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(54) Title: SIGNAL PROCESSING SYSTEMS AND METHODS FOR DETERMINING SLOPE USING AN ORIGIN POINT

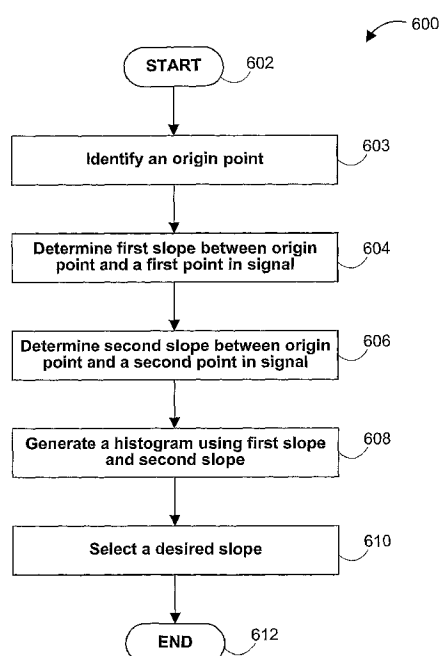


FIG. 6

(57) Abstract: The present disclosure relates to signal processing and, more particularly, relates to determining the slope of a signal. In embodiments, slopes between an origin point of the plot and at least two points in the signal may be determined. The slopes may be used to generate a histogram, and a desired slope of the signal corresponding to a preferred value in the histogram may be selected. In an embodiment, a two-dimensional Lissajous figure may be selected from a three-dimensional Lissajous figure and a histogram of the slopes within the selected Lissajous figure may be created to determine the desired slope. The desired slope may have clinical relevance (e.g., it may be used to determine a patient's blood oxygen saturation level). The three-dimensional Lissajous figure may be derived from surface signals related to two scalograms. Each scalogram may be the result of performing a continuous wavelet transform on a signal. A confidence measure may be generated with respect to determining the desired slope.

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Signal Processing Systems and Methods for Determining Slope Using an Origin Point

Cross-Reference to Related Applications

This application claims the benefit of United States Provisional Application No. 61/080,950, entitled "Signal Processing Systems and Methods for Determining Slope Using an Origin Point," filed July 15, 2008, and United States Provisional Application
5 No. 61/077,079, entitled "Signal Processing Systems and Methods for Determining Slopes," filed June 30, 2008, which are hereby incorporated by reference herein in their entireties.

Summary

10 The present disclosure generally relates to signal processing systems and methods and, more particularly, to systems and methods for determining the slope of a signal, for example, a photoplethysmograph (PPG) signal. In an embodiment, a slope is determined by calculating, for each of a number of data points of the signal, the slope between the origin point and a plurality of other data points of the signal. The calculated slopes are
15 compared to determine a desired slope, such as the most common, or dominant, slope.

The origin point from which slopes may be calculated may be selected using any suitable method. For example, the origin point may have a value of (0,0) on the plot or the origin point may correspond to a data point of the signal. Alternatively, the origin point may be located through an iterative process using a midpoint of the signal in the
20 plot. Alternatively, the origin point may be located by calculating slope values between each data point and each other data point of the plot and constructing a histogram for each set of slope values calculated from each data point. The histogram with the narrowest peak surrounding the dominant calculated slope value for a given set of slope values may indicate that the data point from which the slope values were calculated is the
25 appropriate origin point. Alternatively, any arbitrary point in the plot or any signal data point may serve as the origin point from which to obtain slope values. For example, if calibration information related to the signal indicates that a true slope of interest may

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pass through a particular point or data point, then slope values may be calculated from that data point. Alternatively, slopes may be calculated between data points on the plot and one or more origin points that may be known or may be assumed to be consistent with the system from which the signal may have originated. Alternatively, the origin point may be selected by joining all pairs of data points in the plot with straight lines; the location of the maximum density of the straight lines may be taken as the origin point. Alternatively, the origin point may be chosen using information from another source. For example, a two-dimensional Lissajous figure may be selected from a three-dimensional Lissajous figure which, in turn, may contain any suitable number of two-dimensional Lissajous figures. Data from the other two-dimensional Lissajous figures may be used to determine the origin point of the selected two-dimensional Lissajous figure.

In an embodiment, the plotted signal may be of a Lissajous figure derived from scanning any suitable number of wavelet transform surfaces. The Lissajous figure may be centered around the zero value, or the origin point. Because the Lissajous figure may be oscillating around the origin point without having to separately or iteratively derive the location of the origin point, slope values may be calculated from the origin point, thereby reducing computation time.

In some embodiments, each of the calculated slopes may be used to generate a histogram. For example, the histogram may show a maximum value at the maximum, or dominant, slope of the signal. In an embodiment, the desired slope value may correspond to the dominant slope of the plotted signal, regardless of whether all of the data points in the signal were used to calculate the slope values. Other secondary slopes (*e.g.*, slope values due to calculating the slope of the signal using outlying data points) may exist and may be represented on the histogram, for example, at values spaced apart from the maximum value and thus the secondary slopes may not affect the dominant slope value. In an embodiment, the secondary slope may be the desired slope and the dominant slope may be due to an erroneous (*e.g.*, artifact) slope if, for example, an artifact dominates the signal. It is to be understood that the desired slope may correspond to a preferred value selected from the histogram. In an embodiment, the preferred value may correspond to the maximum value of the histogram and the desired slope may represent the dominant slope of the plotted signal. In an embodiment, the

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preferred value may correspond to a secondary peak of the histogram and the desired slope may represent a secondary slope of the plotted signal.

In an embodiment, the desired slope may be determined using each data point of the plotted signal. Alternatively, in an embodiment, data points in close proximity to each other may be ignored in calculating the slopes to preemptively remove the effect of artifacts in the signal (*e.g.*, noise) on the calculations. In another suitable embodiment, data points close in time or any other suitable unit of measure may be ignored in calculating the slopes. In an embodiment, a secondary slope may represent the desired slope and the dominant slope may be due to an erroneous slope. Therefore, flexibility may be allowed to choose whichever local maxima in the histogram are desired. Calculating only the slopes from the origin point may remove a number of erroneous slopes that may be computed between data points which may lie on distinctly different parts of the plot. The histogram may provide a more resolved slope distribution from which desired information may be derived because each peak in the histogram may be more defined. Since the histogram may allow the outlying data points to appear as a non-dominant peak or peaks, the histogram may be useful in determining one or more secondary slopes contained within the signal due to any suitable secondary signal component or artifact.

The foregoing slope determination method may be employed in any suitable context. In some embodiments, it is employed in a noise reduction algorithm. In an embodiment, a confidence measure may be developed in conjunction with determining the dominant slope of the plotted signal. In an embodiment, the shape of the histogram may be used to measure confidence in the calculation of the dominant slope. In an embodiment, the value of the dominant slope from a histogram may be used for line fitting with respect to the original signal.

For purposes of clarity, and not by way of limitation, some embodiments disclosed herein may include a process for determining physiological parameters from wavelet-transformed signals, such as a photoplethysmograph (PPG) signal and, more particularly, is disclosed for determining oxygen saturation (SpO_2) from wavelet-transformed PPG signals. In such an approach, a three-dimensional Lissajous plot is derived from wavelet transforms of PPG signals (*i.e.*, wavelet transforms of the red and infrared light signals). The Lissajous plot is probed to find a two-dimensional Lissajous plot with a maximum spread along its principal axis and a minimum spread along an axis

orthogonal to the principal axis. A representative slope is calculated from the two-dimensional Lissajous plot using the method described herein. The slope is used to index into an SpO₂ lookup table or used in a calibration equation to determine the oxygen saturation level of a patient from whom the PPG signals were obtained.

5 In an embodiment, a method for determining a slope of a signal on a plot is provided. The method may include identifying an origin point of the plot, determining slopes between the origin point of the plot and at least two points in the signal, generating a histogram from the slopes, and selecting a desired slope of the signal corresponding to a preferred value in the histogram.

