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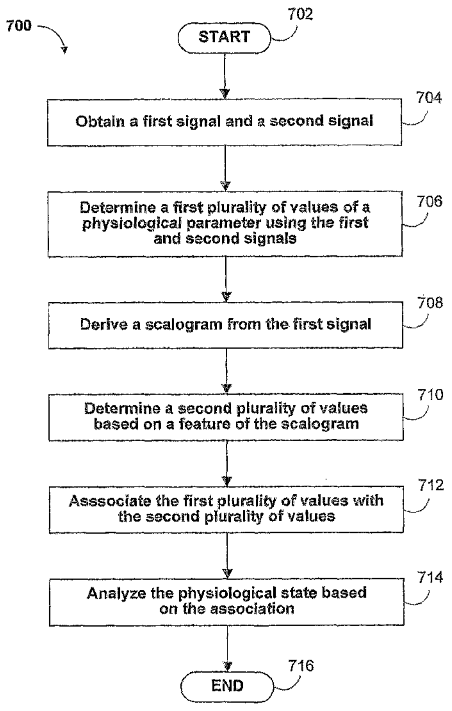

FIG. 7

(57) Abstract: The present disclosure relates to signal processing systems and methods, and more particularly, to systems and methods for analyzing multiparameter spaces to determine changes in a physiological state. A first signal and a second signal may be obtained, from which a first plurality of values of a physiological parameter may be computed. At least one of the signals also may be transformed using a wavelet transform, which may be used to generate a scalogram based at least in part on the transformed signal. A second plurality of values may be determined based at least in part on a feature in the scalogram. The first and second plurality of values may then be associated, and a physiological state may be analyzed using the associated first and second values. In an embodiment, the signals may be PPG signals and the associated first and second values may include a Lissajous figure that may permit a user to determine changes in a patient's ventilation state over time.

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Signal Processing Systems and Methods for Analyzing Multiparameter Spaces to Determine Physiological States

Summary

The present disclosure relates to signal processing systems and methods, and more particularly, to systems and methods for analyzing multiparameter spaces to determine changes in a physiological state. Multiple parameters may be derived from the same signal or signals and may be compared.

Brief Description of the Drawings

The above and other features of the present disclosure, its nature and various advantages will be more apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings in which:

FIG. 1 is a perspective view of a pulse oximetry system;

FIG. 2 is a block diagram of the exemplary pulse oximetry system of **FIG. 1** coupled to a patient;

FIGS. 3(a) and **3(b)** show illustrative views of a scalogram derived from a PPG signal in accordance with an embodiment;

FIG. 3(c) shows an illustrative schematic of a wavelet transform of a signal containing two pertinent components in accordance with an embodiment;

FIG. 3(d) shows an illustrative schematic of signals associated with a ridge in **FIG. 3(c)** and schematics of a further wavelet decomposition of these newly derived signals in accordance with an embodiment;

FIGS. 3(e) and **3(f)** show flow charts of illustrative steps involved in performing an inverse continuous wavelet transform in accordance with embodiments;

FIG. 4 shows an illustrative continuous wavelet processing system in accordance with an embodiment;

FIG. 5 shows a plot of two signals detected in accordance with an embodiment; and

FIG. 6 shows threshold regions in a multiparameter plot in accordance with an embodiment.

Detailed Description

In medicine, a plethysmograph is an instrument that measures physiological parameters, such as variations in the size of an organ or body part, through an analysis of the blood passing through or present in the targeted body part, or a depiction of these variations. An oximeter is an instrument that may determine the oxygen saturation of the blood. One common type of oximeter is a pulse oximeter, which determines oxygen saturation by analysis of an optically sensed plethysmograph.

A pulse oximeter is a medical device that may indirectly measure the oxygen saturation of a patient's blood (as opposed to measuring oxygen saturation directly by analyzing a blood sample taken from the patient) and changes in blood volume in the skin. Ancillary to the blood oxygen saturation measurement, pulse oximeters may also be used to measure the pulse rate of the patient. Pulse oximeters typically measure and display various blood flow characteristics including, but not limited to, the oxygen saturation of hemoglobin in arterial blood.

An oximeter may include a light sensor that is placed at a site on a patient, typically a fingertip, toe, forehead or earlobe, or in the case of a neonate, across a foot. The oximeter may pass light using a light source through blood perfused tissue and photoelectrically sense the absorption of light in the tissue. For example, the oximeter may measure the intensity of light that is received at the light sensor as a function of time. A graph of light intensity versus time may be referred to as the photoplethysmogram. The light intensity or the amount of light absorbed may then used to calculate the amount of the blood constituent (*e.g.*, oxyhemoglobin) being measured as well as the pulse rate and when each individual pulse occurs.

The light passed through the tissue is selected to be of one or more wavelengths that are absorbed by the blood in an amount representative of the amount of the blood constituent present in the blood. The amount of light passed through the tissue varies in accordance with the changing amount of blood constituent in the tissue and the related light absorption. Red and infrared wavelengths may be used because it has been observed that highly oxygenated blood will absorb relatively less red light and more infrared light than blood with a lower oxygen saturation. By comparing the intensities of two wavelengths at different points in the pulse cycle, it is possible to estimate the blood oxygen saturation of hemoglobin in arterial blood.

When the measured blood parameter is the oxygen saturation of hemoglobin, a convenient starting point assumes a saturation calculation based on Lambert-Beer's law. The following notation will be used herein:

$$I(\lambda,t) = I_o(\lambda)\exp(-(s\beta_o(\lambda)+(1-s)\beta_r(\lambda))l(t)) \tag{1}$$

where:

λ=wavelength;

t=time;

I=intensity of light detected;

I_o=intensity of light transmitted;

s=oxygen saturation;

β_o, β_r=empirically derived absorption coefficients; and

l(t)=a combination of concentration and path length from emitter to detector as a function of time.

The traditional approach measures light absorption at two wavelengths (*e.g.*, red and infrared (IR)), and then calculates saturation by solving for the "ratio of ratios" as follows.

1. First, the natural logarithm of (1) is taken ("log" will be used to represent the natural logarithm) for IR and Red

$$\log I = \log I_o - (s\beta_o + (1-s)\,\beta_r)l \tag{2}$$

2. (2) is then differentiated with respect to time

$$\frac{d\log I}{dt} = -(s\beta_o + (1-s)\beta_r)\frac{dl}{dt} \tag{3}$$

3. Red (3) is divided by IR (3)

$$\frac{d\log I(\lambda_R)/dt}{d\log I(\lambda_{IR})/dt} = \frac{s\beta_o(\lambda_R) + (1-s)\beta_r(\lambda_R)}{s\beta_o(\lambda_{IR}) + (1-s)\beta_r(\lambda_{IR})} \tag{4}$$

4. Solving for s

$$s = \frac{\dfrac{d\log I(\lambda_{IR})}{dt}\beta_r(\lambda_R) - \dfrac{d\log I(\lambda_R)}{dt}\beta_r(\lambda_{IR})}{\dfrac{d\log I(\lambda_R)}{dt}(\beta_o(\lambda_{IR}) - \beta_r(\lambda_{IR})) - \dfrac{d\log I(\lambda_{IR})}{dt}(\beta_o(\lambda_R) - \beta_r(\lambda_R))}$$

Note in discrete time

$$\frac{d\log I(\lambda,t)}{dt} \simeq \log I(\lambda,t_2) - \log I(\lambda,t_1)$$

Using log A-log B=log A/B,

$$\frac{d\log I(\lambda,t)}{dt} \simeq \log\left(\frac{I(t_2,\lambda)}{I(t_1,\lambda)}\right)$$

So, (4) can be rewritten as

$$\frac{\frac{d\log I(\lambda_R)}{dt}}{\frac{d\log I(\lambda_{IR})}{dt}} \simeq \frac{\log\left(\frac{I(t_1,\lambda_R)}{I(t_2,\lambda_R)}\right)}{\log\left(\frac{I(t_1,\lambda_{IR})}{I(t_2,\lambda_{IR})}\right)} = R \tag{5}$$

where **R** represents the "ratio of ratios." Solving (4) for s using (5) gives

$$s = \frac{\beta_r(\lambda_R) - R\beta_r(\lambda_{IR})}{R(\beta_o(\lambda_{IR}) - \beta_r(\lambda_{IR})) - \beta_o(\lambda_R) + \beta_r(\lambda_R)}.$$

From (5), **R** can be calculated using two points (*e.g.*, PPG maximum and minimum), or a family of points. One method using a family of points uses a modified version of (5). Using the relationship

$$\frac{d\log I}{dt} = \frac{dt/dt}{I} \tag{6}$$

now (5) becomes

$$\begin{aligned}\frac{\frac{d\log I(\lambda_R)}{dt}}{\frac{d\log I(\lambda_{IR})}{dt}} &\simeq \frac{\frac{I(t_2,\lambda_R)-I(t_1,\lambda_R)}{I(t_1,\lambda_R)}}{\frac{I(t_2,\lambda_{IR})-I(t_1,\lambda_{IR})}{I(t_1,\lambda_{IR})}}\\ &= \frac{[I(t_2,\lambda_R)-I(t_1,\lambda_R)]I(t_1,\lambda_{IR})}{[I(t_2,\lambda_{IR})-I(t_1,\lambda_{IR})]I(t_1,\lambda_R)}\\ &= R\end{aligned} \tag{7}$$

which defines a cluster of points whose slope of y versus x will give **R** where

$$\begin{aligned}x(t) &= [I(t_2,\lambda_{IR}) - I(t_1,\lambda_{IR})]I(t_1,\lambda_R)\\ y(t) &= [I(t_2,\lambda_R) - I(t_1,\lambda_R)]I(t_1,\lambda_{IR})\\ y(t) &= Rx(t)\end{aligned} \tag{8}$$

The optical signal through the tissue can be degraded by noise and motion artifact, among other sources. One source of noise is ambient light which reaches the light detector. Another source of noise is electromagnetic coupling from other electronic instruments. Movement of the patient also introduces noise and affects the signal. For example, the contact between the detector and the skin, or the emitter and the skin, can be temporarily disrupted when movement causes either to move away from the skin. In addition, since blood is a fluid, it responds differently than the surrounding tissue to inertial effects, thus resulting in momentary changes in volume at the point to which the oximeter probe is attached.

Motion artifact can degrade a pulse oximetry signal relied upon by a physician, without the physician's awareness. This is especially true if the monitoring of the patient is remote, the motion is too small to be observed, or the doctor is watching the instrument or other parts of the patient, and not the sensor site.

It will be understood that the present disclosure is applicable to any suitable signals and that PPG signals are used merely for illustrative purposes. Those skilled in the art will recognize that the present disclosure has wide applicability to other signals including, but not limited to other biosignals (*e.g.*, electrocardiogram, electroencephalogram, electrogastrogram, electromyogram, heart rate signals, pathological sounds, ultrasound, or any other suitable biosignal), dynamic signals, non-destructive testing signals, condition monitoring signals, fluid signals, geophysical signals, astronomical signals, electrical signals, financial signals including financial indices, sound and speech signals, chemical signals, meteorological signals including climate signals, and/or any other suitable signal, and/or any combination thereof.

FIG. 1 is a perspective view of an embodiment of a pulse oximetry system **10**. The system **10** includes a sensor **12** and a pulse oximetry monitor **14**. The sensor **12** includes an emitter **16** for emitting light at two or more wavelengths into a patient's tissue. A detector 18 is also provided in the sensor **12** for detecting the light originally from the emitter **16** that emanates from the patient's tissue after passing through the tissue.

