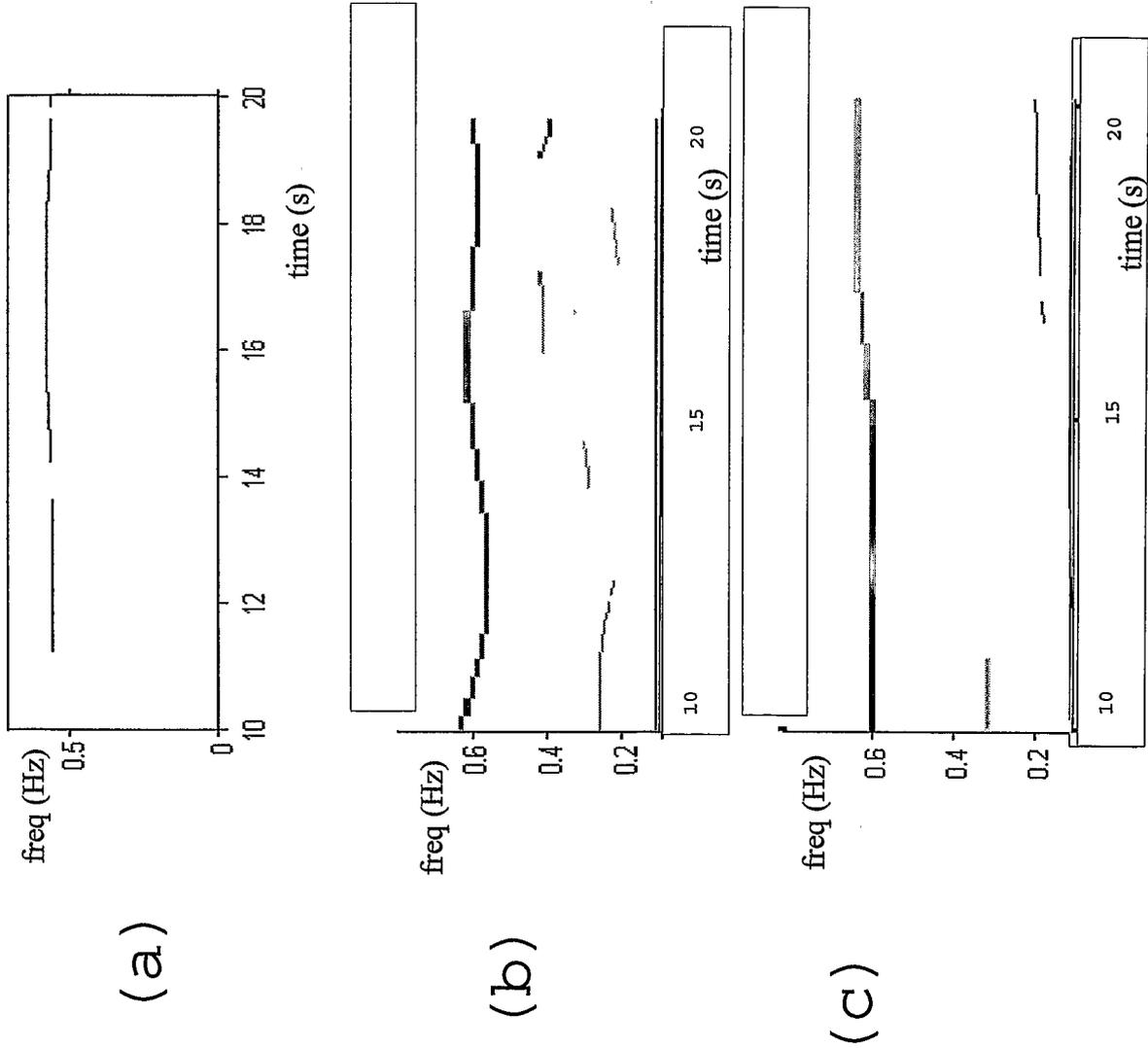


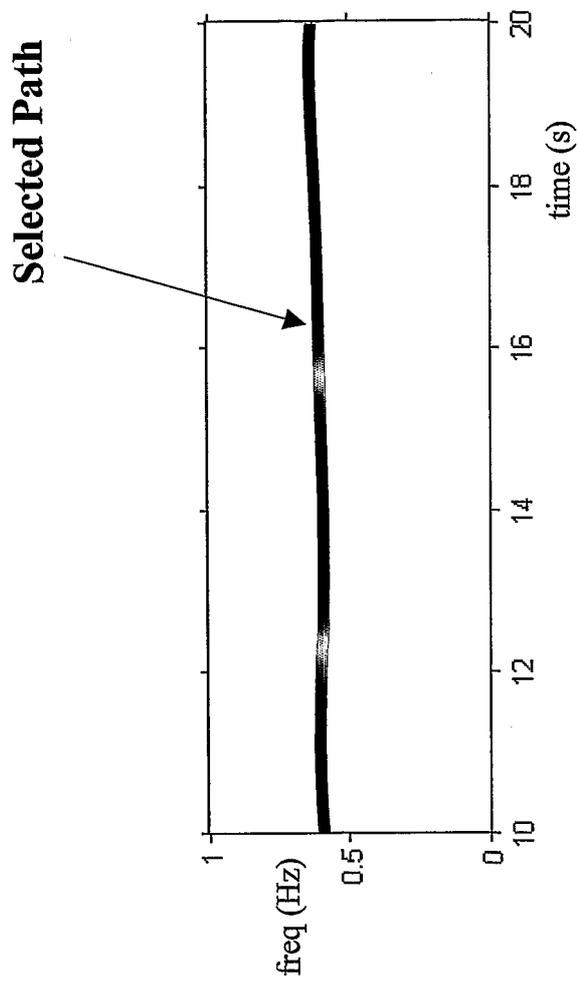
(c)



(d)

Figure 7





(d)

Figure 8 (continued)