10 In an embodiment, a system for determining a slope of a signal on a plot is provided. The system may include an input signal generator for generating the signal, a processor coupled to the input signal generator, and an output coupled to the processor. The output may be capable of displaying information based at least in part on the slope. The processor may be capable of identifying an origin point of the plot, determining
15 slopes between the origin point of the plot and at least two points in the signal, generating a histogram from the slopes, and selecting a desired slope of the signal corresponding to a preferred value in the histogram.

In an embodiment, a computer-readable medium for use in determining a slope of a signal on a plot is provided. The computer-readable medium may include computer
20 program instructions recorded thereon for identifying an origin point of the plot, determining slopes between the origin point of the plot and at least two points in the signal, generating a histogram from the slopes, and selecting a desired slope of the signal corresponding to a preferred value in the histogram.

Brief Description of the Drawings

25 The patent or application file contains at least one drawing executed in color. Copies of this patent or patent application publication with color drawing(s) will be provided by the Office upon request and payment of the necessary fee.

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

FIG. 1 shows an illustrative pulse oximetry system in accordance with an embodiment;

FIG. 2 is a block diagram of the illustrative pulse oximetry system of **FIG. 1** coupled to a patient in accordance with an embodiment;

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

5 **FIG. 3(c)** shows an illustrative scalogram derived from 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 illustrative schematics of a further wavelet decomposition of these newly derived signals in accordance with an embodiment;

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

FIG. 4 is a block diagram of an illustrative continuous wavelet processing system in accordance with some embodiments;

15 **FIG. 5(a)** shows an illustrative schematic of a signal plotted in accordance with an embodiment;

FIGS. 5(b)-(c) show histograms of calculated slope values of the signal plotted in **FIG. 5(a)** in accordance with an embodiment;

FIG. 6 is a flowchart of an illustrative process for determining a slope of a signal in accordance with an embodiment;

20 **FIG. 7** shows a plot of two signals detected in accordance with an embodiment;

FIG. 8 shows a transform-surface of each of the detected signals in **FIG. 7** in accordance with an embodiment;

FIG. 9 shows a three-dimensional Lissajous figure derived at least in part from the transform-surfaces of **FIG. 8** in accordance with an embodiment;

25 **FIG. 10** shows a Lissajous figure selected from the three-dimensional Lissajous figure of **FIG. 9** in accordance with an embodiment;

FIG. 11 shows a histogram of the slopes of the selected Lissajous figure of **FIG. 10** in accordance with an embodiment;

30 **FIG. 12** is a flowchart of an illustrative process for determining a blood oxygen saturation of a patient after a noise algorithm is applied to a two-dimensional Lissajous figure in accordance with an embodiment; and

FIG. 13 is a flowchart of an illustrative process for generating a confidence measure from a histogram in accordance with an embodiment.

Detailed Description

The present disclosure generally relates to signal processing and, more particularly, the present disclosure relates to determining the slope of a signal such as, for example, a Lissajous figure derived from two photoplethysmograph (PPG) signals.

5 An oximeter is a medical device that may determine the oxygen saturation of the blood. One common type of oximeter is a pulse oximeter, which 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
10 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.

15 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 signal representing light intensity versus time or a mathematical manipulation of this signal (*e.g.*, a scaled version thereof, a log taken thereof, a scaled version of a log
20 taken thereof, *etc.*) may be referred to as the photoplethysmograph (PPG) signal. In addition, the term "PPG signal," as used herein, may also refer to an absorption signal (*i.e.*, representing the amount of light absorbed by the tissue) or any suitable mathematical manipulation thereof. The light intensity or the amount of light absorbed may then be used to calculate the amount of the blood constituent (*e.g.*, oxyhemoglobin)
25 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
30 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.

5 The following notation will be used herein:

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

where:

λ =wavelength;

t =time;

10 I =intensity of light detected;

I_o =intensity of light transmitted;

s =oxygen saturation;

β_o, β_r =empirically derived absorption coefficients; and

15 $l(t)$ =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
20 logarithm) for IR and Red

$$\log I = \log I_o - (s\beta_o + (1-s)\beta_r)l \quad (2)$$

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

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

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

$$25 \quad \frac{d \log I(\lambda_R) / dt}{d \log I(\lambda_{IR}) / dt} = \frac{s\beta_o(\lambda_R) + (1-s)\beta_r(\lambda_R)}{s\beta_o(\lambda_{IR}) + (1-s)\beta_r(\lambda_{IR})} \quad (4)$$

4. Solving for s

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

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Note in discrete time

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

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

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

5 So, (4) can be rewritten as

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

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
 10 family of points. One method using a family of points uses a modified version of (5).
 Using the relationship

$$\frac{d \log I}{dt} = \frac{dI / dt}{I} \quad (6)$$

now (5) becomes

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

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

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

20 **FIG. 1** is a perspective view of an embodiment of a pulse oximetry system **10**.
 System **10** may include a sensor **12** and a pulse oximetry monitor **14**. Sensor **12** may

include an emitter **16** for emitting light at two or more wavelengths into a patient's tissue. A detector **18** may also be provided in sensor **12** for detecting the light originally from emitter **16** that emanates from the patient's tissue after passing through the tissue.

According to an embodiment and as will be described, system **10** may include a
5 plurality of sensors forming a sensor array in lieu of 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 another embodiment, the sensor array may be made up of a combination of CMOS and CCD sensors. The CCD sensor may comprise a photoactive region and a
10 transmission region for receiving and transmitting data whereas the CMOS sensor may be made up of an integrated circuit having an array of pixel sensors. Each pixel may have a photodetector and an active amplifier.

According to an embodiment, 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
15 tissue has passed completely through the digit. In an embodiment, emitter **16** and detector **18** may be arranged so that light from emitter **16** penetrates the tissue and is reflected by the tissue into 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
20 power from monitor **14** as shown. In another embodiment, the sensor may be wirelessly connected to monitor **14** and include its own battery or similar power supply (not shown). Monitor **14** may be configured to calculate physiological parameters based at least in part on data received from sensor **12** relating to light emission and detection. In an alternative embodiment, the calculations may be performed on the monitoring device
25 itself and the result of the oximetry reading may be passed to monitor **14**. Further, monitor **14** may include a display **20** configured to display the physiological parameters or other information about the system. In the embodiment shown, monitor **14** may also include a speaker **22** to provide an audible sound that may be used in various other
30 embodiments, such as for example, sounding an audible alarm in the event that a patient's physiological parameters are not within a predefined normal range.

In an embodiment, sensor **12**, or the sensor array, may be communicatively coupled to monitor **14** via a cable **24**. However, in other embodiments, a wireless

transmission device (not shown) or the like may be used instead of or in addition to cable 24.

In the illustrated embodiment, pulse oximetry system 10 may also include 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. Multi-parameter patient monitor 26 may be configured to calculate physiological parameters and to provide a display 28 for information from monitor 14 and from other medical monitoring devices or systems (not shown). For example, multiparameter patient monitor 26 may be configured to display an estimate of a patient's blood oxygen saturation generated by pulse oximetry monitor 14 (referred to as an "SpO₂" measurement), pulse rate information from monitor 14 and blood pressure from a blood pressure monitor (not shown) on display 28.

Monitor 14 may be communicatively coupled to multi-parameter patient monitor 26 via a cable 32 or 34 that is coupled to a sensor input port or a digital communications port, respectively and/or may communicate wirelessly (not shown). In addition, monitor 14 and/or multi-parameter patient monitor 26 may be coupled to a network to enable the sharing of information with servers or other workstations (not shown). 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 a pulse oximetry system, such as pulse oximetry system 10 of **FIG. 1**, which may be coupled to a patient 40 in accordance with an embodiment. Certain illustrative components of sensor 12 and monitor 14 are illustrated in **FIG. 2**. Sensor 12 may include emitter 16, detector 18, and encoder 42. In the embodiment shown, emitter 16 may be configured to emit at least two wavelengths of light (*e.g.*, *RED* and *IR*) into a patient's tissue 40. Hence, emitter 16 may include a *RED* light emitting light source such as *RED* light emitting diode (LED) 44 and an *IR* light emitting light source such as *IR* LED 46 for emitting light into the patient's tissue 40 at the wavelengths used to calculate the patient's physiological parameters. In one embodiment, 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

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emit a single wavelength. For example, a first sensor emits only a *RED* light while a second only emits an *IR* light.