According to another embodiment and as will be described, the system **10** may include a plurality of sensors forming a sensor array in lieu of the single sensor **12**. Each of the sensors of the sensor array may be a complementary metal oxide semiconductor (CMOS) sensor. Alternatively, each sensor of the array may be charged coupled device (CCD) sensor. In yet another embodiment, the sensor array may be made up of a combination of CMOS and CCD sensors. The CCD sensor comprises a photoactive region and a transmission region for receiving and transmitting data while the CMOS sensor is made up of an integrated circuit having an array of pixel sensors. Each pixel has a photodetector and an active amplifier.

According to an embodiment, the emitter **16** and detector **18** may be on opposite sides of a digit such as a finger or toe, in which case the light that is emanating from the tissue has passed completely through the digit. In an embodiment, the emitter **16** and detector **18** may be arranged so that light from the emitter **16** penetrates the tissue and is reflected by the tissue into the detector **18**, such as a sensor designed to obtain pulse oximetry data from a patient's forehead.

In an embodiment, the sensor or sensor array may be connected to and draw its power from the monitor **14** as shown. In another embodiment, the sensor may be wirelessly connected to the monitor **14** and include its own battery or similar power supply (not shown). The monitor **14** may be configured to calculate physiological parameters based on data received from the sensor **12** relating to light emission and detection. In an alternative embodiment, the calculations may be performed on the monitoring device itself and the result of the oximetry reading is simply passed to the monitor **14**. Further, the monitor **14** includes a display **20** configured to display the physiological parameters or other information about the system. In the embodiment shown, the monitor **14** also includes a speaker **22** to provide an audible sound that may be used in various other embodiments, such as for example, sounding an alarm in the event that a patient's physiological parameters are not within a predefined normal range.

In an embodiment, the sensor **12**, or the sensor array, is communicatively coupled to the monitor **14** via a cable **24**. However, in other embodiments a wireless transmission device (not shown) or the like may be utilized instead of or in addition to the cable **24**.

In the illustrated embodiment, the pulse oximetry system **10** also includes a multi-parameter patient monitor **26**. The monitor may be cathode ray tube type, a flat panel display (as shown) such as a liquid crystal display (LCD) or a plasma display, or any other type of monitor now known or later developed. The multi-parameter patient monitor **26** may be configured to calculate physiological parameters and to provide a central display **28** for information from the monitor **14** and from other medical monitoring devices or systems (not shown). For example, the multiparameter patient monitor **26** may be configured to display an estimate of a patient's blood oxygen saturation generated by the pulse oximetry monitor **14** (referred to as an "SpO_2" measurement), pulse rate information from the monitor **14** and blood pressure from a blood pressure monitor (not shown) on the display **28**.

The monitor **14** may be communicatively coupled to the multi-parameter patient monitor **26** via a cable **32** or **34** coupled to a sensor input port or a digital communications port, respectively and/or may communicate wirelessly (not shown). In addition, the monitor **14** and/or the multi-parameter patient monitor **26** may be connected to a network to enable the sharing of information with servers or other workstations (not shown). The monitor **14** may be powered by a battery (not shown) or by a conventional power source such as a wall outlet.

FIG. 2 is a block diagram of the embodiment of a pulse oximetry system **10** of **FIG. 1** coupled to a patient **40** in accordance with present embodiments. Specifically, certain components of the sensor **12** and the monitor **14** are illustrated in **FIG. 2**. The sensor **12** includes the emitter **16**, the detector **18**, and an encoder **42**. In the embodiment shown, the emitter **16** is configured to emit at least two wavelengths of light, e.g., *RED* and *IR*, into a patient's tissue **40**. Hence, the emitter **16** may include a *RED* light emitting light source such as the *RED* light emitting diode (LED) **44** shown and an *IR* light emitting light source such as the *IR* LED **46** shown for emitting light into the patient's tissue **40** at the wavelengths used to calculate the patient's physiological parameters. In certain embodiments, the *RED* wavelength may be between about 600 nm and about 700 nm, and the *IR* wavelength may be between about 800 nm and about 1000 nm. In embodiments where a sensor array is used in place of single sensor, each sensor may be configured to emit a single wavelength. For example, a first sensor emits only a *RED* light while a second only emits an *IR* light.

It should be understood that, as used herein, the term "light" may refer to energy produced by radiative sources and may include one or more of ultrasound, radio, microwave, millimeter wave, infrared, visible, ultraviolet, gamma ray or X-ray electromagnetic radiation. As used herein light may also include any wavelength within the radio, microwave, infrared, visible, ultraviolet, or X-ray spectra, and that any suitable wavelength of electromagnetic radiation may be appropriate for use with the present techniques. Similarly, detector **18** may be chosen to be specifically sensitive to the chosen targeted energy spectrum of the emitter **16**.

In an embodiment, the detector **18** may be configured to detect the intensity of light at the *RED* and *IR* wavelengths. Alternatively, each sensor in the array may be configured to detect an intensity of a single wavelength. In operation, light enters the detector **18** after passing through the patient's tissue **40**. The detector **18** converts the intensity of the received light into an electrical signal. The light intensity is directly related to the absorbance and/or reflectance of light in the tissue **40**. That is, when more light at a certain wavelength is absorbed or reflected, less light of that wavelength is received from the tissue by the detector **18**. After converting the received light to an electrical signal, the detector **18** sends the signal to the monitor **14**, where physiological parameters may be calculated based on the absorption of the *RED* and *IR* wavelengths in the patient's tissue **40**. An example of a device configured to perform such calculations is the Model N600x pulse oximeter available from Nellcor Puritan Bennett LLC.

In an embodiment, the encoder **42** may contain information about the sensor **12**, such as what type of sensor it is (e.g., whether the sensor is intended for placement on a forehead or digit) and the wavelengths of light emitted by the emitter **16**. This information may be used by the monitor **14** to select appropriate algorithms, lookup tables and/or calibration coefficients stored in the monitor **14** for calculating the patient's physiological parameters.

In addition, the encoder **42** may contain information specific to the patient **40**, such as, for example, the patient's age, weight, and diagnosis. This information may allow the monitor **14** to determine patient-specific threshold ranges in which the patient's physiological parameter measurements should fall and to enable or disable additional physiological parameter algorithms. The encoder **42** may, for instance, be a coded resistor which stores values corresponding to the type of the sensor **12** or the type of each sensor in the sensor array, the wavelengths of light emitted by the emitter **16** on each sensor of the sensor array, and/or the patient's characteristics. In another embodiment, the encoder **42** may include a memory on which one or more of the following information may be stored for communication to the monitor **14**: the type of the sensor **12**; the wavelengths of light emitted by the emitter **16**; the particular wavelength each sensor in the sensor array is monitoring; and a signal threshold for each sensor in the sensor array.

In an embodiment, signals from the detector **18** and the encoder **42** may be transmitted to the monitor **14**. In the embodiment shown, the monitor **14** includes a general-purpose microprocessor **48** connected to an internal bus **50**. The microprocessor **48** is adapted to execute software, which may include an operating system and one or more applications, as part of performing the functions described herein. Also connected to the bus **50** are a read-only memory (ROM) **52**, a random access memory (RAM) **54**, user inputs **56**, the display **20**, and the speaker **22**.

The RAM **54** and ROM **52** are illustrated by way of example, and not limitation. Any computer-readable media may be used in the system for data storage. Computer-readable media are capable of storing information that can be interpreted by the microprocessor **48**. This information may be data or may take the form of computer-executable instructions, such as software applications, that cause the microprocessor to perform certain functions and/or computer-implemented methods. Depending on the embodiment, such computer-readable media may comprise computer storage media and communication media. Computer storage media includes volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage of information such as computer-readable instructions, data structures, program modules or other data. Computer storage media includes, but is not limited to, RAM, ROM, EPROM, EEPROM, flash memory or other solid state memory technology, CD-ROM, DVD, or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by components of the system.

In the embodiment shown, a time processing unit (TPU) **58** provides timing control signals to a light drive circuitry **60** which controls when the emitter **16** is illuminated and multiplexed timing for the *RED* LED **44** and the *IR* LED **46**. The TPU 58 also controls the gating-in of signals from detector **18** through an amplifier **62** and a switching circuit **64**. These signals are sampled at the proper time, depending upon which light source is illuminated. The received signal from the detector **18** may be passed through an amplifier **66**, a low pass filter **68**, and an analog-to-digital converter **70**. The digital data may then be stored in a queued serial module (QSM) **72** (or buffer) for later downloading to the RAM **54** as the QSM **72** fills up. In one embodiment, there may be multiple separate parallel paths having the amplifier **66**, the filter **68**, and the A/D converter **70** for multiple light wavelengths or spectra received.

In an embodiment, the microprocessor **48** may determine the patient's physiological parameters, such as SpO_2 and pulse rate, using various algorithms and/or look-up tables based on the value of the received signals and/or data corresponding to the light received by the detector **18**. Signals corresponding to information about the patient **40**, and particularly about the intensity of light emanating from a patient's tissue over time, may be transmitted from the encoder **42** to a decoder **74**. These signals may include, for example, encoded information relating to patient characteristics. The decoder **74** may translate these signals to enable the microprocessor to determine the thresholds based on algorithms or look-up tables stored in the ROM **52**. The user inputs **56** may be used to enter information about the patient, such as age, weight, height, diagnosis, medications, treatments, and so forth. In certain embodiments, the display **20** may exhibit a list of values which may generally apply to the patient, such as, for example, age ranges or medication families, which the user may select using the user inputs **56**.

The embodiments described herein may relate to determining one or more statistical parameters of data from which an estimated physiological parameter value has been determined. Statistical parameters associated with the physiological parameter may include parameters related to the accuracy of the estimated value such as error estimates and probability distributions of the data.

The continuous wavelet transform of a signal x(t) in accordance with the present disclosure may be defined as

$$T(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t)\psi^*\left(\frac{t-b}{a}\right)dt \qquad (9)$$

where $\psi^*(t)$ is the complex conjugate of the wavelet function $\psi(t)$, a is the dilation parameter of the wavelet and b is the location parameter of the wavelet. The transform given by equation (9) can be used to construct a representation of a signal on a transform surface. The transform may be regarded as a time-scale representation. Wavelets are composed of a range of frequencies, one of which may be denoted the characteristic frequency of the wavelet, where the characteristic frequency associated with the wavelet is inversely proportional to the scale a. One example of a characteristic frequency is the dominant frequency. Each scale of a particular wavelet may have a different characteristic frequency. The underlying mathematical detail required for the implementation within a time-scale can be found in the general literature.

The continuous wavelet transform decomposes a signal using wavelets, which are generally highly localized in time. The continuous wavelet transform may provide a higher resolution relative to discrete transforms, thus providing the ability to garner more information from signals than typical frequency transforms such as Fourier transforms (or any other spectral techniques) or discrete wavelet transforms. Continuous wavelet transforms allow for the use of multiple (*e.g.*, on the order of tens, hundreds, thousands, or any other number) wavelets that are each scaled in accordance with scales of interest of a signal such that smaller scale components of a signal are transformed using wavelets scaled more compactly than wavelets used to extract larger scale components of the signal and the window size of data each wavelet gets applied to varies according to scale as well. Thus, a higher resolution transform is possible using continuous wavelets relative to discrete techniques.