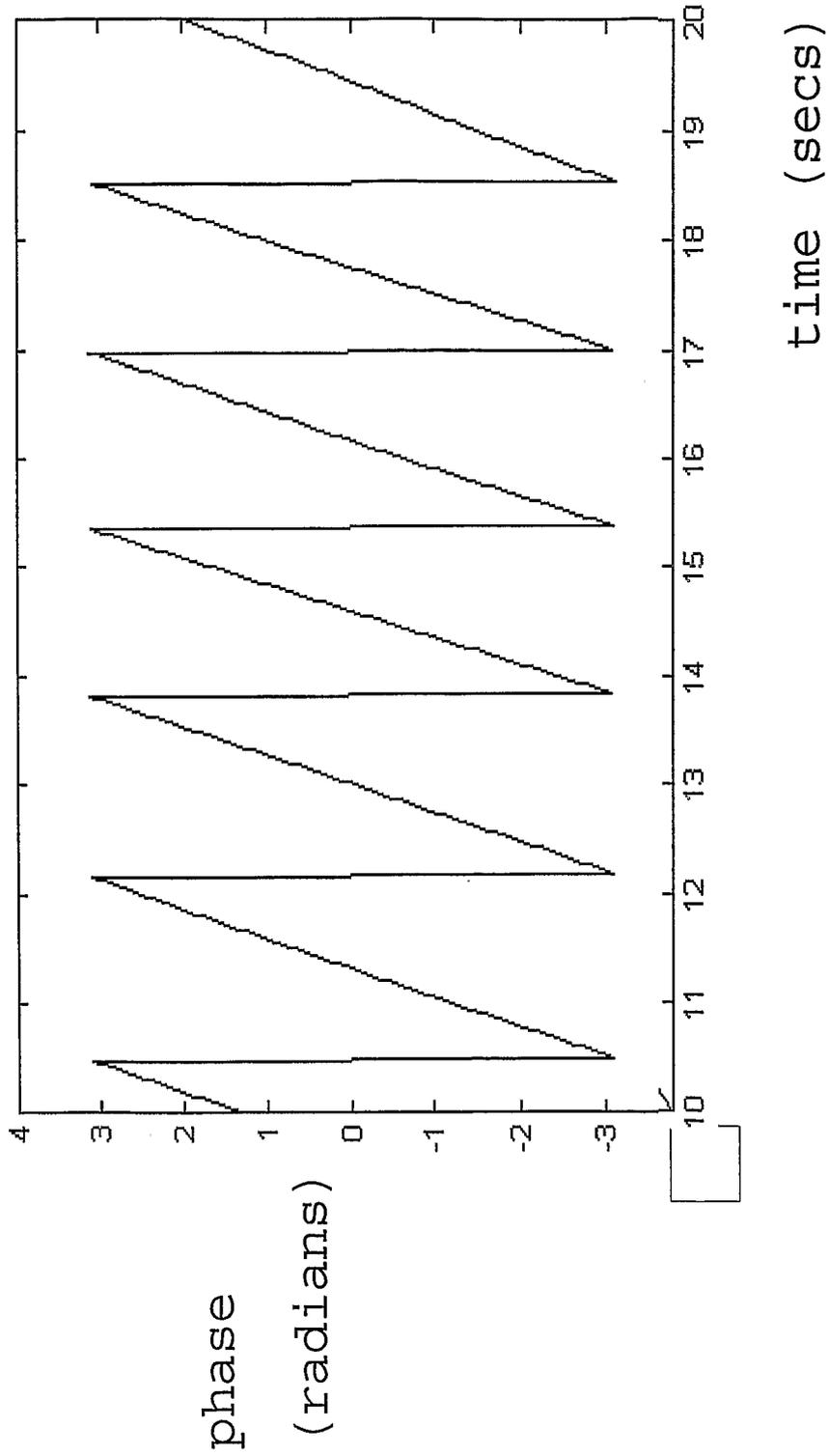


Figure 9

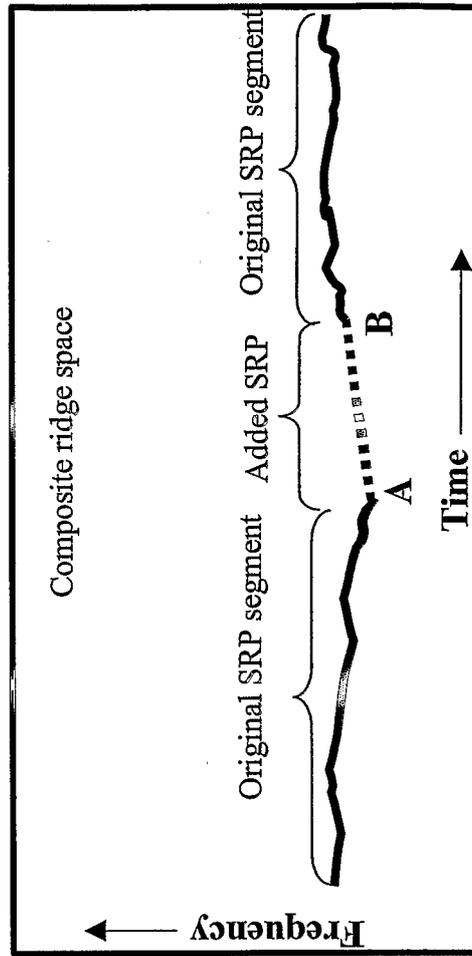


Figure 10

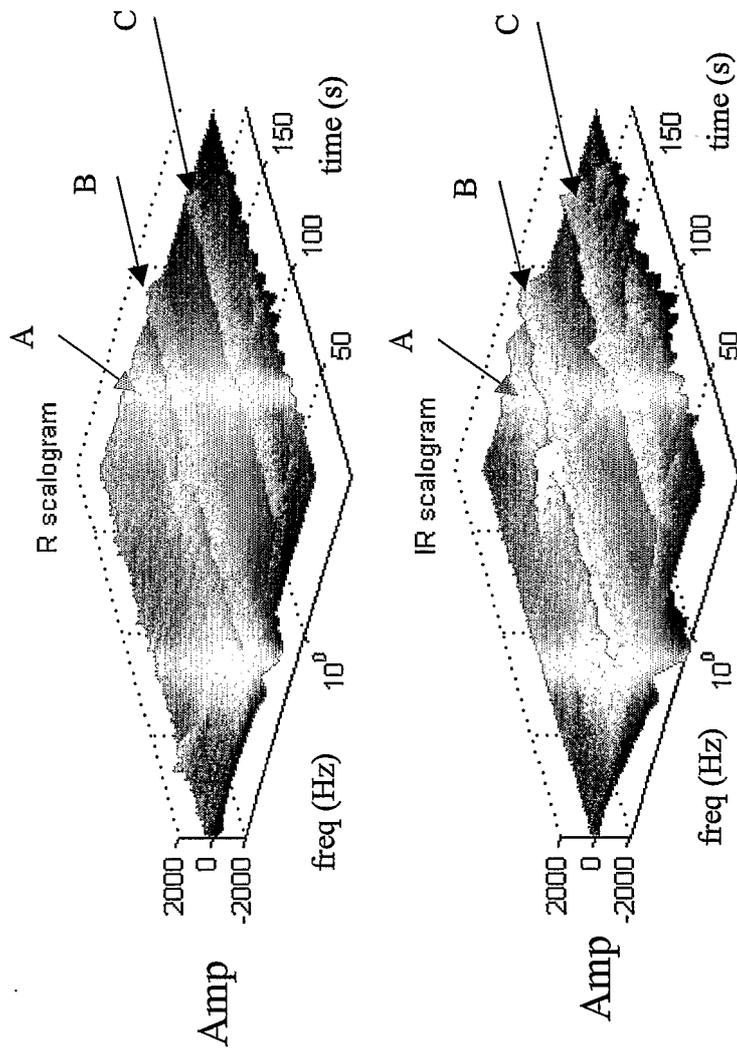


Figure 11

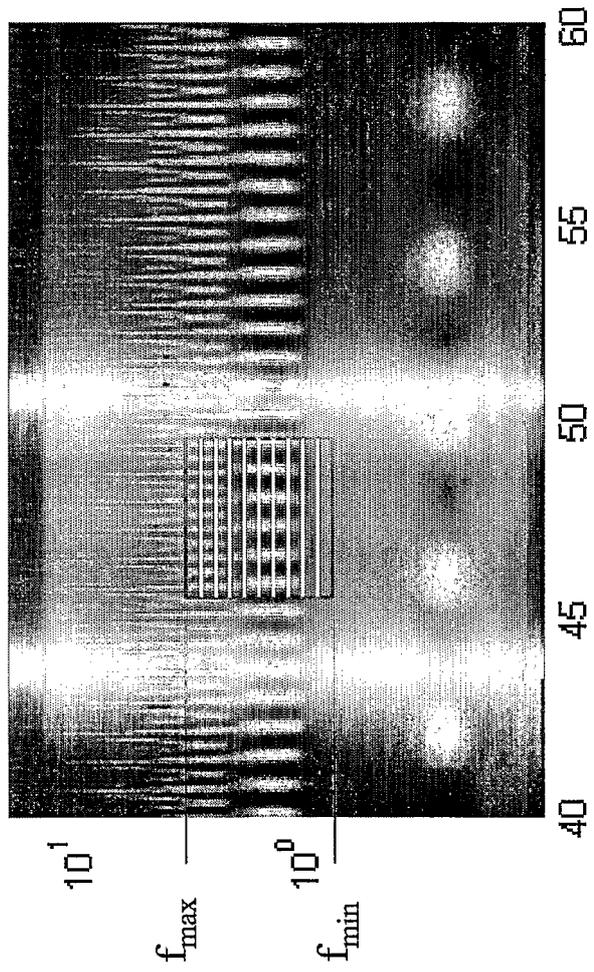
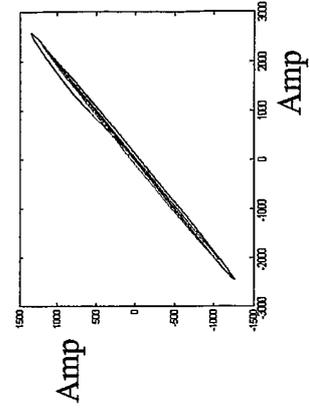
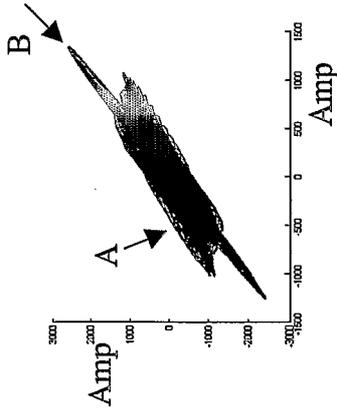


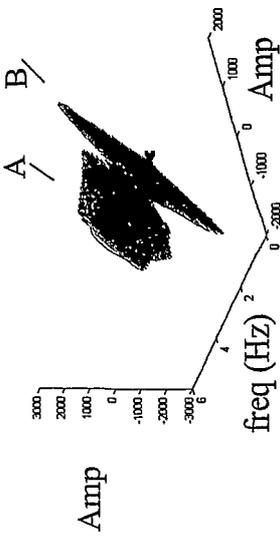
Figure 12



(c)



(b)



(a)