It will 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. Detector **18** may be chosen to be specifically sensitive to the chosen targeted energy spectrum of the emitter **16**.

In an embodiment, 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 may enter detector **18** after passing through the patient’s tissue **40**. Detector **18** may convert 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, detector **18** may send the signal to monitor **14**, where physiological parameters may be calculated based on the absorption of the *RED* and *IR* wavelengths in the patient’s tissue **40**.

In an embodiment, encoder **42** may contain information about 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 emitter **16**. This information may be used by monitor **14** to select appropriate algorithms, lookup tables and/or calibration coefficients stored in monitor **14** for calculating the patient’s physiological parameters.

Encoder **42** may contain information specific to patient **40**, such as, for example, the patient’s age, weight, and diagnosis. This information may allow monitor **14** to determine, for example, patient-specific threshold ranges in which the patient’s physiological parameter measurements should fall and to enable or disable additional physiological parameter algorithms. Encoder **42** may, for instance, be a coded resistor which stores values corresponding to the type of sensor **12** or the type of each sensor in the sensor array, the wavelengths of light emitted by emitter **16** on each sensor of the

sensor array, and/or the patient's characteristics. In another embodiment, encoder **42** may include a memory on which one or more of the following information may be stored for communication to monitor **14**: the type of the sensor **12**; the wavelengths of light emitted by emitter **16**; the particular wavelength each sensor in the sensor array is monitoring; a signal threshold for each sensor in the sensor array; any other suitable information; or any combination thereof.

In an embodiment, signals from detector **18** and encoder **42** may be transmitted to monitor **14**. In the embodiment shown, monitor **14** may include a general-purpose microprocessor **48** connected to an internal bus **50**. Microprocessor **48** may be 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 bus **50** may be a read-only memory (ROM) **52**, a random access memory (RAM) **54**, user inputs **56**, display **20**, and speaker **22**.

RAM **54** and ROM **52** are illustrated by way of example, and not limitation. Any suitable 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 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 include computer storage media and communication media. Computer storage media may include 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 may include, 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** may provide timing control signals to a light drive circuitry **60**, which may control when emitter **16** is illuminated and multiplexed timing for the *RED* LED **44** and the *IR* LED **46**. TPU **58** may also control 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 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 RAM **54** as QSM **72** fills up. In one embodiment, there may be multiple
5 separate parallel paths having amplifier **66**, filter **68**, and A/D converter **70** for multiple light wavelengths or spectra received.

In an embodiment, microprocessor **48** may determine the patient's physiological parameters, such as SpO₂ 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
10 by detector **18**. Signals corresponding to information about patient **40**, and particularly about the intensity of light emanating from a patient's tissue over time, may be transmitted from encoder **42** to a decoder **74**. These signals may include, for example, encoded information relating to patient characteristics. Decoder **74** may translate these signals to enable the microprocessor to determine the thresholds based on algorithms or
15 look-up tables stored in ROM **52**. User inputs **56** may be used to enter information about the patient, such as age, weight, height, diagnosis, medications, treatments, and so forth. In an embodiment, 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 user inputs **56**.

20 The optical signal through the tissue can be degraded by noise, among other sources. One source of noise is ambient light that 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
25 disrupted when movement causes either to move away from the skin. In addition, because 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.

Noise (*e.g.*, from patient movement) can degrade a pulse oximetry signal relied
30 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. Processing pulse oximetry (*i.e.*, PPG) signals may involve operations that reduce the

amount of noise present in the signals or otherwise identify noise components in order to prevent them from affecting measurements of physiological parameters derived from the PPG signals.

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.

In one embodiment, a PPG signal may be transformed using a continuous wavelet transform. Information derived from the transform of the PPG signal (*i.e.*, in wavelet space) may be used to provide measurements of one or more physiological parameters.

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

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

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) may 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 as 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, for example, in Paul S. Addison, *The Illustrated Wavelet Transform Handbook* (Taylor & Francis Group 2002), which is hereby incorporated by reference herein in its entirety.

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 a range of wavelets with scales spanning the scales of interest of a signal such that small scale signal components correlate well with the smaller scale wavelets and thus manifest at high energies at smaller scales in the transform. Likewise, large scale signal components correlate well with the larger scale wavelets and thus manifest at high energies at larger scales in the transform. Thus, components at different scales may be separated and extracted in the wavelet transform domain. Moreover, the use of a continuous range of wavelets in scale and time position allows for a higher resolution transform than is possible 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, in addition to or as an alternative to 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

$$S(a,b) = |T(a,b)|^2 \quad (10)$$

where '||' is the modulus operator. The scalogram may be rescaled for useful purposes.

One common rescaling is defined as

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

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
 5 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
 10 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

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

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
 20 disclosure. One of the most commonly used complex wavelets, the Morlet wavelet, is defined as:

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

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
 25 complex sinusoid within the Gaussian window. In practice, it becomes negligible for values of $f_0 \gg 0$ and can be ignored, in which case, the Morlet wavelet can be written in a simpler form as

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

This wavelet is a complex wave within a scaled Gaussian envelope. While both
 30 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 $f_0 \gg 0$ 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.

In embodiments, pertinent repeating features in a signal may 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)** show two views of an illustrative 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.

In embodiments, 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 embodiments, an inverse continuous wavelet transform may be desired, such as when modifications to a scalogram (or modifications to the coefficients of a

- 20 -

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 :

5

$$x(t) = \frac{1}{C_g} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} T(a,b) \frac{1}{\sqrt{a}} \psi\left(\frac{t-b}{a}\right) \frac{dad b}{a^2} \quad (15)$$

which may also be written as:

10

$$x(t) = \frac{1}{C_g} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} T(a,b) \psi_{a,b}(t) \frac{dad b}{a^2} \quad (16)$$

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

15

$$C_g = \int_{-\infty}^{\infty} \frac{|\hat{\psi}(f)|^2}{f} df \quad (17)$$

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 (15) 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. It will be understood that any other suitable technique for performing an inverse continuous wavelet transform may be used in accordance with the present disclosure.

25

FIG. 4 is an illustrative continuous wavelet processing system **400** 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
5 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,
10 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
15 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
20 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 one or more memory devices (not shown) or incorporate one or more memory devices such as any suitable volatile memory device (*e.g.*, RAM, registers, *etc.*), non-volatile memory device (*e.g.*, ROM, EPROM, magnetic storage device, optical storage device, flash memory, *etc.*), or both. The memory may be used by processor **412** to, for example, store data corresponding to a continuous wavelet
25 transform of input signal **416**, such as data representing a scalogram. In one embodiment, data representing a scalogram may be stored in RAM or memory internal to processor **412** as any suitable three-dimensional data structure such as a three-
30

dimensional array that represents the scalogram as energy levels in a time-scale plane. Any other suitable data structure may be used to store data representing a scalogram.

In some embodiments, 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.

It will be understood that system **400** may be incorporated into system **10** (FIGS. **1** and **2**) in which, for example, input signal generator **410** may be implemented as parts of sensor **12** and monitor **14** and processor **412** may be implemented as part of monitor **14**, according to an embodiment.

The slope determination process of the present disclosure will now be discussed in reference to FIGS. **5-11**.

FIG. **5(a)** shows an illustrative schematic of data points of a signal plotted in accordance with an embodiment. The signal may be any suitable signal, including a continuous signal, a discrete signal, or a signal formed from multiple data points. In an embodiment, the signal may include features of a scalogram or a Lissajous figure. In FIG. **5(a)**, plot **500** may include data points **A, B, C, D, E, F**, and **G**, and any other suitable number of data points within the signal. Plot **500** 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.