In addition, transforms and operations that convert a signal or any other type of data into a spectral (*i.e.*, frequency) domain necessarily create a series of frequency transform values in a two-dimensional coordinate system where the two dimensions may be frequency and, for example, amplitude. For example, any type of Fourier transform would generate such a two-dimensional spectrum. In contrast, wavelet transforms, such as continuous wavelet transforms, are required to be defined in a three-dimensional coordinate system and generate a surface with dimensions of time, scale and, for example, amplitude. Hence, operations performed in a spectral domain cannot be performed in the wavelet domain; instead the wavelet surface must be transformed into a spectrum (*i.e.*, by performing an inverse wavelet transform to convert the wavelet surface into the time domain and then performing a spectral transform from the time domain). Conversely, operations performed in the wavelet domain cannot be performed in the spectral domain; instead a spectrum must first be transformed into a wavelet surface (*i.e.*, by performing an inverse spectral transform to convert the spectral domain into the time domain and then performing a wavelet transform from the time domain). Nor does a cross-section of the three-dimensional wavelet surface along, for example, a particular point in time equate to a frequency spectrum upon which spectral-based techniques may be used. At least because wavelet space includes a time dimension, spectral techniques and wavelet techniques are not interchangeable. It will be understood that converting a system that relies on spectral domain processing to one that relies on wavelet space processing would require significant and fundamental modifications to the system in order to accommodate the wavelet space processing (*e.g.*, to derive a representative energy value for a signal or part of a signal requires integrating twice, across time and scale, in the wavelet domain while, conversely, one integration across frequency is required to derive a representative energy value from a spectral domain. As a further example, to reconstruct a temporal signal requires integrating twice, across time and scale, in the wavelet domain while, conversely, one integration across frequency is required to derive a temporal signal from a spectral domain). It is well known in the art that, as well as amplitude, parameters such as energy density, modulus, phase, among others may all be generated using such transforms and that these parameters have distinctly different contexts and meanings when defined in a two-dimensional frequency coordinate system rather than a three-dimensional wavelet coordinate system. For example, the phase of a Fourier system is calculated with respect to a single origin for all frequencies while the phase for a wavelet system is unfolded into two dimensions with respect to a wavelet's location (often in time) and scale.

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

$$S(a,b) = \left|T(a,b)\right|^2 \tag{10}$$

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

$$S_R(a,b) = \frac{|T(a,b)|^2}{a} \qquad (11)$$

and is useful for defining ridges in wavelet space when, for example, the Morlet wavelet is used. Ridges are defined as the locus of points of local maxima in the plane. Any reasonable definition of a ridge may be employed in the method. Also included as a definition of a ridge herein are paths displaced from the locus of the local maxima. A ridge associated with only the locus of points of local maxima in the plane are labeled a "maxima ridge".

For implementations requiring fast numerical computation, the wavelet transform may be expressed as an approximation using Fourier transforms. Pursuant to the convolution theorem, because the wavelet transform is the cross-correlation of the signal with the wavelet function, the wavelet transform may be approximated in terms of an inverse FFT of the product of the Fourier transform of the signal and the Fourier transform of the wavelet for each required a scale and then multiplying the result by $\sqrt{a}$.

In the discussion of the technology which follows herein, the "scalogram" may be taken to include all suitable forms of rescaling including, but not limited to, the original unscaled wavelet representation, linear rescaling, any power of the modulus of the wavelet transform, or any other suitable rescaling. In addition, for purposes of clarity and conciseness, the term "scalogram" shall be taken to mean the wavelet transform, T(a,b) itself, or any part thereof. For example, the real part of the wavelet transform, the imaginary part of the wavelet transform, the phase of the wavelet transform, any other suitable part of the wavelet transform, or any combination thereof is intended to be conveyed by the term "scalogram".

A scale, which may be interpreted as a representative temporal period, may be converted to a characteristic frequency of the wavelet function. The characteristic frequency associated with a wavelet of arbitrary a scale is given by

$$f = \frac{f_c}{a} \qquad (12)$$

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

Any suitable wavelet function may be used in connection with the present disclosure. One of the most commonly used complex wavelets, the Morlet wavelet, is defined as:

$$\psi(t) = \pi^{-1/4}(e^{i2\pi f_0 t} - e^{-(2\pi f_0)^2/2})e^{-t^2/2} \tag{13}$$

where f_0 is the central frequency of the mother wavelet. The second term in the parenthesis is known as the correction term, as it corrects for the non-zero mean of the complex sinusoid within the Gaussian window. In practice, it becomes negligible for values of $f_0 >> 0$ and can be ignored, in which case, the Morlet wavelet can be written in a simpler form as

$$\psi(t) = \frac{1}{\pi^{1/4}} e^{i2\pi f_0 t} e^{-t^2/2} \tag{14}$$

This wavelet is a complex wave within a scaled Gaussian envelope. While both definitions of the Morlet wavelet are included herein, the function of equation (14) is not strictly a wavelet as it has a non-zero mean (*i.e.,* the zero frequency term of its corresponding energy spectrum is non-zero). However, it will be recognized by those skilled in the art that equation (14) may be used in practice with $f_0 >> 0$ with minimal error and is included (as well as other similar near wavelet functions) in the definition of a wavelet herein. A more detailed overview of the underlying wavelet theory, including the definition of a wavelet function, can be found in the general literature. Discussed herein is how wavelet transform features may be extracted from the wavelet decomposition of signals. For example, wavelet decomposition of PPG signals may be used to provide clinically useful information within a medical device.

Pertinent repeating features in a signal give rise to a time-scale band in wavelet space or a rescaled wavelet space. For example, the pulse component of a PPG signal produces a dominant band in wavelet space at or around the pulse frequency. **FIGS. 3(a)** and **(b)** contain two views of a scalogram derived from a PPG signal, according to an embodiment. The figures show an example of the band caused by the pulse component in such a signal. The pulse band is located between the dashed lines in the plot of **FIG. 3(a)**. The band is formed from a series of dominant coalescing features across the scalogram. This can be clearly seen as a raised band across the transform surface in **FIG. 3(b)** located within the region of scales indicated by the arrow in the plot (corresponding to 60 beats per minute). The maxima of this band with respect to scale is the ridge. The locus of the ridge is shown as a black curve on top of the band in **FIG. 3(b)**. By employing a suitable rescaling of the scalogram, such as that given in equation

(11), the ridges found in wavelet space may be related to the instantaneous frequency of the signal. In this way, the pulse rate may be obtained from the PPG signal. Instead of rescaling the scalogram, a suitable predefined relationship between the scale obtained from the ridge on the wavelet surface and the actual pulse rate may also be used to determine the pulse rate.

By mapping the time-scale coordinates of the pulse ridge onto the wavelet phase information gained through the wavelet transform, individual pulses may be captured. In this way, both times between individual pulses and the timing of components within each pulse may be monitored and used to detect heart beat anomalies, measure arterial system compliance, or perform any other suitable calculations or diagnostics. Alternative definitions of a ridge may be employed. Alternative relationships between the ridge and the pulse frequency of occurrence may be employed.

As discussed above, pertinent repeating features in the signal give rise to a time-scale band in wavelet space or a rescaled wavelet space. For a periodic signal, this band remains at a constant scale in the time-scale plane. For many real signals, especially biological signals, the band may be non-stationary; varying in scale, amplitude, or both over time. **FIG. 3(c)** shows an illustrative schematic of a wavelet transform of a signal containing two pertinent components leading to two bands in the transform space, according to an embodiment. These bands are labeled band A and band B on the three-dimensional schematic of the wavelet surface. In this embodiment, the band ridge is defined as the locus of the peak values of these bands with respect to scale. For purposes of discussion, it may be assumed that band B contains the signal information of interest. This will be referred to as the "primary band". In addition, it may be assumed that the system from which the signal originates, and from which the transform is subsequently derived, exhibits some form of coupling between the signal components in band A and band B. When noise or other erroneous features are present in the signal with similar spectral characteristics of the features of band B then the information within band B can become ambiguous (*i.e.*, obscured, fragmented or missing). In this case, the ridge of band A may be followed in wavelet space and extracted either as an amplitude signal or a scale signal which will be referred to as the "ridge amplitude perturbation" (RAP) signal and the "ridge scale perturbation" (RSP) signal, respectively. The RAP and RSP signals may be extracted by projecting the ridge onto the time-amplitude or time-scale planes, respectively. The top plots of **FIG. 3(d)** show a schematic of the RAP and RSP signals associated with ridge A in **FIG. 3(c)**. Below these RAP and RSP signals are schematics of a further wavelet decomposition of these newly derived signals. This secondary wavelet decomposition allows for information in the region of band B in **FIG. 3(c)** to be made available as band C and band D. The ridges of bands C and D may serve as instantaneous time-scale characteristic measures of the signal components causing bands C and D. This technique, which will be referred to herein as secondary wavelet feature decoupling (SWFD), may allow information concerning the nature of the signal components associated with the underlying physical process causing the primary band B (**FIG. 3(c)**) to be extracted when band B itself is obscured in the presence of noise or other erroneous signal features.

In some instances, an inverse continuous wavelet transform may be desired, such as when modifications to a scalogram (or modifications to the coefficients of a transformed signal) have been made in order to, for example, remove artifacts. In one embodiment, there is an inverse continuous wavelet transform which allows the original signal to be recovered from its wavelet transform by integrating over all scales and locations, a and b:

$$x(t)=\frac{1}{C_g}\int_{-\infty}^{\infty}\int_{0}^{\infty}T(a,b)\frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right)\frac{\mathrm{d}a\mathrm{d}b}{a^2} \qquad \text{(a)}$$

which may also be written as:

$$x(t)=\frac{1}{C_g}\int_{-\infty}^{\infty}\int_{0}^{\infty}T(a,b)\psi_{a,b}(t)\frac{\mathrm{d}a\mathrm{d}b}{a^2} \qquad \text{(b)}$$

where C_g is a scalar value known as the admissibility constant. It is wavelet type dependent and may be calculated from:

$$C_g=\int_{0}^{\infty}\frac{\left|\hat{\psi}(f)\right|^2}{f}\mathrm{d}f \qquad \text{(c)}$$

FIG. 3(e) is a flow chart of illustrative steps that may be taken to perform an inverse continuous wavelet transform in accordance with the above discussion. An approximation to the inverse transform may be made by considering equation (a) to be a series of convolutions across scales. It shall be understood that there is no complex conjugate here, unlike for the cross correlations of the forward transform. As well as integrating over all of a and b for each time t, this equation may also take advantage of the convolution theorem which allows the inverse wavelet transform to be executed using a series of multiplications. **FIG. 3(f)** is a flow chart of illustrative steps that may be taken to perform an approximation of an inverse continuous wavelet transform.

FIG. 4 is an illustrative continuous wavelet processing system in accordance with an embodiment. In this embodiment, input signal generator **410** generates an input signal **416**. As illustrated, input signal generator **410** may include oximeter **420** coupled to sensor **418**, which may provide as input signal **416**, a PPG signal. It will be understood that input signal generator **410** may include any suitable signal source, signal generating data, signal generating equipment, or any combination thereof to produce signal **416**. Signal **416** may be any suitable signal or signals, such as, for example, biosignals (*e.g.,* electrocardiogram, electroencephalogram, electrogastrogram, electromyogram, heart rate signals, pathological sounds, ultrasound, or any other suitable biosignal), dynamic signals, non-destructive testing signals, condition monitoring signals, fluid signals, geophysical signals, astronomical signals, electrical signals, financial signals including financial indices, sound and speech signals, chemical signals, meteorological signals including climate signals, and/or any other suitable signal, and/or any combination thereof.

In this embodiment, signal **416** may be coupled to processor **412**. Processor **412** may be any suitable software, firmware, and/or hardware, and/or combinations thereof for processing signal **416**. For example, processor **412** may include one or more hardware processors (*e.g.*, integrated circuits), one or more software modules, computer-readable media such as memory, firmware, or any combination thereof. Processor **412** may, for example, be a computer or may be one or more chips (*i.e.*, integrated circuits). Processor **412** may perform the calculations associated with the continuous wavelet transforms of the present disclosure as well as the calculations associated with any suitable interrogations of the transforms. Processor **412** may perform any suitable signal processing of signal **416** to filter signal **416**, such as any suitable band-pass filtering, adaptive filtering, closed-loop filtering, and/or any other suitable filtering, and/or any combination thereof.