Figure 13

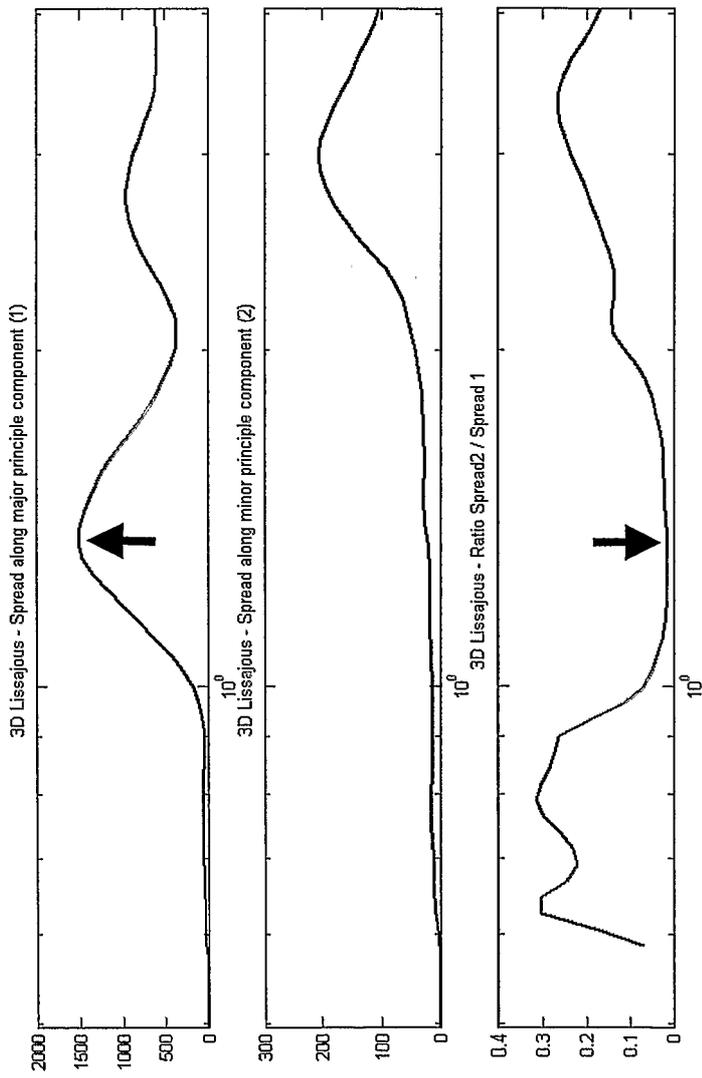


Figure 14

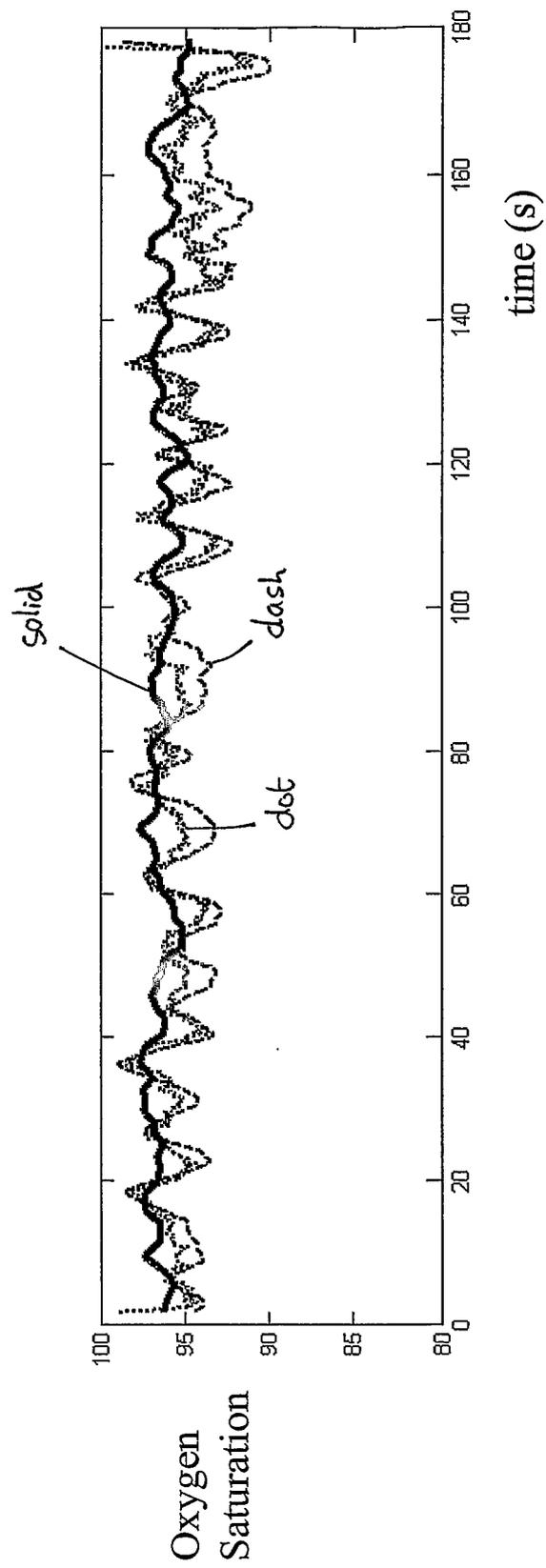


Figure 15

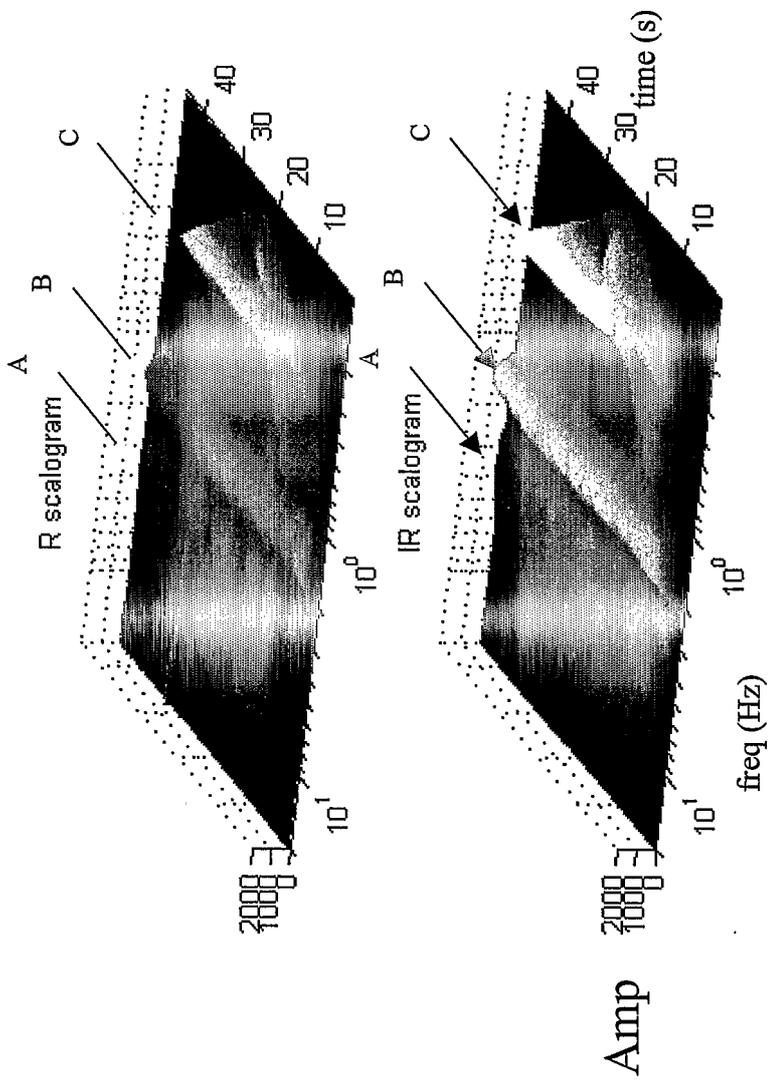


Figure 16

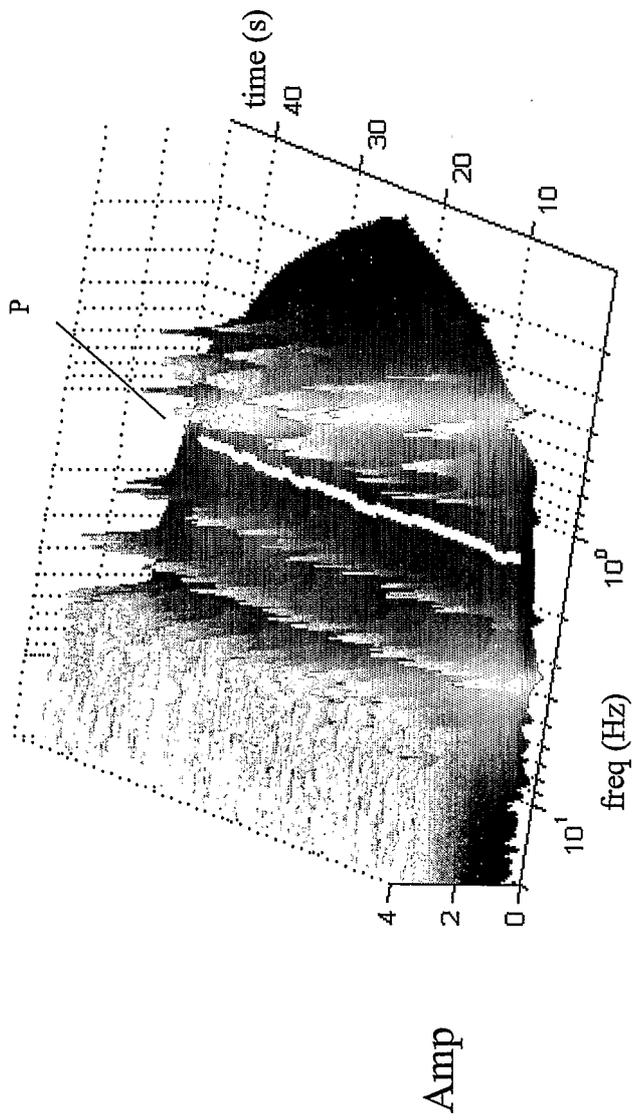