Point **X** may represent the origin point from which slopes may be calculated between point **X** and the data points of the signal in accordance with an embodiment. The slopes of the signal may be determined in any suitable manner. In some embodiments, a slope value may be determined between point **X** and any suitable data point by taking the ratio of the rise from point **X** to the data point to the run from the point **X** to the data point. The ratio may be taken with reference to any suitable axis (e.g., axis **T**, FIG. **5(a)**). In some embodiments, a slope value may be determined by

first determining the angle made between the same axis and a straight line connecting point **X** and the data point. The determined angle may be thereafter converted to a slope value. If the slope value is determined from the data point to point **X**, an angle may be similarly determined between axis **T** and the straight line connecting the data point and point **X**. In some embodiments, determining angles and converting those angles into slope values may be more computationally efficient than determining the slope values because the angle values may span a narrower, linearly distributed range. For example, the angle values present between the reference axis, point **X**, and the points in the signal may span from -90° to 90° (passing through 0°), whereas the slope values may span from negative infinity to infinity (passing through zero). It is to be understood that the words "slope" or "gradient," as used in this disclosure, may include any of the foregoing manners for determining a slope value.

Point **X** may be chosen to represent the origin point using any suitable method. For example, point **X** may have a value of (0,0) on plot **500** (e.g., the position (0,0) in plot **500**). As another example, point **X** may correspond to a data point of the signal in plot **500**. In an embodiment, point **X** may be located through an iterative process. For example, a midpoint of the signal in plot **500** may be initially selected using any suitable method (e.g., using the mean value or the average value of the data points in plot **500**). Once the midpoint has been selected, slope values may be calculated between the selected midpoint and all of the data points in plot **500**. The calculated slope values between certain of the points in plot **500** may be compared with the calculated slope values between other points in plot **500**. For example, the slope values calculated between the selected midpoint and the data points to the left of the midpoint may be compared against the slope values calculated between the midpoint and the data points to the right of the midpoint. As another example, the slope values calculated using the data points above the midpoint may be compared against the slope values calculated using the data points below the midpoint. As yet another example, the data points may be analyzed to determine a maximum spread of the data points or a line fitting method may be used. For example, the maximum spread of plot **500** may extend approximately from data point **A** to the right most data point in plot **500**. A line that passes through the midpoint and that is perpendicular to the maximum spread or the best fit line may be used to separate the data points whose corresponding slopes are to be compared.

The slopes of the two groups of data points may be compared using any suitable method. For example, the slopes may be compared by using the mean or median slope value within each group. As another example, the slopes calculated for each group may be inputted into a histogram and the slope corresponding to the maximum value may be used for the comparison. If the slopes that are compared between the two groups of data points are not substantially similar or the same, then the midpoint may be moved to decrease the difference between the two groups of slopes. As an example, if data point **F** in plot **500** was initially selected as the origin point, the slope values calculated based on the data points to the right of data point **F** may be higher than the slope values calculated based on the data points to the left of data point **F**. If this were the case, then the midpoint may be moved upwards to decrease the slopes to the right of the origin point and increase the slopes to the left of the origin point. This process may be repeated until the slope values within the two groups are substantially similar or the same. Once this process is complete, the latest location may be selected as the origin point or point **X** of the plot.

In another embodiment, slope values may be calculated between each data point and each other data point of plot **500** (e.g., for 100 data points, 100 sets of 99 slope values may be calculated). A histogram may be constructed for each set of slope values calculated from each data point (e.g., 100 histograms may be constructed). The histogram with the narrowest peak surrounding the dominant calculated slope value for a given set of slope values may indicate that the data point from which the slope values were calculated is the appropriate point **X**.

In an embodiment, plot **500** may be of a Lissajous figure derived from scanning any suitable number of wavelet transform surfaces. Each wavelet transform surface may be the result of applying a wavelet transform to a signal (e.g., a PPG signal), as described above with respect to **FIGS. 3(a), (b), and (c)**. Signal drift may not affect plot **500** because the signal drift may be manifested in lower scales of the wavelet scalograms from which the wavelet transform surfaces may be obtained. The lower scales may not be the scales of interest and may not be used in deriving a Lissajous figure from the wavelet transform surfaces. In an embodiment, signal drift may also be removed, or filtered, from the signal prior to its wavelet transform processing. As a result, the signal or signals may include a zero mean or may oscillate about a zero point. The transform surface values that may be derived from the signals also may oscillate around a zero

point and the derived Lissajous figure may be centered around the zero value, or origin point **X**. Because the Lissajous figure may be oscillating around point **X** without having to separately or iteratively derive the location of point **X**, slope values may be calculated from point **X**, thereby reducing computation time.

5 In an embodiment, any arbitrary point in plot **500** or any signal data point may be used to obtain slope values. For example, if calibration information related to the signal exists from another source, and the calibration information indicates that a true slope of interest may pass through a particular point or data point, then slope values may be calculated from that data point. Alternatively, slopes may be calculated between data
10 points on plot **500** (*e.g.*, data points of a Lissajous figure) and one or more origin points that may be known or may be assumed to be consistent with the system from which the signal may have originated. For example, for a signal oscillating about zero (*e.g.*, a filtered PPG signal), slope values may be calculated between point **X** and all of the data points of the signal and a histogram may be constructed from the calculated slope values.

15 In an embodiment, the slope of the signal may be determined using each data point in plot **500**, as shown in **FIG. 5(b)**. Such a method is described, for example, in Watson, et al., U.S. Application No. 12/242,882 (Attorney Docket No. H-RM-01189-01 (COV-8-01)), filed September 30, 2008, entitled "Signal Processing Systems and Methods for Determining Slopes of Electronic Signals," which is hereby incorporated by
20 reference herein in its entirety. For example, a first slope of the signal may be determined between data point **A** and data point **B**, a second slope of the signal may be determined between data point **A** and data point **C**, and so on until each data point is used with each other data point to determine all of the slopes between the data points of the signal. Alternatively, in an embodiment, data points in close proximity to each other
25 (*e.g.*, data points **C** and **E**) may be ignored in calculating the slopes to preemptively remove the effect of artifacts in the signal (*e.g.*, noise) on the calculations. The slopes of the signal may also be determined between any data points of the signal, including, for example, between data points **D** and **G**, between data points **D** and other data points in the signal, and between data point **G** and other data points in the signal. Data points **D**
30 and **G** may be "outlying" data points on plot **500**, and may represent any suitable component within the signal, such as correlated noise. If outlying data points were used within an analysis of the slope of the plotted signal using a least squares technique, then the determined slope value may be skewed due to the presence of the outlying data

points. The best fit line calculated by a least squares technique on plot **500** may be skewed (*e.g.*, translated and rotated) from a proper best-fit line due to the presence of noise in the signal or other features of the signal as represented by the outlying data points.

FIG. 5(b) shows a histogram of the slopes between all points of the signal plotted in **FIG. 5(a)**, according to an embodiment. Histogram **510** may include any suitable axes representing any suitable units of measure. In an embodiment, histogram **510** may graph the number of occurrences of each calculated slope value or each calculated range of slope values as a function of the slope value and may be of any suitable shape as a result of plotting all of the calculated slopes using all points of the signal. For example, histogram **510** may have a relatively smooth profile, with one peak value and one lesser peak value in close proximity. Histogram **510** may include erroneous slopes that result from using data points that may lie on distinctly different parts of plot **500**, such as outlying data points **D** and **G**, to calculate slope values. Histogram **510** may include a maximum value at the most frequently calculated slope value **S1**. This may represent the dominant slope value of the signal plotted in plot **500**, but the value of slope **S1** may be skewed through the use of all of the data points in plot **500** (*e.g.*, outlying data points **D** and **G**) to calculate the slope values. In an embodiment, histogram **510** may be smoothed prior to analysis using, for example, a smoothing technique such as Gaussian kernel smoothing, low pass filtering, or any other suitable means.

In an embodiment, the presence of the outlying data points **D** and **G** may not affect the calculation of a desired slope. As discussed above, slopes of the signal may be determined solely from the origin point **X** to each other data point of the signal. Each of the calculated slopes may be input into a histogram. The histogram may show a maximum value at the dominant slope of the signal. Other secondary slopes (*e.g.*, slope values due to calculating the slope of the signal using outlying data points, such as data points **D** and **G**) may exist and may be represented on the histogram, for example, as peaks spaced apart from the maximum value and thus the secondary slopes may not affect the dominant slope value.