Processor **412** may be coupled to output **414**. Output **414** may be any suitable output device such as, for example, one or more medical devices (e.g., a medical monitor that displays various physiological parameters, a medical alarm, or any other suitable medical device that either displays physiological parameters or uses the output of processor **412** as an input), one or more display devices (*e.g.*, monitor, PDA, mobile phone, any other suitable display device, or any combination thereof), one or more audio devices, one or more memory devices (*e.g.*, hard disk drive, flash memory, RAM, optical disk, any other suitable memory device, or any combination thereof), one or more printing devices, any other suitable output device, or any combination thereof.

The signal processing of the present disclosure will now be discussed in reference to **FIGS. 5-6**.

In an embodiment, a signal or a number of signals may be processed to obtain clinically relevant information. The signal may include any suitable signal, including a continuous signal, a discrete signal, a signal formed from multiple data points, or features of a scalogram or a Lissajous figure. For example, the signal may include two PPG signals that may be analyzed to derive blood oxygen saturation information about a patient from whom the PPG signals were obtained. The clinically relevant information may also be used to derive further useful information. For example, the blood oxygen saturation information derived from the processed PPG signals may be used in conjunction with the processed PPG signals to also evaluate changes in the patient's ventilation over time.

The signal or signals may be processed in any suitable manner to obtain the clinically relevant information. For example, the signals may be analyzed using the "ratio of ratios" method, in which a ratio is taken between changes in one signal and changes in the other signal after both signals have passed through human tissue. The underlying mathematical detail is discussed above and may also be found in the general literature. The resulting ratio of ratios may be used to derive the clinically relevant information, such as blood oxygen saturation. Alternatively, a wavelet transform may be applied to one or more signals to generate one or more scalograms, as described above with respect to **FIGS. 3(a)** and **3(b)**. The transform-surfaces that may be derived from the scalograms may be further analyzed to obtain the clinically relevant information. For example, a three-dimensional Lissajous figure and a subsequently selected two-dimensional Lissajous figure may each be derived from the transform surfaces of the scalograms. The slope of the two-dimensional Lissajous figure may be used to derive the desired information, as described in U.S. Patent Pub. No. 2006/0258921, published November 16, 2006, entitled "Method of Analyzing and Processing Signals," which is incorporated by reference herein in its entirety. U.S. Patent Pub. No. 2006/0258921 also describes other techniques for deriving desired information from wavelet transforms of signals that may be used in connection with this disclosure.

In an embodiment, slope values may be calculated using each data point of a two-dimensional Lissajous figure and the slope values may be plotted on a histogram to derive the clinically relevant information. Such a method is described more fully in Watson, U.S. Provisional Application No. 61/077,079, (Attorney Docket No. H-RM-01189 (COV-8 Prov)), filed June 30, 2008, entitled "Signal Processing Systems and Methods for Determining Slope," which is incorporated by reference herein in its entirety. In another embodiment, slope values may be calculated between any suitable origin point selected from the plot containing the two-dimensional Lissajous figure and each data point of the Lissajous figure, and the slope values may be plotted on a histogram to derive the clinically relevant information. Such a method is described more fully in Watson, U.S. Provisional Application No. 61/080950, (Attorney Docket No. H-RM-01204 (COV-15 Prov)), filed July 15, 2008, entitled "Signal Processing Systems and Methods for Determining Slope Using an Origin Point," which is incorporated by reference herein in its entirety.

The clinically relevant information may be analyzed in conjunction with the processed signal or signals to obtain further useful information using any suitable method. In an embodiment, the blood oxygen saturation information obtained using any of the methods described above or using any other suitable method may be plotted against respiration information obtained from any of the derived transform-surfaces. The respiration information may correspond to band B of the selected transform-surface, as described above with respect to **FIG. 3(c)**. Changes in the scale value in the ridge of band B may indicate changes in a patient's respiration rate. For example, in a healthy patient, a change in respiration rate may correspond to a change in blood oxygen saturation. A change in respiration rate that does not correspond to a change in blood oxygen saturation, however, may indicate a problem with the patient's ventilation.

The ridge of band B may be followed in wavelet space for a given period of time, and the scale values of the ridge may be plotted. For each plotted scale value of the ridge, the blood oxygen saturation amplitude corresponding to the plotted scale value may also be plotted and a two-dimensional region may be derived. In an embodiment, the region may include a Lissajous figure. The resulting region, and any figure that may lie within the region, may be evaluated to determine physiologically relevant information. For example, the shape or the slope of the region, or the inclusion of a figure within the region, may provide information regarding the patient's ventilation. In an embodiment, the respiration rate may be computed based on the ridge of the respiration band and the respiration rate may be plotted in place of the scale values of the ridge.

FIG. 5 shows a plot of two signals detected in accordance with an embodiment. The two signals may include signals from any suitable source and may include a continuous signal, a discrete signal, or a signal formed from multiple data points. In an embodiment, the signals may include a red light signal **520** and an infrared light signal **540** obtained from a pulse oximeter sensor, as described above. Red light signal **520** and infrared signal **540** may be plotted as shown in **FIG. 5** after passing through a portion of the patient's blood perfused tissue (e.g., a fingertip, a toe, a foot). The pulse oximeter sensor may transmit red light signal **520** and infrared light signal **540** to any suitable processing unit (*e.g.*, processor **412** in **FIG. 4**) for further analysis. For example, analyzing the ratio between changes in the red light signal **520** and changes in the infrared light signal **540** after both signals have passed through human tissue may be useful in determining a patient's blood oxygen saturation.

FIG. 6 shows a multiparameter plot that may include threshold regions derived in accordance with an embodiment. Plot **600** may include axes related to any suitable unit of measure, such as axes related to time, amplitude, scale, length, frequency, distance, or any other suitable unit of measure. In **FIG. 6**, plot **600** may include a blood oxygen saturation ("SpO_2") axis and a respiration scale value axis. Plot **600** may be used to plot changes in SpO_2 values as a function of changes in respiration scale values over a defined time period (not shown). The SpO_2 values may be obtained using any suitable method, such as any of the methods described above.

Plot **600** is shown as including threshold regions **630** and **660**. Threshold regions **630** and **660** may be derived or determined using any suitable method. Threshold region **630**, for example, may be a region where a plot of respiration scale values versus SpO_2 values may be expected for a healthy person. On the other hand, threshold region **660** may be a region where a plot of respiration scale values versus SpO_2 values are expected for a person who has a health problem such as a ventilation problem. Threshold regions **630** and **660** are discussed in further detail below.

The respiration scale values may be obtained using any suitable method. For example, the respiration scale values may be obtained from the ridge of the respiration component of any suitable transform-surface, as described above with respect to **FIGS.**

3(a), 3(b), and 3(c). The transform-surface may include any suitable number of ridges at any suitable scale value. In an embodiment, red light signal **520** and infrared light signal **540** may each include components relating to the pulse of a patient, the breathing rate of a patient, and one or more signal artifacts (*e.g.*, noise). The signal components related to pulse rate and breathing rate may contain higher energy than other signal components. Transform-surfaces derived at least in part from the application of a wavelet transform to each of red light signal **520** and infrared light signal **540**, respectively, may include a ridge at a particular scale value that may be related to the pulse component and another ridge at a particular scale value that may be related to the breathing component of red light signal **520** and infrared light signal **540**. The respiration information may correspond to band B of the selected transform-surface, as described above with respect to **FIG. 3(c)**, and the ridge of the respiration component of interest may correspond to ridge B. Whereas signals **520** and **540** may both be used to calculate changes in blood oxygen saturation amplitude, the respiration scale values may be obtained from the ridge of the respiration component of a transform-surface derived from either signal **520** or **540** (*e.g.*, using the ridge of the respiration component of the transform-surface derived from infrared light signal **540** or red light signal **520**). The respiration scale values may also be obtained by performing a secondary wavelet decomposition of RAP and/or RSP signals associated with the pulse ridge from a transform-surface derived from either signal **520** or **540**. The respiration scale values may also be obtained using any other suitable technique.

The orientation of threshold regions **630** and **660** on plot **600** may be based on clinically relevant information. For example, a plot of data points on plot 600 may be analyzed to determine whether they are located within threshold region **630** or within threshold region **660**. This may enable a user or a system to evaluate a patient's physiological state. Threshold region **630** is oriented such that when the respiration scale value increases, the SpO_2 value also increases at a particular rate. This orientation may be consistent with an expected increase in a healthy individual's blood oxygen saturation level as the respiration rate (*e.g.*, number of breaths in a defined time period) or respiration scale increases. Region **675** may indicate a central respiratory depression, in which the patient's central nervous system may no longer be triggering or stimulating the breathing mechanism, thereby reducing the patient's breathing rate. The orientation of region **660** may indicate that as the respiration rate or scale value increases, the SpO_2 value may increase only slightly, or may not change. This orientation may be consistent with a ventilation problem, or a "ventilation-perfusion mismatch," in which the patient's blood oxygen saturation level may not be altered by an increase or decrease in breathing rate. Such a mismatch may be an indication of hypoxemia, and thus plot **600** may be useful in evaluating a patient's respiratory state as a result of obtaining signals **520** and **540** from a pulse oximeter coupled to the patient.

In an embodiment, plot **600** may include any suitable number of Lissajous figures that may lie within either region **630** or region **660**. The Lissajous figures may be derived using any suitable method, such as the methods described more fully in U.S. Patent Pub. No. 2006/0258921, U.S. Provisional Application No. 61/077,079, (Attorney Docket No. H-RM-01189 (COV-8 Prov)), or U.S. Provisional Application No. 61/080950, (Attorney Docket No. H-RM-01204 (COV-15 Prov)). A Lissajous figure oriented within region **630** may indicate proper ventilation, as may be expected for a healthy patient from whom data may be obtained to derive the Lissajous figure. By contrast, a Lissajous figure oriented within region **660** may indicate that the patient does not have proper ventilation.

In an embodiment, the shape, or the distribution, of the data points plotted in plot **600** may be used instead of or in addition to threshold regions to determine clinically relevant information. For example, a slope (*e.g.*, a dominant slope) of the data distribution may be used. The slope of the data points can be determined using any suitable method. In one suitable approach, a least squares line fitting method may be used. In another suitable approach a dominant slop may be calculated from the data points using the methods described in U.S. Provisional Application No. 61/077079, (Attorney Docket No. H-RM-01189 (COV-8 Prov)) and U.S. Provisional Application No. 61/080950, (Attorney Docket No. H-RM-01204 (COV-15 Prov)). If the derived slope has a value above a certain threshold, for example, that may be an indication of proper ventilation. If the derived slope has a value that falls below the threshold, that may be an indication of poor ventilation. The derived slope may be analyzed using any suitable method to provide further information about the patient's physiological state.

The foregoing is merely illustrative of the principles of this disclosure and various modifications can be made by those skilled in the art without departing from the scope and spirit of the disclosure. The following numbered paragraphs may also describe various aspects of this disclosure.

Claims

1. A method for analyzing a physiological state, comprising obtaining a first signal and a second signal, computing a first plurality of values of a physiological parameter using at least the first signal and the second signal, transforming at least the first signal using a first wavelet transform, generating a scalogram based at least in part on the transformed signal, determining a second plurality of values based at least in part on a feature in the scalogram, associating the first plurality of values with the second plurality of values, and analyzing the physiological state based at least in part on the associated first and second plurality of values.

2. The method of paragraph 1, wherein the first signal and the second signal are photoplethysmograph signals from a user.

3. The method of paragraph 2, wherein analyzing the physiological state comprises analyzing a ventilation state of the user.

4. The method of paragraph 1, wherein determining a second plurality of values based at least in part on a feature in the scalogram comprises selecting a plurality of scale values based at least in part on a respiration ridge in the scalogram.