Figure 17

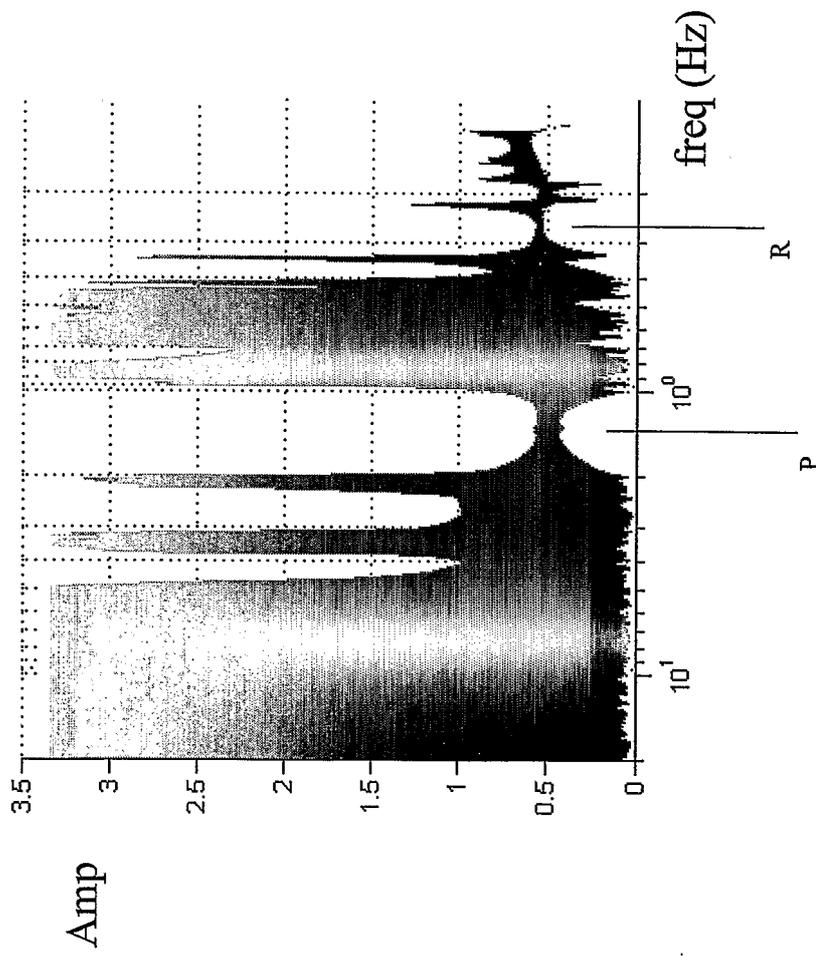


Figure 18

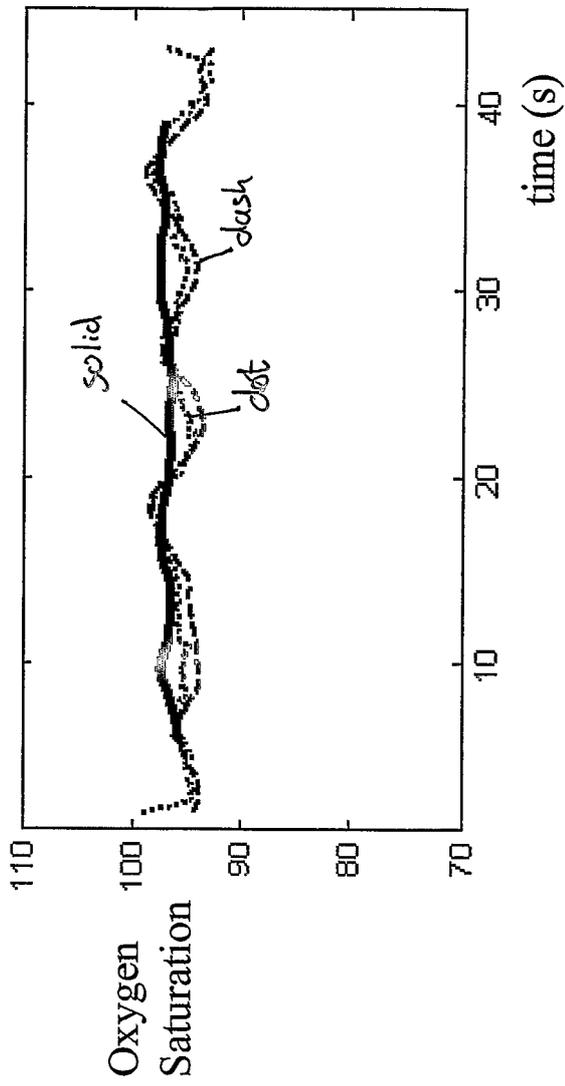
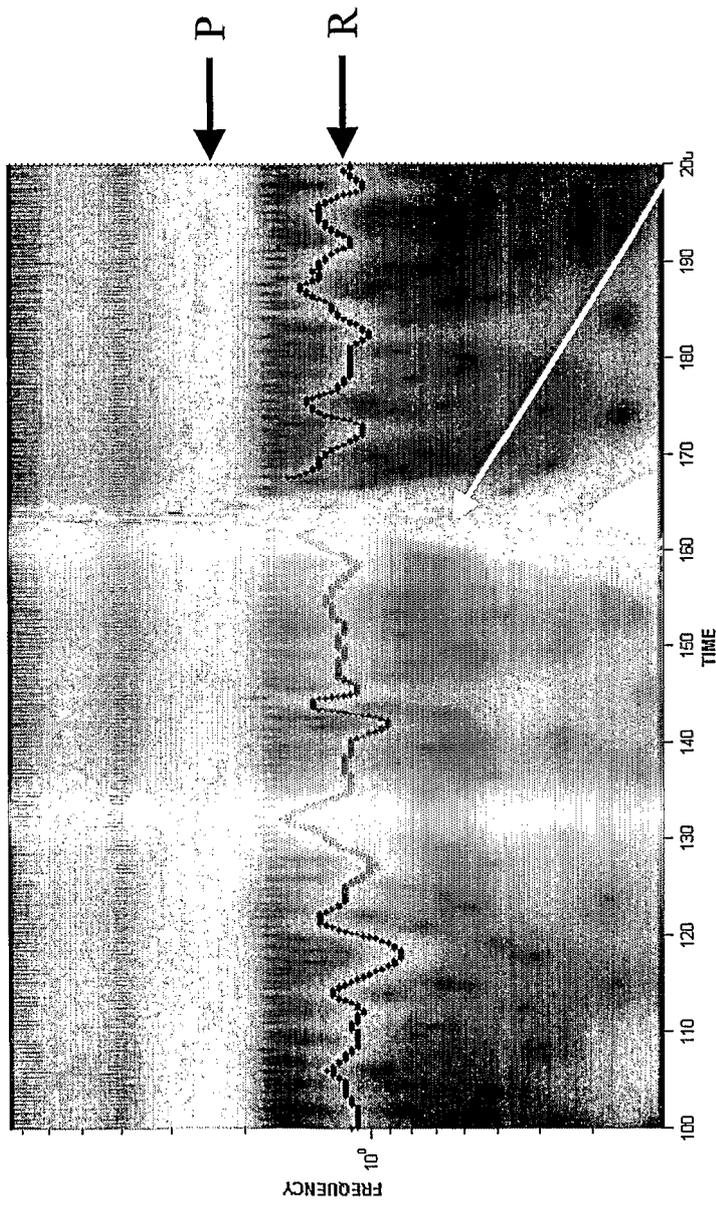


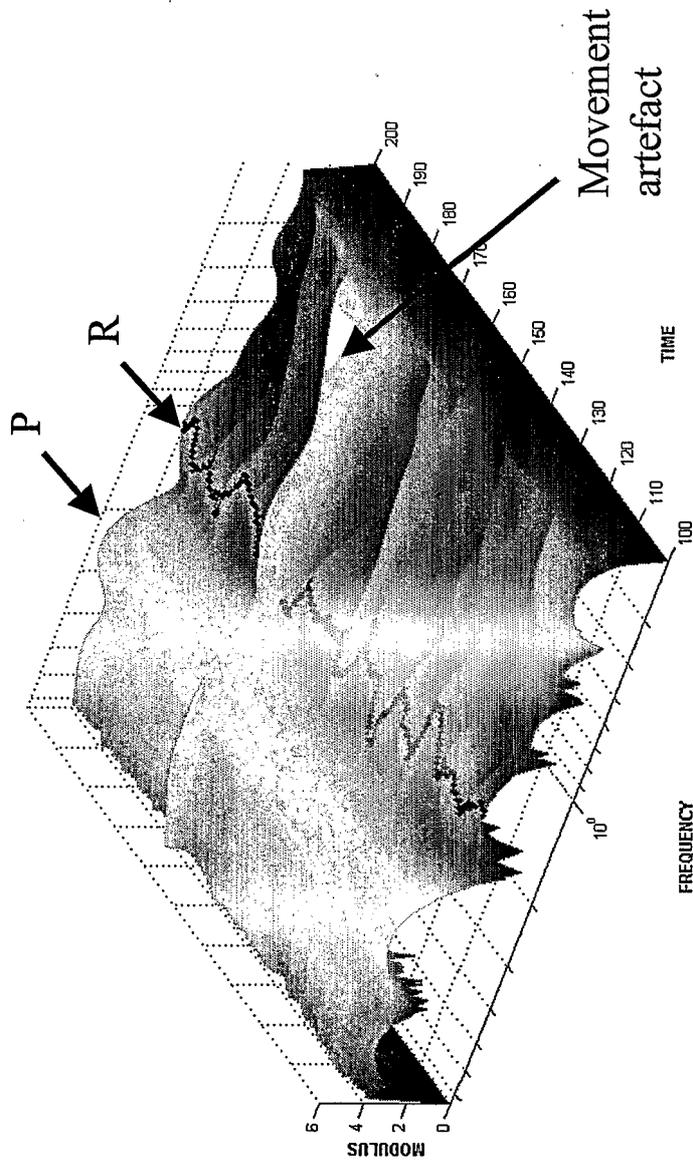
Figure 19



(a)