FIG. 5(c) shows a histogram of the slopes of the signal plotted in **FIG. 5(a)** using point **X** in accordance with an embodiment. Histogram **550** may include any suitable axes representing any suitable units of measure. In one embodiment, histogram **550** may graph the number of occurrences of each calculated slope value or each calculated range

of slope values between point **X** and each other data point of plot **500** as a function of the slope value. In another suitable embodiment, data points close in time to the origin point **X** or any other suitable unit of measure may be ignored in calculating the slopes and in populating histogram **550**. In yet another suitable embodiment, histogram **550** may be smoothed using, for example, a smoothing technique such as Gaussian kernel smoothing, low pass filtering, or any other suitable means. The most frequently calculated slope value **S2** may represent the dominant slope of the signal in plot **500**, regardless of whether all of the data points in the signal were used to calculate the slope values. Due to their outlying nature, the slope values of the signal calculated between point **X** and outlying data points **D** and **G** may be represented as a secondary peak **S3** on histogram **550**. Calculating only the slopes from origin point **X** may remove a number of erroneous slopes, such as a slope calculation between data points **B** and **D**, or a slope calculation between data points **F** and **G**, which may be computed between data points which may lie on distinctly different parts of plot **500**. Histogram **550** may provide a more resolved slope distribution from which desired information (*e.g.*, clinically relevant information about a patient) may be derived because each peak in histogram **550** may become more defined (*e.g.*, each peak will include less spread), even if the original signal used to create plot **500** includes more than one dominant component.

In an embodiment, it may be the case that secondary slope **S3** represents the desired slope and that the dominant slope **S2** may be due to an erroneous (*e.g.*, artifact) slope, which could happen if, for example, an artifact dominates the signal. Therefore, flexibility may be allowed to choose whichever local maxima in histogram **550** is desired. For example, a slope value of 1 may be ignored, which may be present due to correlated noise. Also, as an example, the maxima corresponding to the highest slope may be selected under certain circumstances. Any suitable criteria may be used to select a slope according to any suitable information using any suitable techniques such as neural networks, empirically derived heuristics, weighted bin counts, any other suitable technique, or any combination thereof. Since histogram **550** may allow the outlying data points to appear as a non-dominant peak or peaks, histogram **550** may be useful in not only determining the desired dominant slope of the signal in plot **500**, but also in determining one or more secondary slopes contained within the signal due to any suitable secondary signal component or artifact (*e.g.*, correlated noise).

FIG. 6 is a flowchart of an illustrative process for determining a desired slope of a signal in accordance with an embodiment. Process **600** may begin at step **602**. At step **603**, an origin point may be identified using any suitable method, such as those methods described above. In an embodiment, the origin point may have a value of (0,0) on a plot (e.g., plot **500**) to be analyzed. In another embodiment, the origin point may correspond to a data point of a signal in the plot. In another embodiment, the origin point may be located through an iterative process as described above. In yet another embodiment, the origin point may be located using slope values, using a point about which the signal on the plot may be oscillating, or using calibration information provided by the system from which the plot may have been created. Step **603** may be performed by, for example, microprocessor **48** (**FIG. 2**) or processor **412** (**FIG. 4**).

In an embodiment, process **600** may advance to step **604**, at which a first slope value is calculated between any point (e.g., origin point **X**, **FIG. 5(a)**) and a first data point within the signal. Origin point **X** may be a data point of the signal. Any data point may be included in determining the first slope value, including outlying data points, a data point not within a close proximity or other unit of measure of the origin point, or a data point within a particular portion of the signal. Step **604** may be performed by microprocessor **48** operating in real time on samples from QSM **72** (**FIG. 2**) or from samples stored in RAM **54** (**FIG. 2**).

In an embodiment, process **600** may advance to step **606**, in which a second slope value of the signal may be determined. The second slope value may be calculated in the same manner in which the first slope value was determined (e.g., using the origin point **X**), but using a second data point from which to determine the second slope value. In an embodiment, process **600** may include any suitable number of additional steps (not shown) to determine any suitable number of slope values for other data points in the signal. For example, the signal used in process **600** may contain 100 data points, and process **600** may include 100 steps to determine 100 sets of slope values before advancing to step **608**.

In an embodiment, process **600** may advance to step **608**, in which the calculated slope values each may be used to generate a histogram (e.g., by microprocessor **48** or processor **412**). The histogram may include any suitable axes representing any suitable units of measure. In one embodiment, the histogram may plot the number of occurrences of each slope value as a function of the slope value. Each slope value may be

represented in any suitable manner on the histogram, such as by an individual peak. The height of each peak on the histogram may correspond to the number of occurrences of slope that occur at the slope value or within the range of slope values for that peak value.

In an embodiment, process **600** may advance to step **610**, in which a desired
5 slope may be selected from the histogram. In an embodiment, it may be desirable to determine the dominant slope value of the signal. The slope value with the maximum number of occurrences on the histogram (*e.g.*, the histogram peak with the maximum height) may indicate the signal's dominant slope value. In an embodiment, it may be desirable to determine another slope value within the signal. For example, the signal
10 may contain other components or artifacts, such as correlated noise. The histogram may illustrate that one or more of these components has a particular slope value with a number of occurrences greater than other determined slope values, but not the greatest number of occurrences as compared with the dominant slope value of the signal. The histogram may allow this secondary slope value to be located and its value determined.
15 In some embodiments, slope values may be automatically selected from the histogram by microprocessor **48** or processor **412** and then displayed on any suitable output mechanism, such as display **20** (**FIG. 2**), display **28**, (**FIG. 2**) or output **414** (**FIG. 4**). In other embodiments, microprocessor **48** (**FIG. 2**) may display the histogram on display **20**, display **28**, or output **414**, and the desired slopes may be selected or otherwise
20 identified by a user of system **10** (**FIG. 1**) via user inputs **56** (**FIG. 2**). Process **600** may then advance to step **612** and end. It is to be understood that process **600** may be performed with any suitable signals, including signals that may form a Lissajous figure and may be obtained from one or more scalograms (described above with respect to **FIGS. 3(a), 3(b), and 3(c)**), and/or the original signals from which the scalograms may
25 be derived.

FIG. 7 shows a plot of two signals detected in accordance with an embodiment in which PPG signals are employed. In this embodiment, one PPG signal may include a red light signal **720** and another PPG signal may include an infrared light signal **740**
obtained from a pulse oximeter sensor as described above. Red light signal **720** and
30 infrared signal **740** may be plotted as shown in **FIG. 7** after passing through a portion of the patient's blood perfused tissue (*e.g.*, a fingertip, a toe, a foot). Red light signal **720** and infrared signal **740** may each oscillate about a zero value, as shown, if each signal is filtered to remove, for example, any low-magnitude frequency drift. The pulse oximeter

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sensor may transmit red light signal **720** and infrared light signal **740** to any suitable processing unit (*e.g.*, processor **412** or microprocessor **48**) for further analysis. For example, analyzing the ratio between changes in the red light signal **720** and changes in the infrared light signal **740** after both signals have passed through human tissue may be useful in determining a patient's blood oxygen saturation.

FIG. 8 shows the real part of the wavelet transform of each of the detected PPG signals in **FIG. 7** in accordance with an embodiment. The wavelet transform, from which **FIG. 8** was derived, may be computed using a complex wavelet such as a Morlet wavelet. The imaginary parts of the wavelet transform, or the real part of the transform, and/or other forms of the transform, may also be utilized in the method. If, for example a wavelet with only a real component is used, then the transform itself may be used. The scalogram, as defined above, may also be utilized. However, the real-only (or imaginary-only) parts of the transform may produce more pronounced oscillatory behavior of the transform surface, which enhances the technique. All such transforms that may be used are herein referred to as a "transform-surface." A transform-surface may or may not be continuous. In an embodiment, a transform-surface may be represented in a three-dimensional array. Transform-surface **820** and transform-surface **840** may be derived using any suitable method. In one embodiment, each of transform-surface **820** and transform-surface **840** may be the result of taking a transform modulus of red light signal **820** and infrared light signal **840**, respectively, as described above with respect to **FIGS. 3(a), 3(b), and 3(c)**.