5. The method of paragraph 1, wherein determining a second plurality of values based at least in part on a feature in the scalogram comprises deriving a plurality of respiration rate values based at least in part on a respiration ridge in the scalogram.

6. The method of paragraph 2, wherein the physiological parameter corresponds to blood oxygen saturation of the user.

7. The method of paragraph 6, further comprising using a ratio of ratios to obtain the first plurality of values.

8. The method of paragraph 1, further comprising deriving a Lissajous figure to obtain the first plurality of values.

9. The method of paragraph 1, wherein the first wavelet transform is a complex continuous wavelet transform.

10. The method of paragraph 1, wherein associating the first plurality of values with the second plurality of values further comprises deriving a Lissajous figure.

11. The method of paragraph 10, wherein analyzing the physiological state further comprises analyzing whether the Lissajous figure is located within a threshold region.

12. The method of paragraph 10, wherein analyzing the physiological state further comprises calculating a slope value from the Lissajous figure.

13. The method of paragraph 12, further comprising comparing the slope value of the Lissajous figure to a threshold value.

14. The method of paragraph 13, wherein when the slope value is lower than the threshold value indicates a poor physiological state.

15. The method of paragraph 14, wherein the poor physiological state is hypoxemia.

16. The method of paragraph 13, wherein the slope value having a higher value than the threshold value indicates a good physiological state.

17. A system capable of performing the methods of paragraphs 1 – 16.

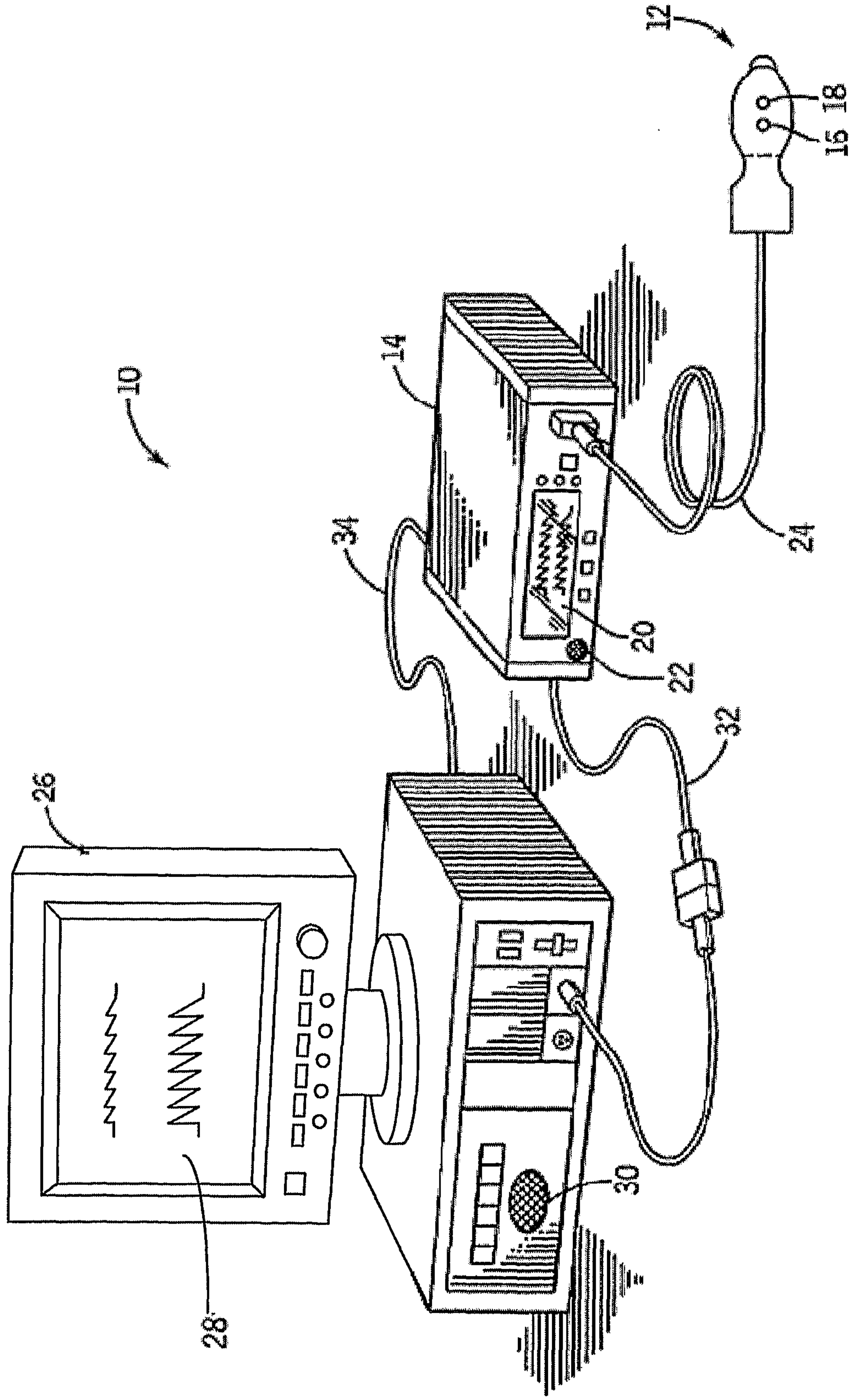

FIG.1

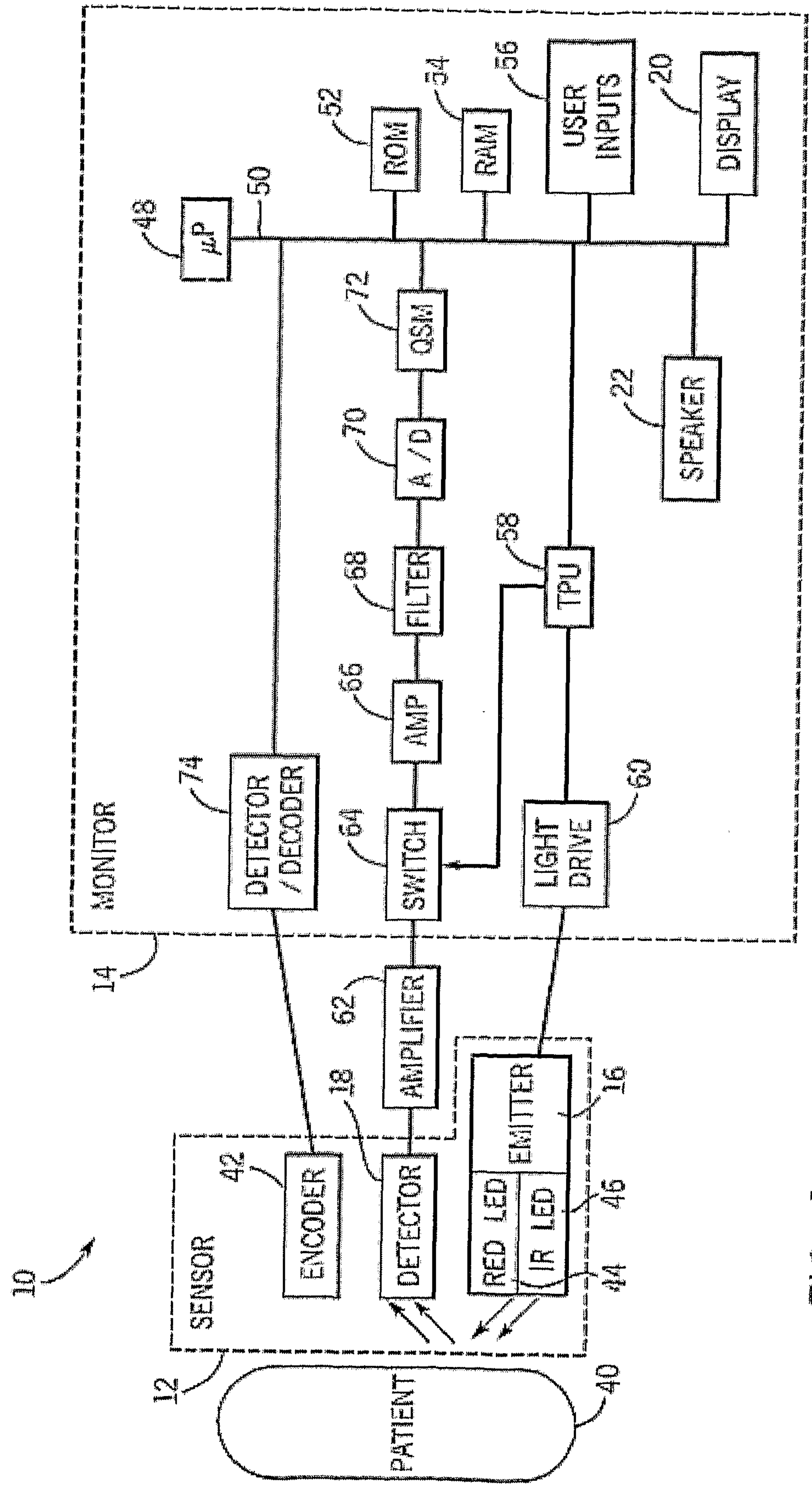
10
PATIENT
40
SENSOR
12
ENCODER
42
DETECTOR
18
RED LED
IR LED
44
46
EMITTER
16
AMPLIFIER
62
14
MONITOR
DETECTOR / DECODER
74
SWITCH
64
LIGHT DRIVE
60
AMP
66
FILTER
68
A / D
70
QSM
72
TPU
58
SPEAKER
22
μP
48
50
ROM
52
RAM
54
USER INPUTS
56
DISPLAY
20

FIG. 2

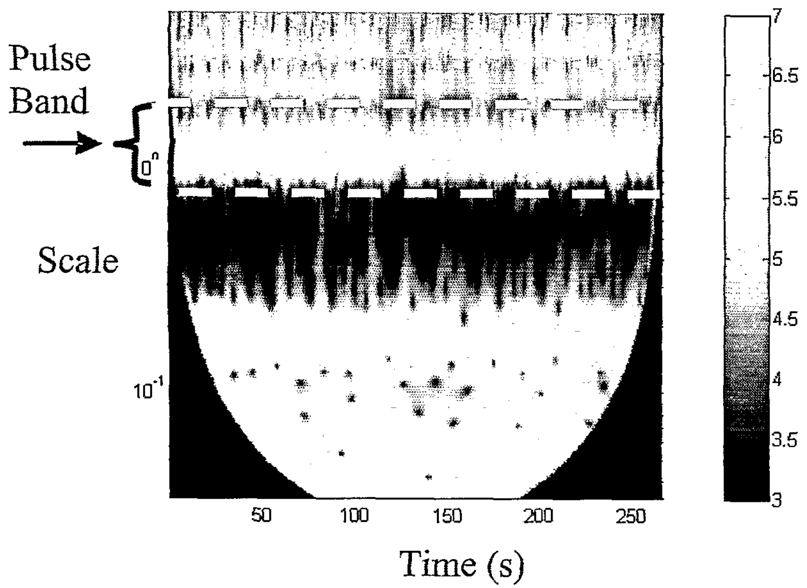
Pulse
Band
Scale
10^0
10^{-1}
50
100
150
200
250
Time (s)
7
6.5
6
5.5
5
4.5
4
3.5
3

FIG. 3(a)