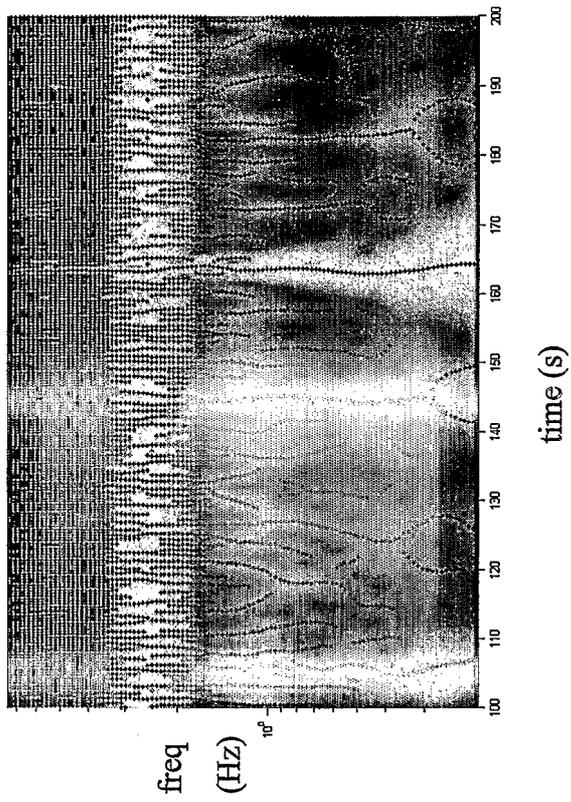
Movement
artefact

Figure 20



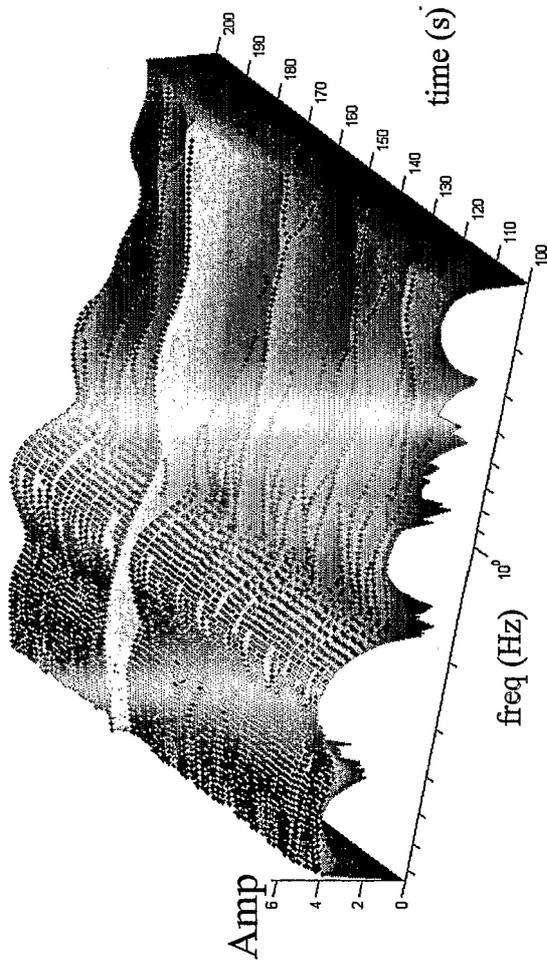
(b)

Figure 20 (continued)



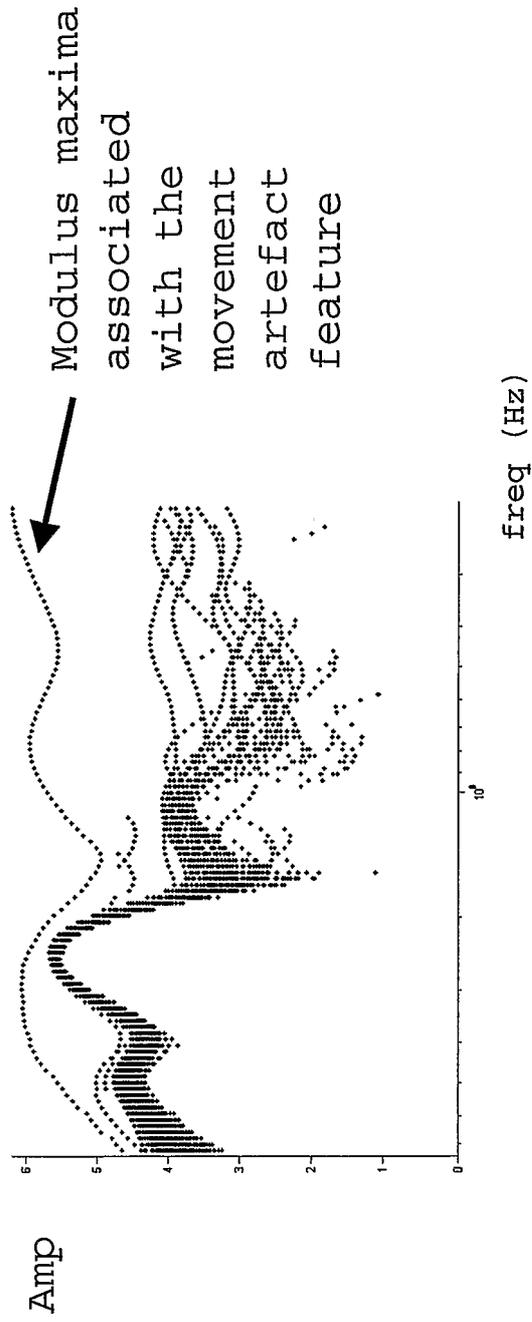
(a)

Figure 21



(b)

Figure 21 (continued)



(a)