In an embodiment, transform-surface **820** and transform-surface **840** may each include any suitable number of ridges at any suitable scale value. In one embodiment, red light signal **720** and infrared light signal **740** 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-surface **820** and transform-surface **840** may each include a ridge at particular scale values that may be related to the pulse component and the breathing component of red light signal **720** and infrared light signal **740**, respectively. In each of transform-surface **820** and transform-surface **840**, arrow **A** may indicate a ridge related to the pulse component of each signal, and arrow **B** may indicate a ridge related to the breathing component of each signal. Other ridges

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shown in transform-surfaces **820** and **840** may indicate other components of signals **720** and **740**, such as high- or low-frequency noise.

FIG. 9 shows a three-dimensional Lissajous figure derived at least in part from the transform-surfaces of **FIG. 8** in accordance with an embodiment. The surfaces of transform-surfaces **820** and **840** may be plotted against each other over a range of scales using, for example, a sliding time window (not shown). For each scale value, the amplitude surface of transform-surface **820** may be plotted against the amplitude surface of transform-surface **840** to derive a Lissajous figure. For example, one Lissajous figure may result from plotting the changes in amplitude of transform-surface **820** against the changes in amplitude of transform-surface **840** for each particular scale value over a period of time. A three-dimensional Lissajous figure **900** may be assembled from plotting all of the Lissajous figures of transform-surfaces **820** and **840** for a given time period.

In an embodiment, figure **900** may be analyzed further to select one Lissajous figure using any suitable method. For example, one Lissajous figure within figure **900** may have the greatest length along its major axis and the least spread perpendicular to the major axis. The dimensions of this selected Lissajous figure may indicate a low amount of noise or a high signal to noise ratio in signals **720** and **740** at the scale corresponding to the selected Lissajous figure.

FIG. 10 shows a Lissajous figure selected from the three-dimensional Lissajous figure of **FIG. 9** in accordance with an embodiment. Lissajous figure **1000** may be selected from three-dimensional Lissajous figure **900** because it may include the greatest length along its major axis and the least spread perpendicular to the major axis, thereby indicating a minimal amount of associated noise. In **FIG. 10**, the amplitude of transform-surface **820** may be plotted as a function of the amplitude of transform-surface **840** for the scale corresponding to the selected Lissajous figure **1000** over a period of time. Lissajous figure **1000** may oscillate about an origin point **W**, which may be the same as, and may include some or all of the features of, origin point **X** (**FIG. 5(a)**). Origin point **W**, in an embodiment, may include a data point of Lissajous figure **1000**.

In an embodiment, Lissajous figure **1000** may have a dominant slope that in an embodiment may have relevance. For example, if three-dimensional Lissajous figure **900** was created using transform-surfaces **820** and **840** based at least in part on red light signal **720** and infrared light signal **740**, respectively, then the dominant slope of figure

1000 may correspond to a ratio between changes in red light signal **720** and changes infrared light signal **740**. The ratio may be used with a look-up table of values or used in a calibration equation to determine the blood oxygen saturation level of a patient from which red light signal **720** and infrared light signal **740** were obtained. The lookup table
5 may be created, for example, using empirical patient data. It is to be understood from this disclosure that using Lissajous figure **1000** to determine a patient's blood oxygen saturation level does not require a determination of the patient's pulse rate. In an embodiment, however, the scale at which the patient's pulse rate may manifest itself in transform-surface **820** and/or transform-surface **840** may be used to select figure **1000**
10 from three-dimensional Lissajous figure **900**.

In an embodiment, to determine the dominant slope of figure **1000**, a least squares technique may be applied to create a best-fit line using the data points within figure **1000**. The least squares technique may be skewed, however, by the presence of other signal components, such as correlated noise that may be present within signals **720**
15 and **740**. The presence of the other signal components may represent a secondary slope within figure **1000** that may skew the determination of the dominant slope and may affect the analysis of patient information using the dominant slope.

In an embodiment, the dominant slope, which may be related to the dominant components (*e.g.*, the components with the highest energy) within signals **720** and **740**
20 may be determined using any suitable approach. **FIG. 11** shows a histogram of the slopes or range of slope values of figure **1000** in accordance with an embodiment. In an embodiment, the slope of figure **1000** between an origin point (*e.g.*, origin point **W**) and each of the data points of figure **1000**, including any outlying data points, may be determined. In an embodiment, data points close in time to origin point **W** or any other
25 suitable unit of measure may be ignored in calculating the slopes of figure **1000**. The resulting calculations may be graphed in any suitable manner, such as by creating histogram **1100**. Histogram **1100** may represent graphically the number of times that a particular slope value or range of slope values may occur within figure **1000**. The maximum of histogram **1100**, shown at dominant peak **M**, may indicate the dominant
30 slope of figure **1100**. In an embodiment, dominant slope **M** may be used with a look-up table or used in a calibration equation to determine a patient's blood oxygen saturation level.

In an embodiment, histogram **1100** may also represent graphically one or more other slope values or range of slope values present within figure **1000** due to one or more other components within signal **720** and/or signal **740**. By using histogram **1100** to ascertain the dominant slope of figure **1000**, the one or more secondary slopes or range of secondary slope values represented, for example by histogram peak **N**, may not skew the determination of the dominant slope of figure **1000**. In an embodiment, the slopes between data points close in time to origin point **W** or any other suitable unit of measure may not be plotted on histogram **1100** to remove some of the effect of the other signal components. Alternatively, the presence or relative impact of one or more secondary slopes may be of interest. For example, a secondary slope within figure **1100** (*e.g.*, histogram peak **N**) that may be related to noise within signals **720** and **740** may be analyzed by creating histogram **1100**.

FIG. 12 is a flowchart of an illustrative process for determining a blood oxygen saturation of a patient after a noise algorithm is applied to a two-dimensional Lissajous figure in accordance with an embodiment. Process **1200** may begin at step **1202**. At step **1204**, a first PPG signal and a second PPG signal may be obtained from a patient using any suitable method. For example, the first and second PPG signals may be obtained from sensor **12** that may be coupled to patient **40** (**FIG. 2**). Alternatively, the PPG signals may be obtained from input signal generator **410**, which may include oximeter **420** coupled to sensor **418**, which may provide as input signal **416** (**FIG. 4**) PPG signals. In an embodiment, the PPG signals may be obtained from patient **40** using sensor **12** or input signal generator **410** in real time. In an embodiment, the PPG signals may have been stored in ROM **52**, RAM **52**, and/or QSM **72** (**FIG. 2**) in the past and may be accessed by microprocessor **48** within monitor **14** to be processed. In an embodiment, the first PPG signal may include a red light signal (*e.g.*, signal **720**) and the second PPG signal may include an infrared light signal (*e.g.*, signal **740**). The first and second PPG signals may be obtained simultaneously from patient **40**.

In an embodiment, process **1200** may advance to step **1206**, where a first scalogram may be derived from the first PPG signal. Process **1200** may advance to step **1208**, where a second scalogram may be derived from the second PPG signal. In an embodiment, step **1208** may occur simultaneously with step **1206**. For example, the scalograms may be derived as described above with respect to **FIGS. 3(a), 3(b), and 3(c)** after the PPG signals have been sent to microprocessor **48** or alternatively, to processor

412 (FIG. 4). In an embodiment, processor **412** or microprocessor **48** may perform the calculations associated with the continuous wavelet transforms of the PPG signals.

In an embodiment, process **1200** may advance to step **1210**, where a three-dimensional Lissajous figure may be generated from the two scalograms. For example, the three-dimensional Lissajous figure may be generated as described above with respect to **FIG. 9**. One Lissajous figure may result from plotting the changes in amplitude of, for example, the first scalogram against the changes in amplitude of the second scalogram for each particular scale value over a period of time. A three-dimensional Lissajous figure may be assembled from plotting all of the Lissajous figures of the scalograms for a given time period. In an embodiment, processor **412** or microprocessor **48** may include any suitable software, firmware, and/or hardware, and/or combinations thereof for processing the scalograms of steps **1206** and **1208** to generate the three-dimensional Lissajous figure.