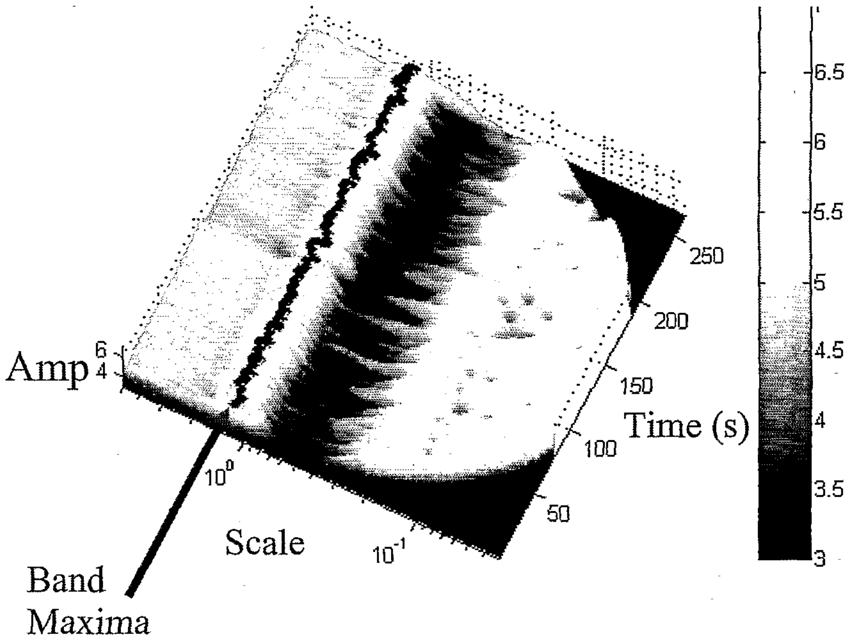
Amp
6
4
Band
Maxima
Scale
10^0
10^{-1}
50
100
150
200
250
Time (s)
6.5
6
5.5
5
4.5
4
3.5
3

FIG. 3(b)

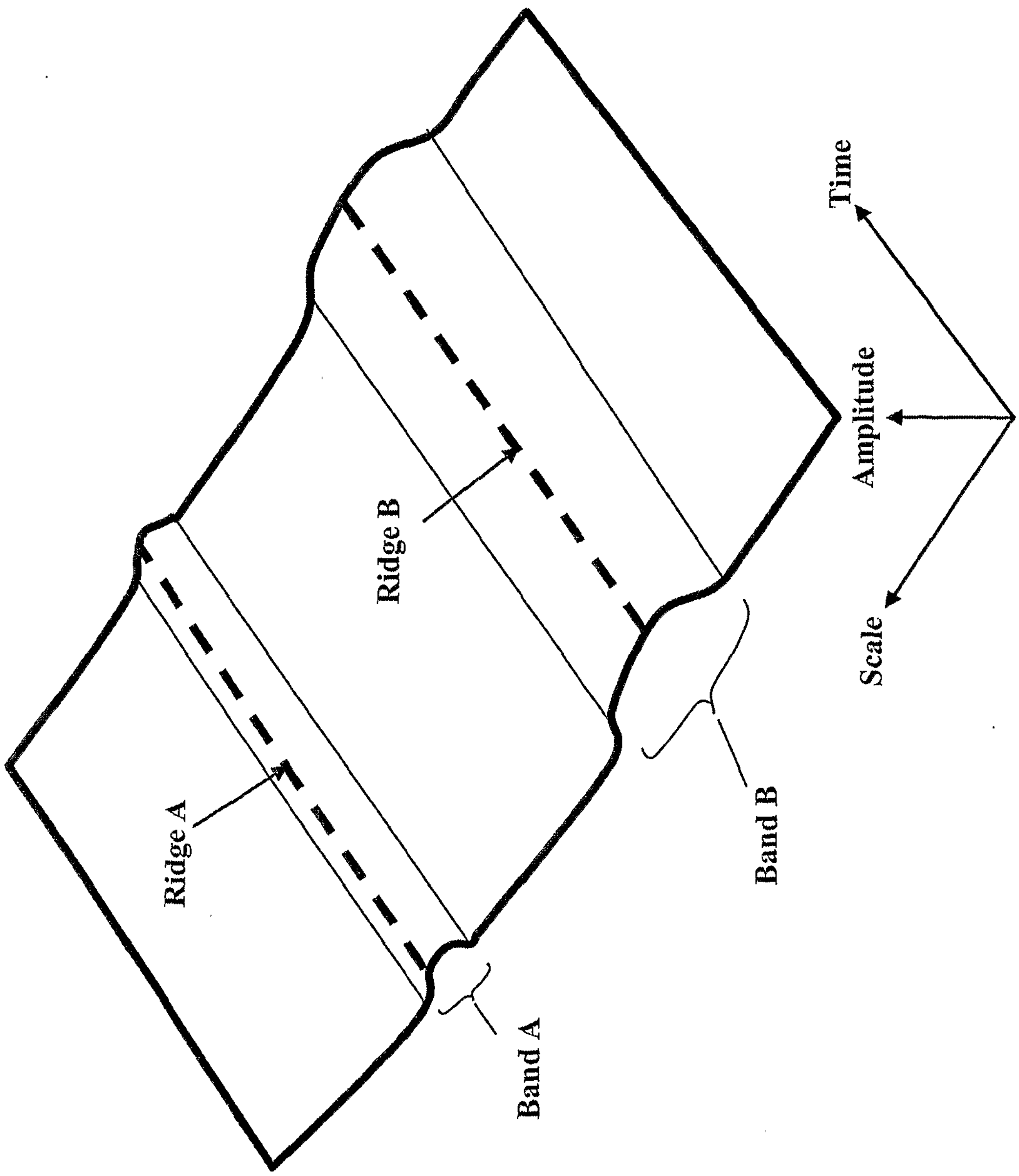

FIG. 3(c)

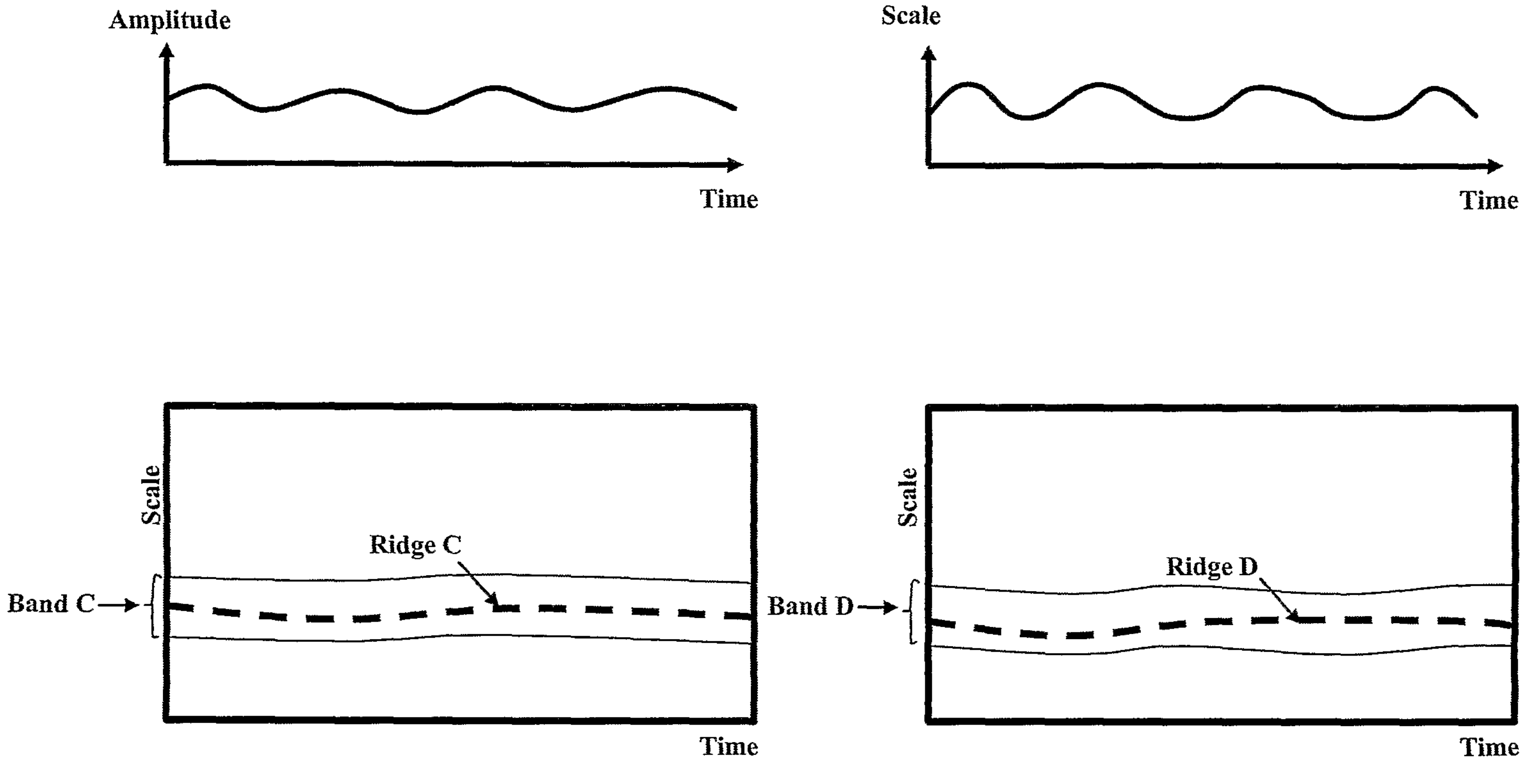
Amplitude
Time
Scale
Time
Scale
Ridge C
Band C
Time
Scale
Ridge D
Band D
Time

FIG. 3(d)

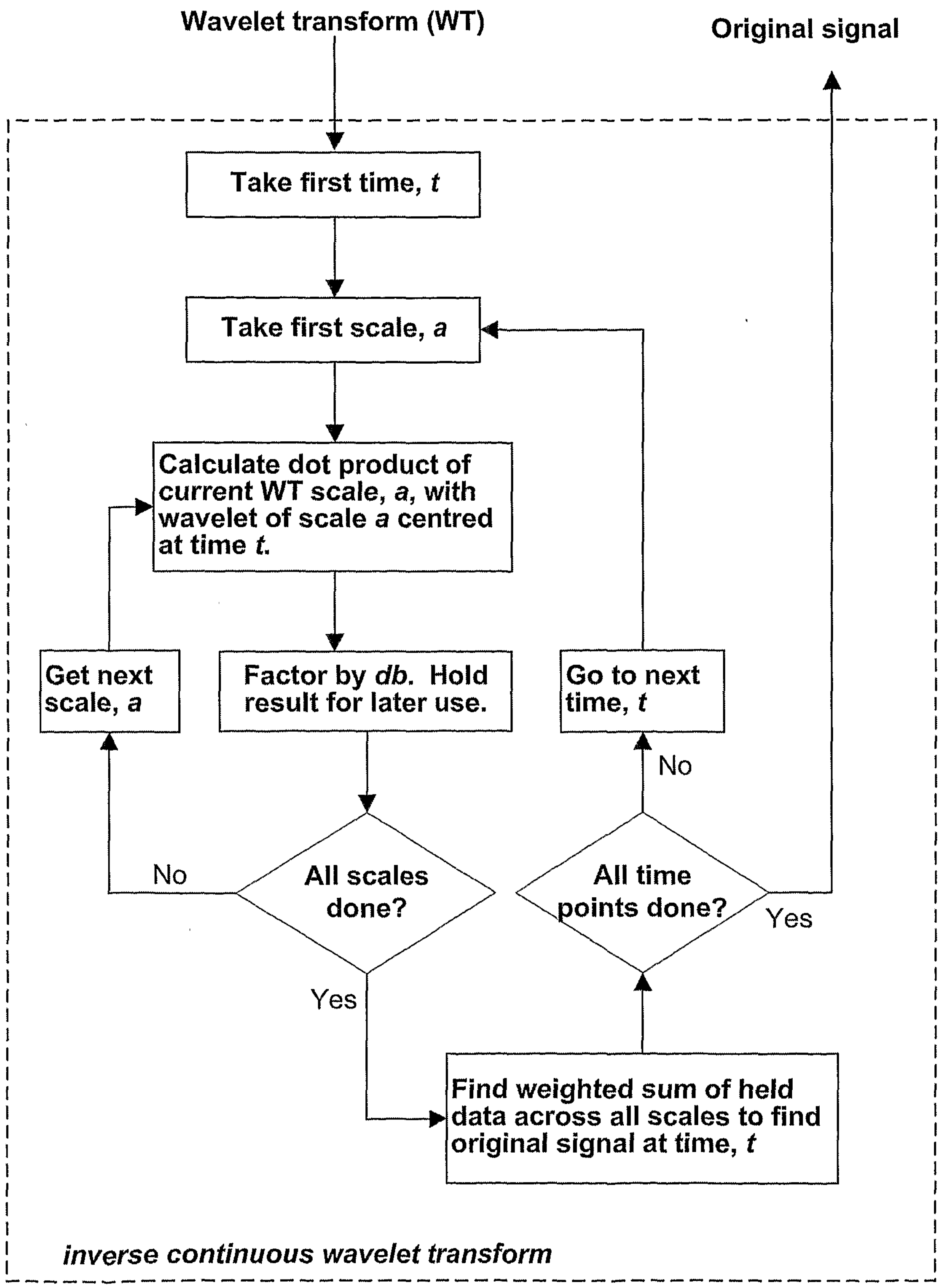
Wavelet transform (WT)
Original signal
Take first time, *t*
Take first scale, *a*
Calculate dot product of current WT scale, *a*, with wavelet of scale *a* centred at time *t*.
Get next scale, *a*
Factor by *db*. Hold result for later use.
Go to next time, *t*
No
All scales done?
No
Yes
All time points done?
Yes
Find weighted sum of held data across all scales to find original signal at time, *t*
inverse continuous wavelet transform