Figure 22

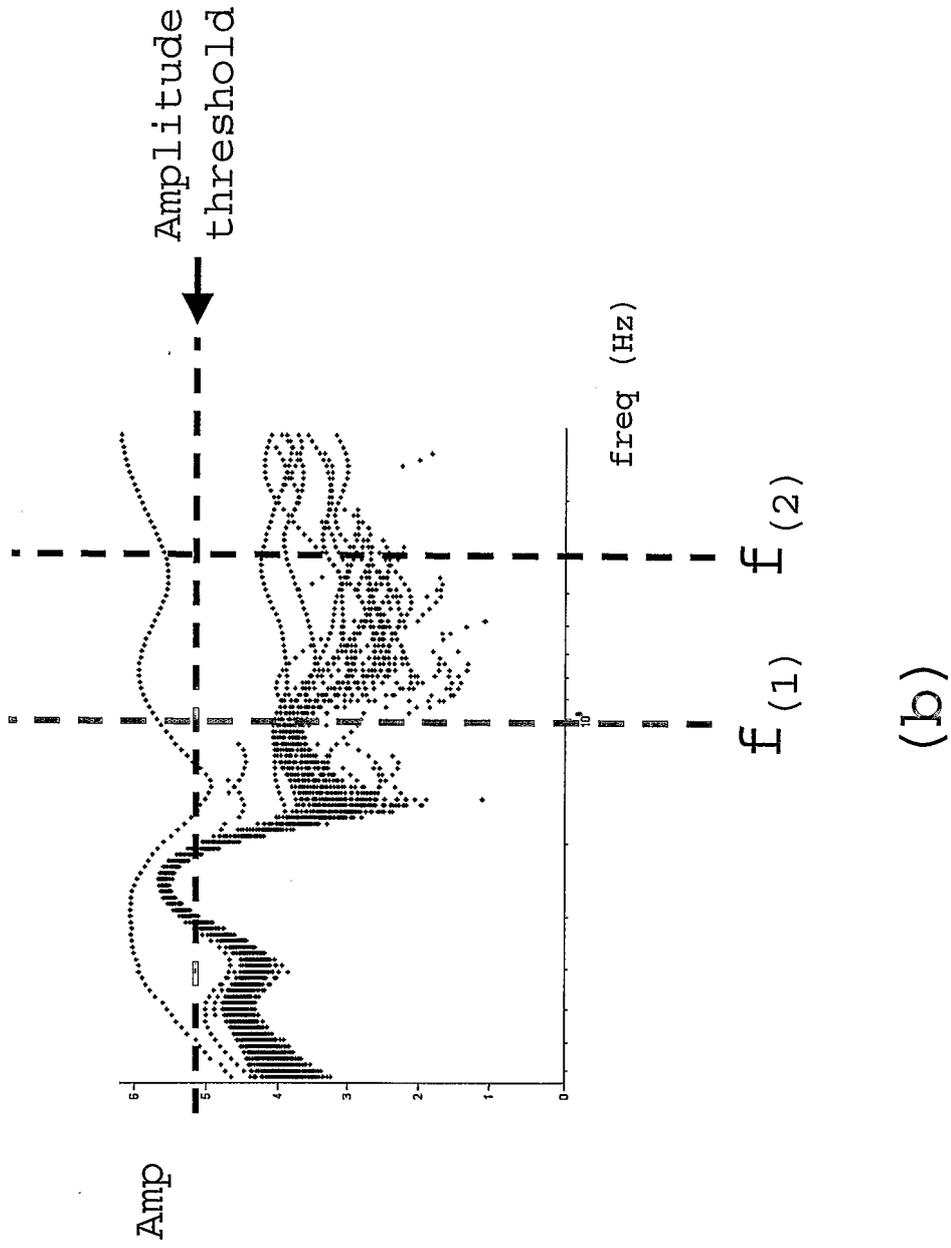
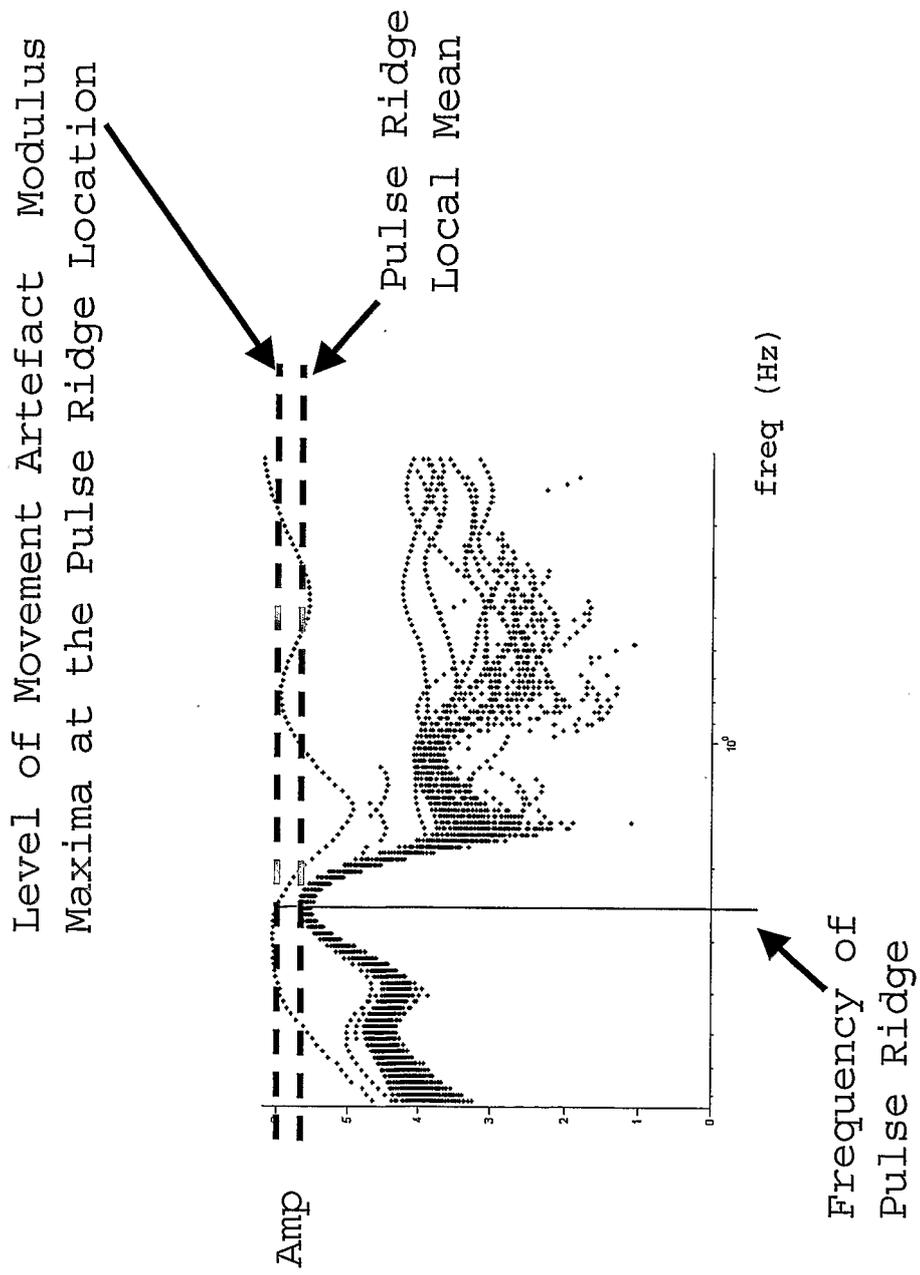


Figure 22



(C)

Figure 22

Level of Movement Artefact Modulus
Maxima at the Repiration Ridge Location

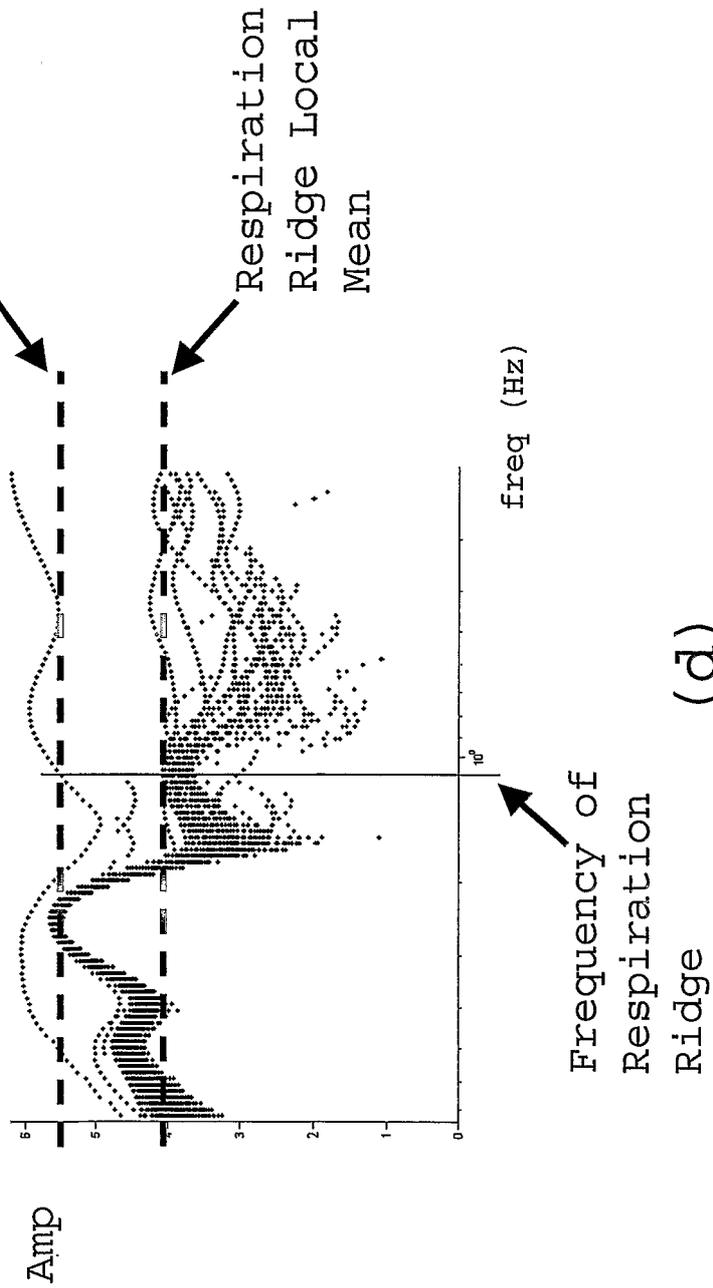


Figure 22 (d)