In an embodiment, process **1200** may advance to step **1212**, where a two-dimensional Lissajous figure may be selected from the three-dimensional Lissajous figure as described above with respect to **FIG. 10**. The two-dimensional Lissajous figure may be selected from the three-dimensional Lissajous figure because it may include the greatest length along its major axis and the least spread perpendicular to the major axis, thereby indicating a minimal amount of associated noise. The two-dimensional Lissajous figure may have a dominant slope that has clinical relevance (*e.g.*, the slope may be used with a look-up table of values or in a calibration equation to determine the blood oxygen saturation level of a patient from which the PPG signals were obtained at step **1204**) because the dominant slope of the two-dimensional Lissajous figure may correspond to a ratio between changes in the red light signal and infrared light signal. In an embodiment, processor **412** or microprocessor **48** may include any suitable software, firmware, and/or hardware, and/or combinations thereof for isolating the desired two-dimensional Lissajous figure from the three-dimensional Lissajous figure.

In an embodiment, process **1200** may advance to step **1214**, where a first slope may be determined between a first point of the two-dimensional Lissajous figure and an origin point using any suitable approach. In an embodiment, any data point may be used with the origin point at step **1214**. In an embodiment, data points close in time, proximity, or any other suitable unit of measure to one another may not be used and outlying data points may also not be used with the origin point to determine the first

slope. The origin point (*e.g.*, origin point **X**) may be located using any suitable approach, including for example, the approaches described above with respect to **FIG. 5(a)**. At step **1216**, a second slope may be determined between a second point of the two-dimensional Lissajous figure and the origin point used at step **1214** using any suitable approach. Any data point other than the first data point used in step **1214** may be used at step **1216** or alternatively, data points close in time, proximity, or any other suitable unit of measure to one another may not be used and outlying data points may also not be used with the origin point to determine the second slope. In an embodiment, processor **412** or microprocessor **48** may include any suitable software, firmware, and/or hardware, and/or combinations thereof for determining the slope values and determining which data points to use in calculating the slope values. In an embodiment, process **1200** may include any suitable number of additional steps (not shown) to determine any suitable additional number of slope values for other data points in the signal.

In an embodiment, at step **1218**, at least one point in the two-dimensional Lissajous figure may be identified. This at least one point may be an offshoot, or an outlying point, of the two-dimensional Lissajous figure. The offshoot may result from any suitable cause, such as noise generated by input signal generator **410** (**FIG. 4**) or noise generated by system **10**, including for example, sensor **12**, monitor **14**, display **28**, or cables **32** and/or **24** (**FIG. 2**). The outlying point or points may be identified at any suitable time, regardless of when the first and second PPG signals may have been obtained from patient **40**. For example, noise may be detected in real time as the PPG signals are obtained from patient **40** by examining the two-dimensional Lissajous figure for outlying data points at step **1218**. In an embodiment, the noise may be detected in real time using a separate noise determination component. Alternatively, the first and second PPG signals may have been stored in ROM **52**, RAM **52**, and/or QSM **72** (**FIG. 2**) in the past and may be accessed by microprocessor **48** to be analyzed using process **1200**. Outlying data points may be identified in step **1218** in any suitable manner. In an embodiment, outlying data points may be identified by comparing the slope values calculated in steps **1214** and/or **1216** using adjacent or approximately adjacent data points. For example, slope values that are significantly different from the adjacent or approximately adjacent first slope value determined in step **1214** or the second slope value determined in step **1216** may indicate the presence of one or more outlying data points. In an embodiment, processor **412** or microprocessor **48** may include any suitable

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software, firmware, and/or hardware, and/or combinations thereof for comparing slope values to locate at least one outlying point in the two-dimensional Lissajous figure.

In an embodiment, process **1200** may advance to step **1220**, where the slope values determined in steps **1214**, **1216**, or any other additional steps (not shown) using any of the points identified in step **1218** as outlying data points of the two-dimensional Lissajous figure may be removed as the first slope, the second slope, or any other additional determined slope value. In an embodiment, processor **412** or microprocessor **48** may include any suitable software, firmware, and/or hardware, and/or combinations thereof for manipulating the first slope, the second slope, and/or any other determined slope value to remove any slope values that may include one or more outlying points identified in step **1218**.

In an embodiment, process **1200** may advance to step **1222**, where a histogram may be generated from the first slope determined in step **1214** and the second slope determined in step **1216** (and any other determined slope values not shown as part of process **1200**), but excluding the slope values determined using any of the identified outlying data points, using any suitable approach. In an embodiment, processor **412** or microprocessor **48** may include any suitable software, firmware, and/or hardware, and/or combinations thereof for generating the histogram at step **1318**. The histogram may be displayed in any suitable manner, such as on display **20** (**FIG. 2**), display **28** (**FIG. 2**) or using output **414** (**FIG. 4**), for review by patient **40**, a user of system **10** or system **400**, and/or a medical professional treating patient **40**. The histogram may represent graphically the number of times that a particular slope value or range of slope values may occur within the two-dimensional Lissajous figure. The maximum of the histogram may indicate the dominant slope of the two-dimensional Lissajous figure. Because the slope values calculated using the outlying points may not be plotted on the histogram, a secondary slope may not appear on the histogram related to noise, thereby further reducing the effect of noise on the calculation of the desired slope.

In an embodiment, process **1200** may advance to step **1224**, where a desired slope may be selected from the histogram using any suitable approach and the desired slope may correspond to the maximum value in the histogram. The maximum value of the histogram may be displayed in any suitable manner, such as on display **20**, display **28**, or using output **414**. In an embodiment, processor **412** or microprocessor **48** may include any suitable software, firmware, and/or hardware, and/or combinations thereof for

automatically identifying and displaying the maximum value of the histogram. In an embodiment, patient 40, a user of system 10 or system 400, and/or a medical professional treating patient 40 may review the displayed histogram and may identify the maximum value of the histogram, and thereby identify the desired slope, visually. In an embodiment, output 414 or pulse oximetry system 10 may present the maximum value of the histogram as an audio output to speaker 22 (**FIG. 2**) (e.g., a spoken statement).

In an embodiment, process 1200 may advance to step 1226, where the desired slope may be used with a look-up table or in a calibration equation to determine a patient's blood oxygen saturation level. In an embodiment, processor 412 or microprocessor 48 may include any suitable software, firmware, and/or hardware, and/or combinations thereof for determining the blood oxygen saturation of the patient 40. For example, processor 412 or microprocessor 48 may incorporate a look-up table or the calibration equation and may determine the blood oxygen saturation using the desired slope value identified from the histogram in step 1224. In an embodiment, the maximum value of the histogram identified in step 1224 may not be displayed on display 20, display 28, or output 414, as the maximum value may not have clinical relevance apart from the look-up table or the calibration equation. In an embodiment, a user of pulse oximetry system 10 or continuous wavelet processing system 400 may use the desired slope displayed at step 1224 in conjunction with a look-up table or in a calibration equation to determine the blood oxygen saturation of patient 40. The blood oxygen saturation of patient 40 may be displayed in any suitable manner, such as on display 20, display 28, or using output 414. In an embodiment, pulse oximetry system 10 or continuous wavelet processing system 400 may present the blood oxygen saturation as an audio output to speaker 22 (e.g., a spoken statement). Process 1200 may then advance to step 1228 and end.

It is to be understood that process 1200 may be performed in any suitable manner to determine the desired slope, and in any suitable order of steps. In some embodiments, one or more of the steps of process 1200, such as steps 1218 and/or 1220, may be optional. For example, process 1200 may be performed without the noise filtering steps 1218 and 1220 to determine the blood oxygen saturation level of patient 40 from the desired slope on the histogram.

In an embodiment, a confidence measure may be generated in conjunction with determining dominant slope **M**. **FIG. 13** is a flowchart of an illustrative process for

generating a confidence measure from a histogram in accordance with an embodiment. Process **1300** may begin at step **1302**. At step **1304**, a first PPG signal and a second PPG signal may be obtained from a patient using any suitable method. For example, the first and second PPG signals may be obtained from sensor **12** that may be coupled to patient **40** (**FIG. 2**). Alternatively, the PPG signals may be obtained from input signal generator **410**, which may include oximeter **420** coupled to sensor **418**, which may provide as input signal **416** (**FIG. 4**) PPG signals. In an embodiment, the PPG signals may be obtained from patient **40** using sensor **12** or input signal generator **410** in real time. In an embodiment, the PPG signals may have been stored in ROM **52**, RAM **52**, and/or QSM **72** (**FIG. 2**) in the past and may be accessed by microprocessor **48** within monitor **14** to be processed. In an embodiment, the first PPG signal may include a red light signal (*e.g.*, signal **720**) and the second PPG signal may include an infrared light signal (*e.g.*, signal **740**). The first and second PPG signals may be obtained simultaneously from patient **40**.