FIG. 3(e)

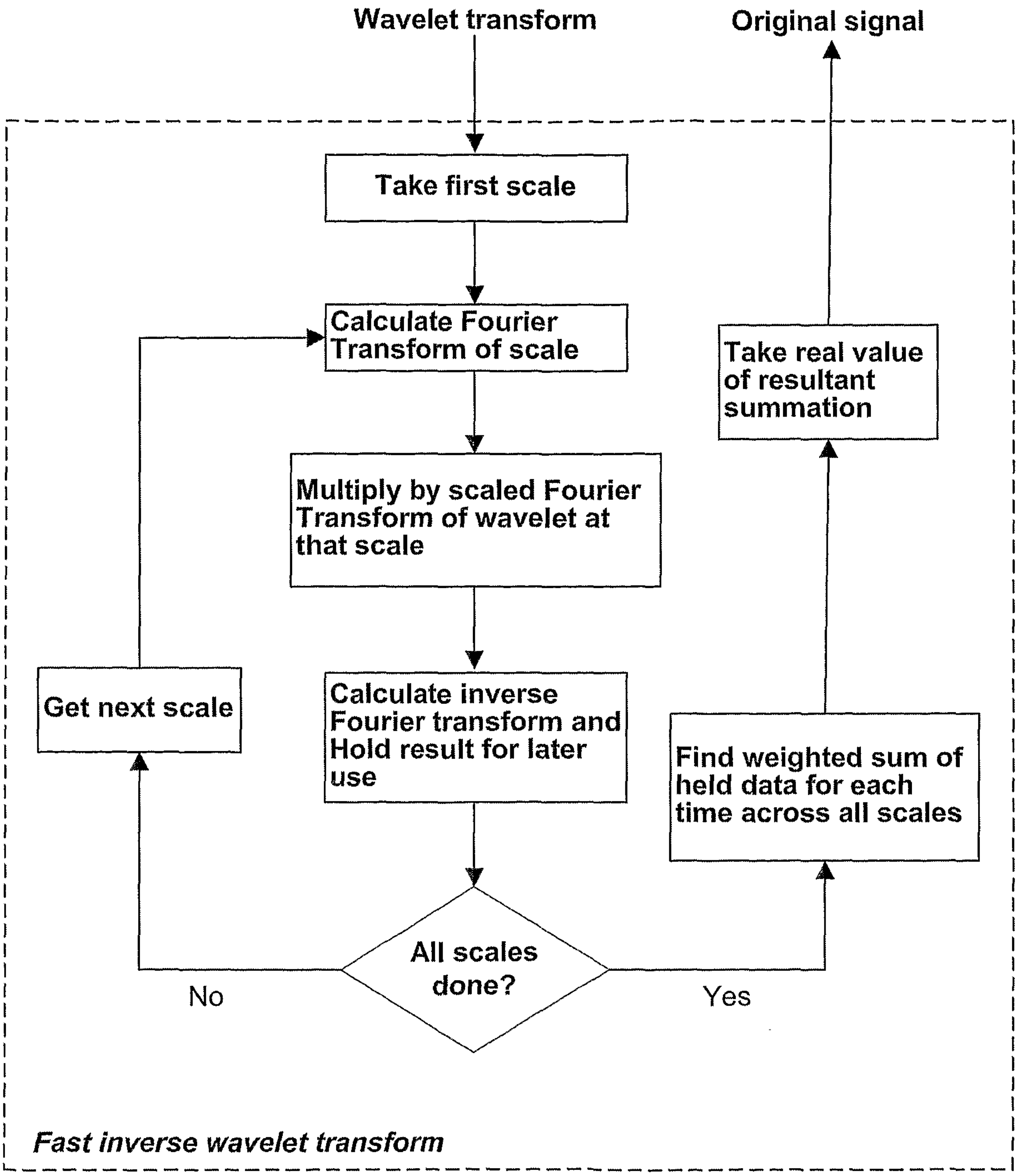
Wavelet transform
Original signal
Take first scale
Calculate Fourier Transform of scale
Multiply by scaled Fourier Transform of wavelet at that scale
Calculate inverse Fourier transform and Hold result for later use
All scales done?
No
Yes
Get next scale
Find weighted sum of held data for each time across all scales
Take real value of resultant summation
Fast inverse wavelet transform

FIG. 3(f)

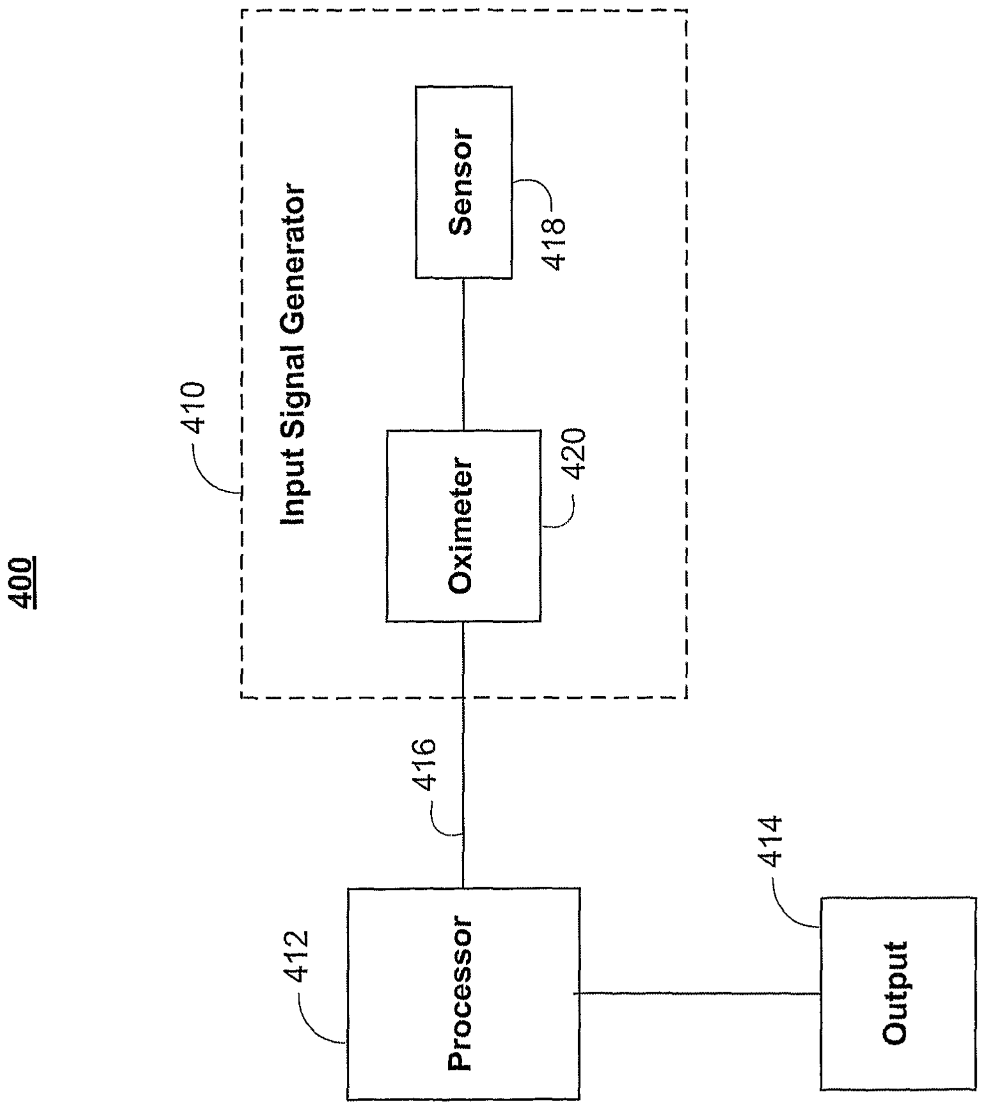
400
410
Input Signal Generator
Sensor
418
Oximeter
420
416
412
Processor
414
Output