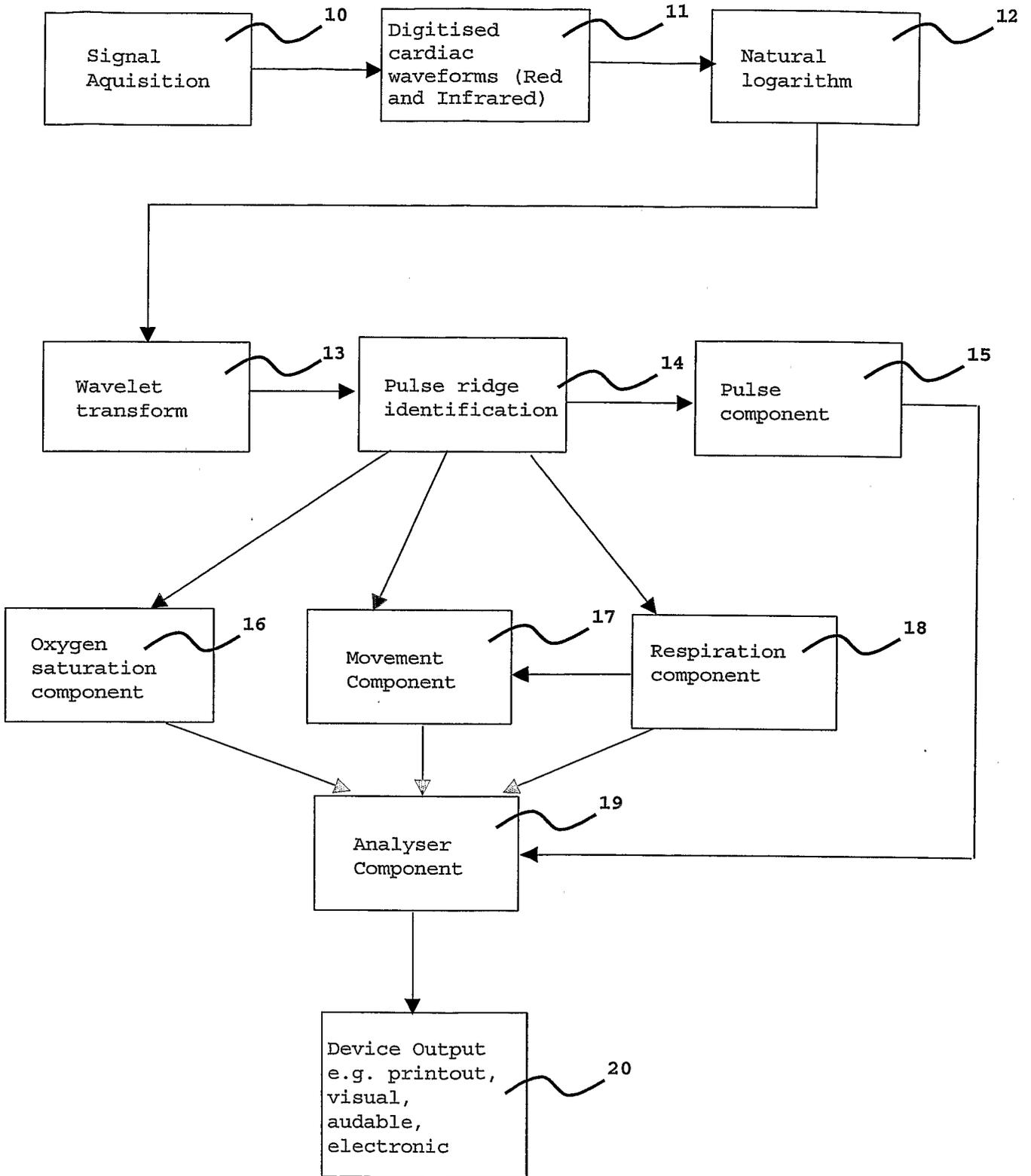


Figure 23

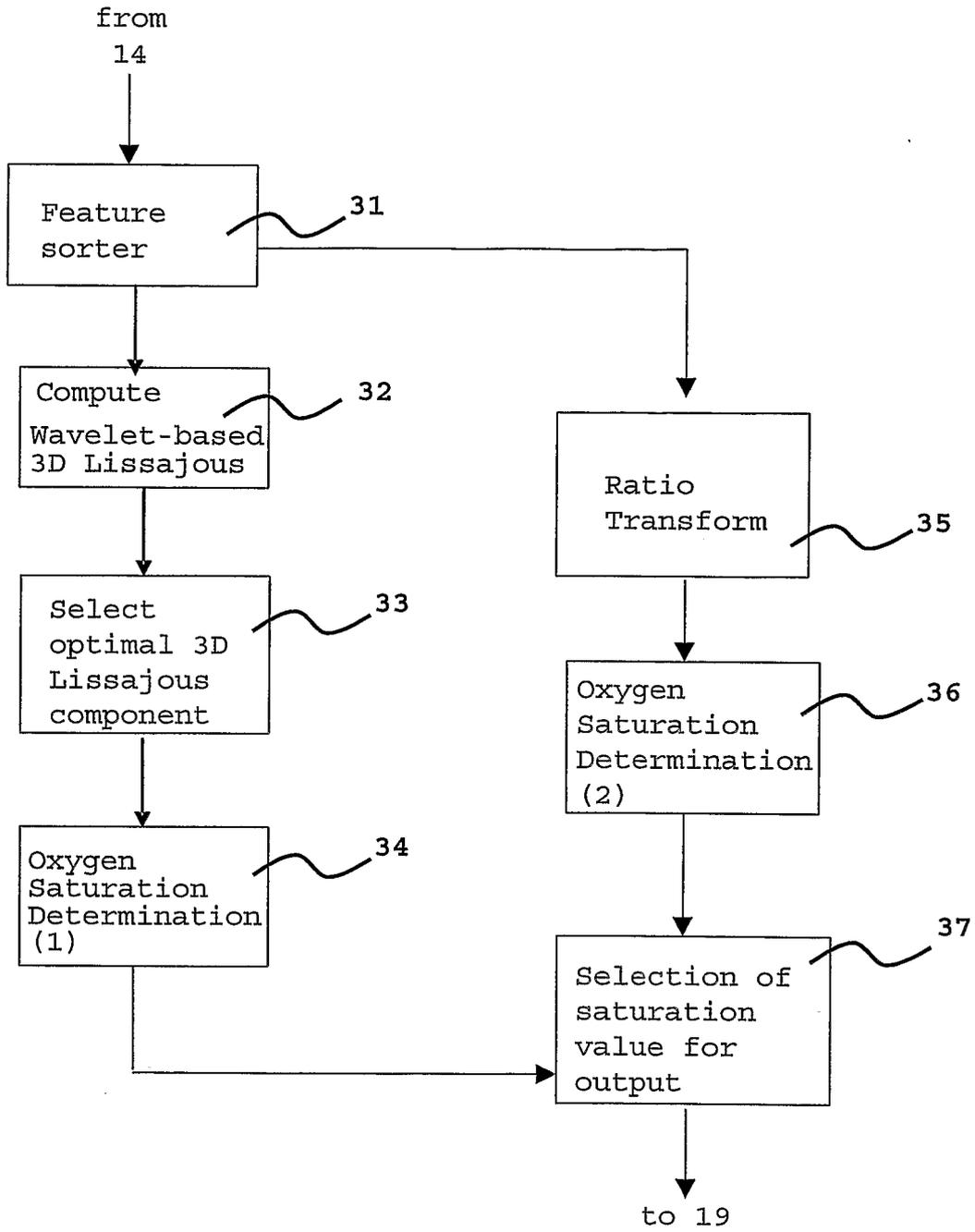


Figure 24

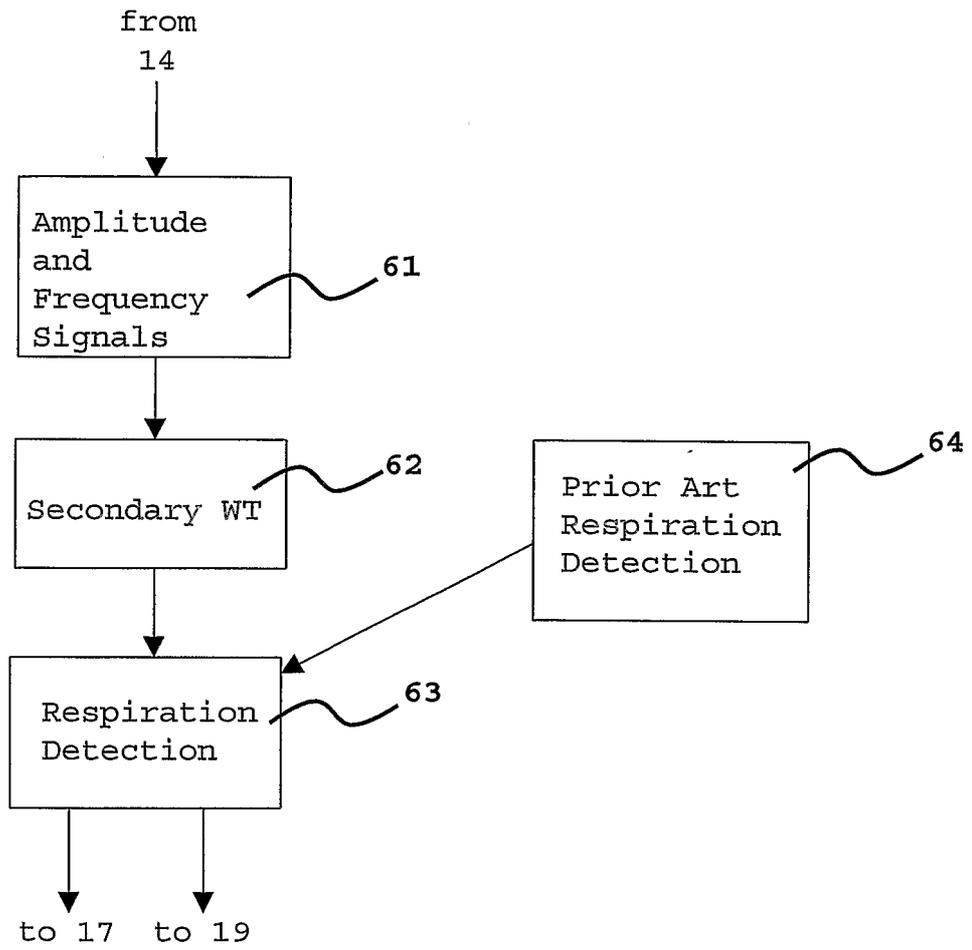


Figure 25

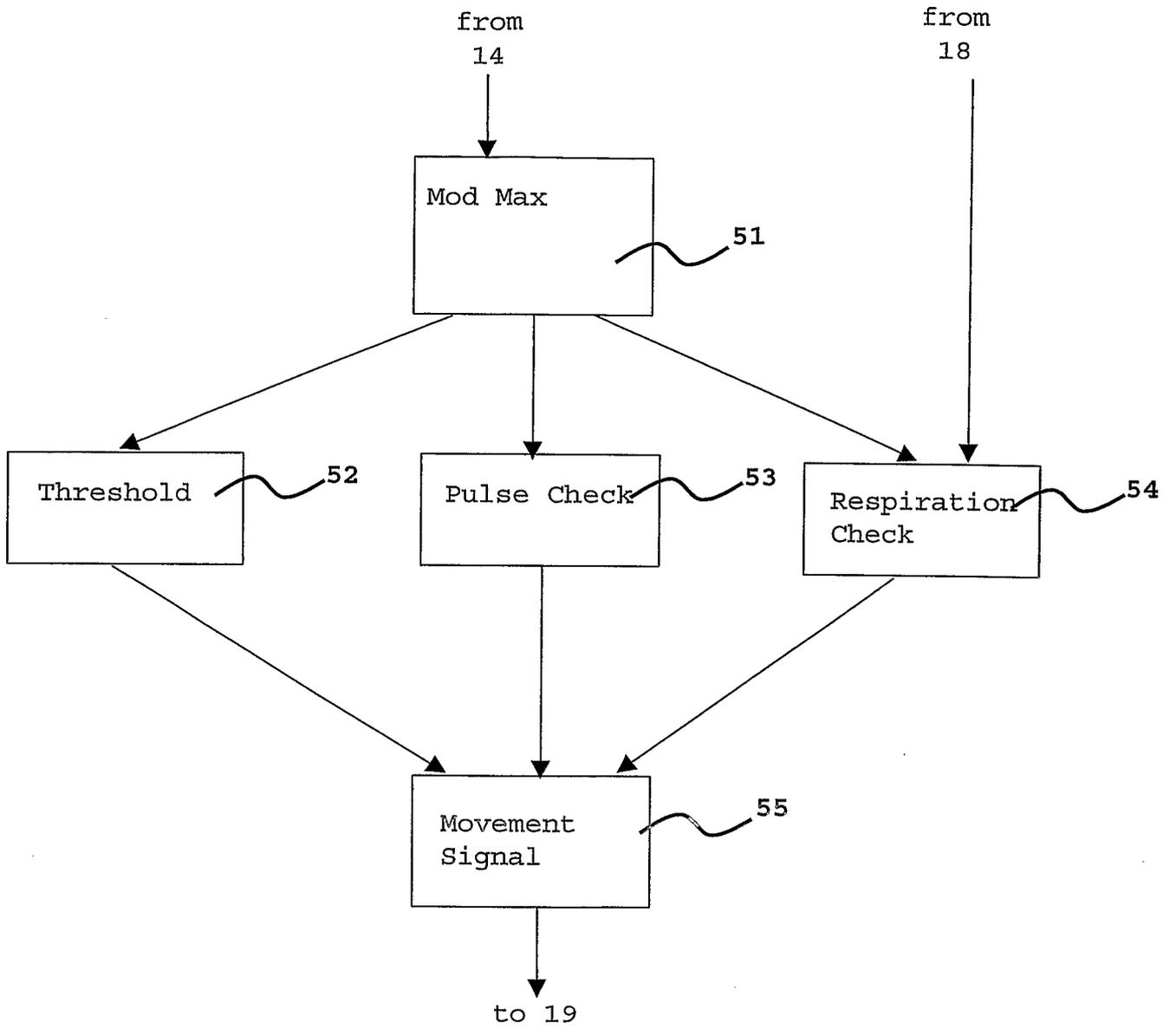


Figure 26

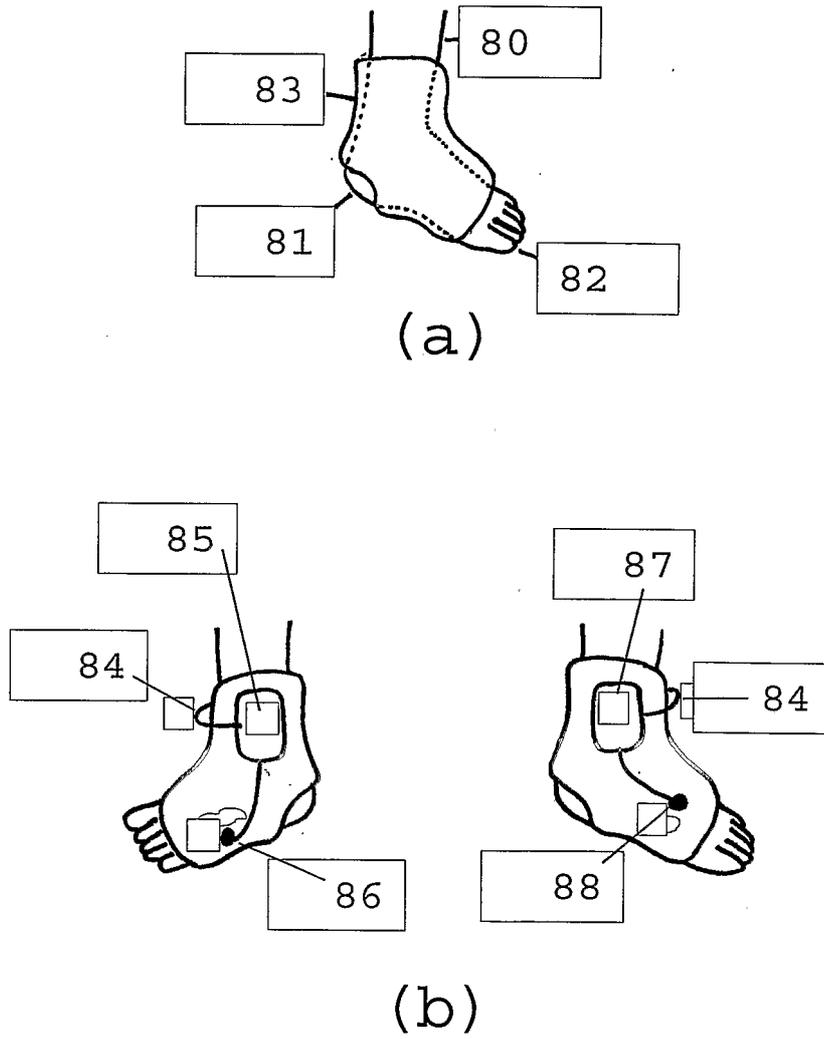


Figure 27

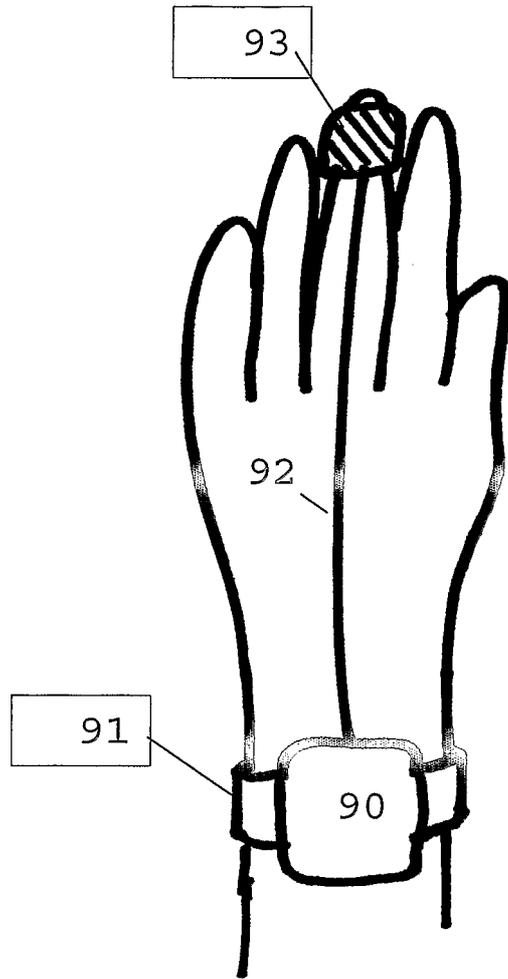


Figure 28

专利名称(译)	使用小波变换分析分析和处理光电容积描记图信号的方法和系统		
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申请(专利权)人(译)	CARDIODIGITAL有限公司		
当前申请(专利权)人(译)	NELLCOR PURITAN BENNETT爱尔兰		
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代理机构(译)	COOPER, JOHN		
优先权	2003005168 2003-03-07 GB 2003004413 2003-02-27 GB 2004003066 2004-02-12 GB		
其他公开文献	EP1628571B1		
外部链接	Espacenet		

摘要(译)

公开了一种生理测量系统，其可以从患者获取脉冲血氧测量信号，例如光电容积分，然后分析该信号以测量生理参数，包括呼吸，脉搏，氧饱和度和运动。该系统可用作一般监测器，或更具体地，用于婴儿或成人呼吸暂停，并用于防止婴儿猝死综合症。该系统包括脉冲血氧计，该脉搏血氧计包括发光装置和可附接到受试者的光电检测器，以获得脉搏血氧测定信号；模数转换器装置，用于将所述脉搏血氧饱和度信号转换成数字脉搏血氧饱和度信号；信号处理装置，适于接收所述数字脉搏血氧测定信号，并用于通过小波变换装置分解该信号；特征提取装置，用于从分解的信号中导出生理信息；分析器组件，用于从特征提取装置收集信息；数据输出装置设置成与分析器部件通信。