FIG. 4

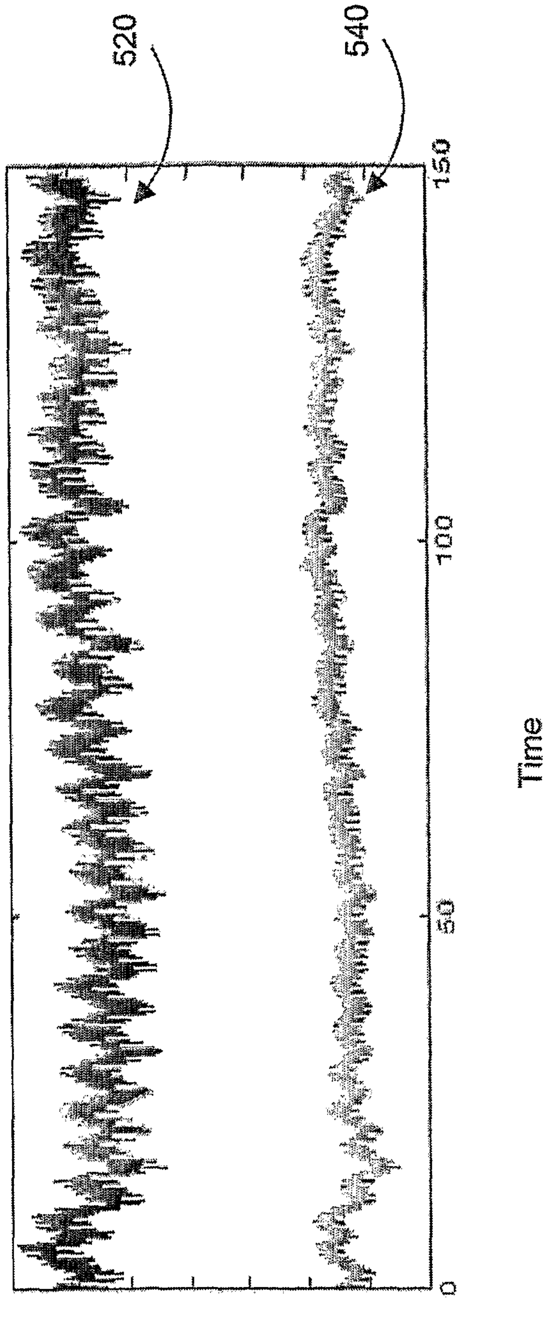

FIG. 5

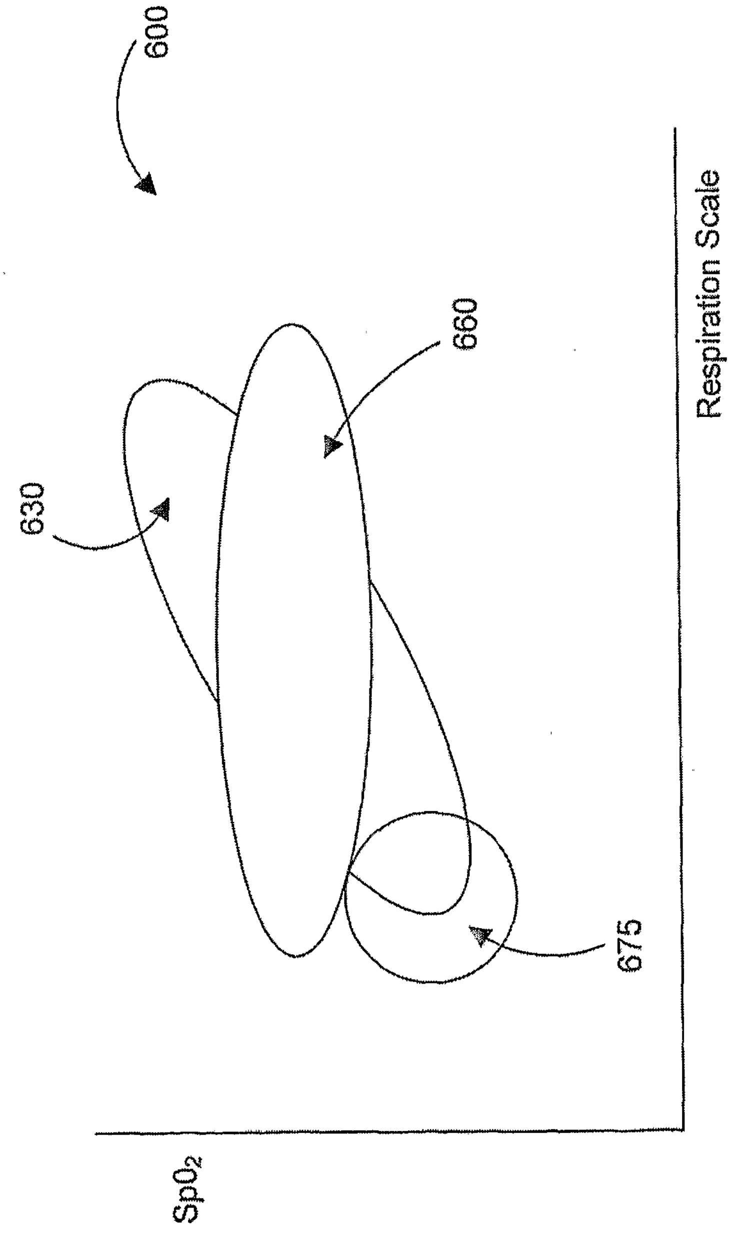

FIG. 6

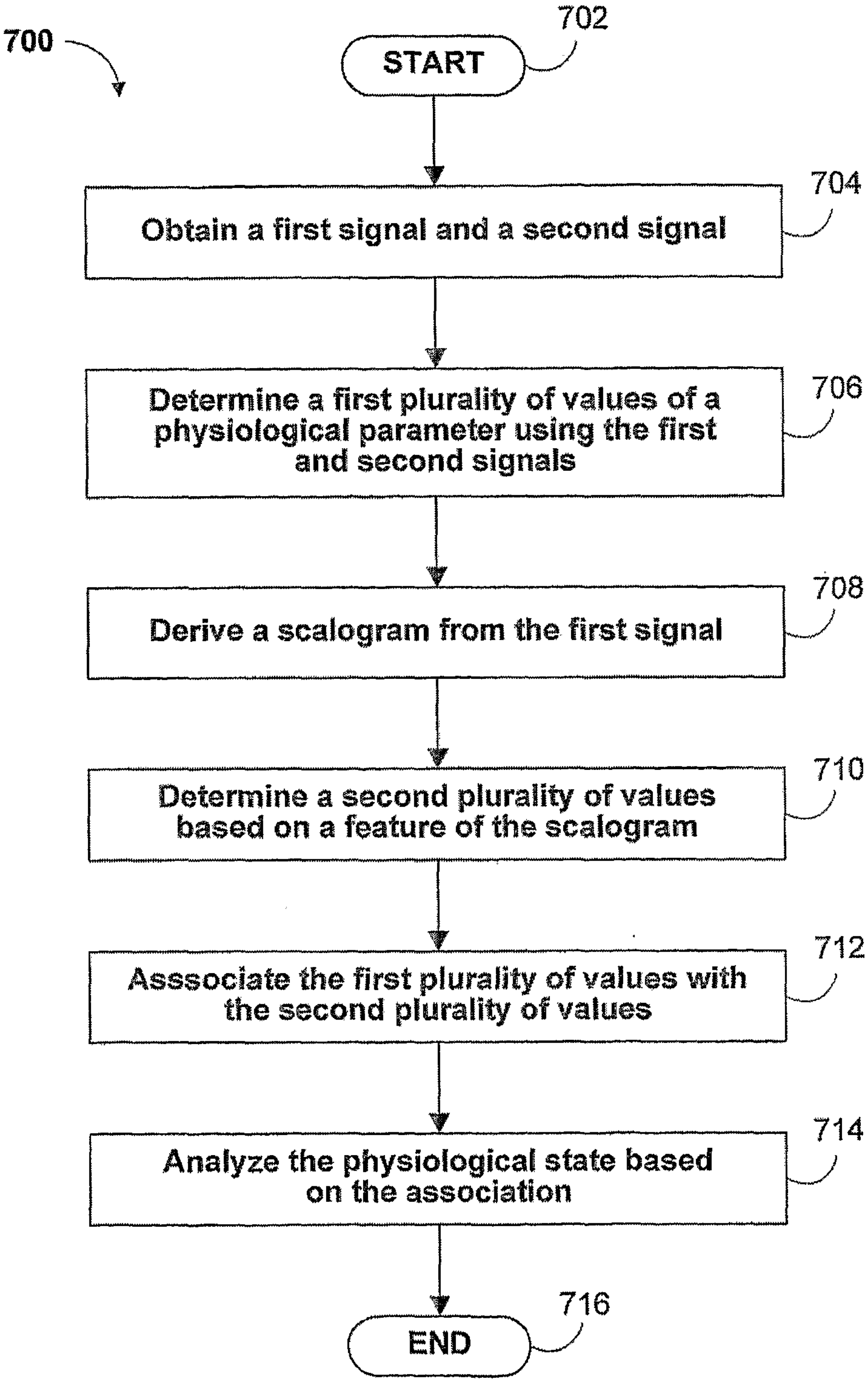
700
START
702
Obtain a first signal and a second signal
704
Determine a first plurality of values of a physiological parameter using the first and second signals
706
Derive a scalogram from the first signal
708
Determine a second plurality of values based on a feature of the scalogram
710
Asssociate the first plurality of values with the second plurality of values
712
Analyze the physiological state based on the association
714
END
716

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/006216

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/024 G06F19/00 A61B5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B G01N G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2004/075746 A (CARDIODIGITAL LTD [GB]; ADDISON PAUL STANLEY [GB]; WATSON JAMES NICHOL) 10 September 2004 (2004-09-10) cited in the application page 1, line 1 - page 36, line 13 -----	1-13,17
A	POUDOV V S: "The comparison of possibilities of continuous and discrete wavelet transforms for MCG data processing" ELECTRON DEVICES AND MATERIALS, 2004. PROCEEDINGS. 5TH ANNUAL. 2004 IN TERNATIONAL SIBERIAN WORKSHOP ON ERLAGOL, ALTAI JULY 1-5, 2004, PISCATAWAY, NJ, USA,IEEE, 1 July 2004 (2004-07-01), pages 138-142, XP010741839 ISBN: 978-5-7782-0463-8 the whole document ----- -/--	1-13,17

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

Date of the actual completion of the international search
6 October 2009

Date of mailing of the international search report
16/10/2009

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INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2009/006216

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2004/105601 A (EVEREST BIOMEDICAL INSTR [US]; CAUSEVIC ELVIR [US]) 9 December 2004 (2004-12-09) page 12, line 9 - page 14, line 12 -----	1-13,17

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2009/006216

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.: 14-16
because they relate to subject matter not required to be searched by this Authority, namely:

see FURTHER INFORMATION sheet PCT/ISA/210

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers allsearchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search reportcovers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.1

Claims Nos.: 14-16

Rule 39.1(iv) PCT - Diagnostic method practised on the human or animal body.
The methods defined in claims 14 to 16 comprise the phases of
(i) collecting physiological data (present claim 1),
(ii) comparing these data with standard values (present claim 13),
(iii) finding a significant deviation during the comparison (present claim 13, comparison to threshold), and
(iv) attributing the deviation to a particular clinical picture (claims 14, 15, claim 16 represents the inversion and hence püroduces the same information as the method described in claim 14).
These claims hence relate to a diagnostic method for which no search report is established.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2009/006216

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2004075746 A	10-09-2004	EP 1628571 A2	01-03-2006
		JP 2007515977 T	21-06-2007
		US 2006258921 A1	16-11-2006
WO 2004105601 A	09-12-2004	AU 2003241369 A1	21-01-2005
		EP 1622510 A1	08-02-2006
		JP 2006514570 T	11-05-2006
		US 2004243017 A1	02-12-2004

专利名称(译)	用于分析多参数空间以确定生理状态的信号处理系统和方法		
公开(公告)号	EP2339960A1	公开(公告)日	2011-07-06
申请号	EP2009786007	申请日	2009-07-08
[标]申请(专利权)人(译)	NELLCOR PURITAN BENNETT爱尔兰		
申请(专利权)人(译)	NELLCOR PURITAN BENNETT爱尔兰		
当前申请(专利权)人(译)	NELLCOR PURITAN BENNETT爱尔兰		
[标]发明人	WATSON JAMES NICHOLAS ADDISON PAUL STANLEY MCKENNA EDWARD M		
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IPC分类号	A61B5/024 G06F19/00 A61B5/00		
CPC分类号	G06K9/00536 A61B5/14551 A61B5/7207 A61B5/726 G06K9/00516 G16H50/20		
优先权	61/080957 2008-07-15 US		
其他公开文献	EP2339960B1		
外部链接	Espacenet		

摘要(译)

本公开涉及信号处理系统和方法，更具体地，涉及用于分析多参数空间以确定生理状态的变化的系统和方法。可以获得第一信号和第二信号，从中可以计算生理参数的第一多个值。还可以使用小波变换来变换至少一个信号，小波变换可以用于至少部分地基于变换后的信号来生成校正图。可以至少部分地基于标度图中的特征来确定第二多个值。然后可以关联第一和第二多个值，并且可以使用关联的第一和第二值来分析生理状态。在一个实施例中，信号可以是PPG信号，并且相关联的第一和第二值可以包括Lissajous图，其可以允许用户确定患者的通气状态随时间的变化。