In an embodiment, process **1300** may advance to step **1306**, in which a first cycle may be defined for the first and second PPG signals. For example, a cycle may be defined by any suitable mechanism (*e.g.*, by microprocessor **48** or by processor **412**) as a finite period of time over which transform-surface **620** and transform-surface **640** (**FIG. 8**) may be created. As a result, at step **1308**, a three-dimensional Lissajous figure, a first two-dimensional Lissajous figure, and a first histogram each may be derived at least in part as described above with respect to steps **1206** through **1218** of **FIG. 12** from the portion of the first and second PPG signals collected during the first cycle. Process **1300** may advance to step **1310**, where a first desired slope may be selected from the first histogram, and the first desired slope may correspond to a maximum value in the first histogram. In an embodiment, the first desired slope may have clinical relevance, as it may be input into a look-up table or used in a calibration equation to determine a blood oxygen saturation level of a patient **40** from whom the PPG signals were obtained. In an embodiment, processor **412** or microprocessor **48** may include any suitable software, firmware, and/or hardware, and/or combinations thereof for automatically selecting the maximum value of the first histogram.

In an embodiment, process **1300** may advance to step **1312**, where at the end of the first cycle, a second cycle may be defined. In an embodiment, the second cycle may overlap the first cycle, be consecutive with the first cycle, or be spaced apart from the

first cycle. Process **1300** may advance to step **1314**, where a second three-dimensional Lissajous figure, a second two-dimensional Lissajous figure, and a second histogram may be derived at least in part as described above with respect to steps **1206** through **1218** of **FIG. 12** from the portion of the first and second PPG signals collected during the second cycle. At step **1316**, a second desired slope may be selected from the second histogram, and the second desired slope may correspond to a maximum value in the second histogram. As with the first desired slope, the second desired slope also may have clinical relevance related to a patient's blood oxygen saturation level. In an embodiment, processor **412** or microprocessor **48** may include any suitable software, firmware, and/or hardware, and/or combinations thereof for automatically selecting the maximum value of the second histogram. This process **1300** of deriving successive Lissajous figures and related histograms from successive transform-surfaces may continue for any additional desired number of cycles (not shown).

In an embodiment, process **1300** may advance to step **1318**, where the first desired slope and the second desired slope obtained from the first and second cycles may be compared. In an embodiment, processor **412** or microprocessor **48** may include any suitable software, firmware, and/or hardware, and/or combinations thereof for making a comparison between any suitable number of slope values. At step **1320**, at least one of the desired slopes may be identified. In an embodiment, one cycle may include a histogram that may generate a significantly different desired slope value, if for example the data from the PPG signals used to generate the histogram may have been distorted by patient movement, a poor connection between patient **40** and sensor **12**, or was otherwise faulty. It would be undesirable to use the significantly different desired slope value to calculate the blood oxygen saturation level of patient **40**. Therefore, it would be beneficial to identify the one or more portions of the PPG signals that contain the data points leading to the significantly different desired slope value and to remove those portions from further analysis of the PPG signals in relation to determining blood oxygen saturation. The desired slope value that may be significantly different than the one or more other desired slope values to which it is being compared may be automatically identified by microprocessor **48** or processor **412** using any suitable technique.

In an embodiment, process **1300** may advance to step **1322**, where the cycle that may be related to the identified desired slope value may be identified as having a low confidence as compared to the other cycles and resulting histograms that may have been

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generated from the first and second PPG signals. In an embodiment, the data from the PPG signals that may be included in the cycle identified as having low confidence may be removed from further analysis by a user of system **10** or system **400** or automatically by microprocessor **48** or processor **412**. Process **1300** may then advance to step **1324** and end.

In an embodiment, the shape of histogram **1100** may be used to measure confidence in the calculation of dominant slope **M**. For example, dimensions such as the height of peak **M** on histogram **1100**, or the width of histogram **1100**, may be used to measure a confidence level as to whether the value of dominant slope **M** is reliable.

Alternatively, the ratio of the area underneath peak **M** to the area underneath histogram **1100** using the entire data set of histogram **1100** may also be used to determine whether the calculation of dominant slope **M** is reliable.

In an embodiment, the value of the dominant slope from a histogram may be used for line fitting with respect to the original signal using any suitable method. For example, in a line fitting equation such as $y = a + bx$, dominant slope **M** may represent the "b" value. The offset of the line, represented by the "a" value, may be calculated using any suitable method. In one embodiment, the offset may be calculated by examining the data points that were used to calculate the slope values that fall within the dominant slope represented on the histogram. The data points that were not used to calculate the slope values that fall within the dominant slope may be ignored in calculating the offset value. This may exclude one or more outlying data points from affecting the calculation of the offset for the best-fit line.

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.

What is Claimed is:

1. A method for determining a slope of a signal on a plot,
comprising:
5 identifying an origin point of the plot;
determining slopes between the origin point of the plot and at least
two points in the signal;
generating a histogram from the slopes; and
selecting a desired slope of the signal corresponding to a preferred
value in the histogram.
- 10 2. The method of claim 1, further comprising:
selecting at least a portion of the signal on the plot; and
determining the slopes between the origin point and at least two
points within the selected portion of the signal.
- 15 3. The method of claim 1, further comprising excluding at least one
point in the signal from the determined slopes.
4. The method of claim 1, wherein the signal is a Lissajous figure
selected from a three-dimensional Lissajous figure.
- 20 5. The method of claim 4, further comprising:
performing a first continuous wavelet transform on a first
underlying signal to derive a first scalogram;
performing a second continuous wavelet transform on a second
underlying signal to derive a second scalogram; and
deriving the three-dimensional Lissajous figure from the first
scalogram and the second scalogram.
- 25 6. The method of claim 5, wherein the first underlying signal is a red
light signal collected by a pulse oximeter from a patient, and wherein the second
underlying signal is an infrared light signal collected by the pulse oximeter from the
patient.
- 30 7. The method of claim 6, further comprising determining blood
oxygen saturation information about a patient based at least in part on the desired slope.
8. The method of claim 1, further comprising generating a
confidence measure from the histogram.

9. The method of claim 1, further comprising filtering the signal with a noise reduction algorithm.

10. The method of claim 1, wherein the origin point is selected using the mean value or the average value of all of the points in the signal.

5 11. The method of claim 1, further comprising:
identifying the origin point of the plot by selecting an initial point;
calculating second slopes between the initial point and at least two points in the signal within a first region;

calculating third slopes between the initial point and at least two
10 points within a second region;

comparing the second slopes and the third slopes; and
adjusting the initial point based at least in part on the comparison of the second and third slopes.

12. The method of claim 1, further comprising:
15 identifying the origin point of the plot by determining second slopes between a first point in the signal and at least two other points in the signal;
determining third slopes between a second point in the signal and at least two other points in the signal;

generating a second histogram from the second slopes;
20 generating a third histogram from the third slopes; and
selecting the origin point to be either the first point or the second point based at least in part on the second and third histograms.

13. A system for determining a slope of a signal on a plot, the device comprising:

25 an input signal generator for generating the signal;
a processor coupled to the input signal generator; and
an output coupled to the processor, wherein the output is capable of displaying information based at least in part on the slope and wherein the processor is capable of:

30 identifying an origin point of the plot;
determining slopes between the origin point of the plot and at least two points in the signal;
generating a histogram from the slopes; and

selecting a desired slope of the signal corresponding to a preferred value in the histogram.

14. The system of claim 13, wherein the processor is further capable of:

5 selecting at least a portion of the signal on the plot; and
 determining the slopes between the origin point and at least two points within the selected portion of the signal.

15. The system of claim 13, wherein the processor is further capable of excluding at least one point in the signal from the determined slopes.

10 16. The system of claim 13, wherein the input signal generator is a pulse oximeter coupled to a sensor.

17. The system of claim 14, wherein the processor is further capable of determining blood oxygen saturation information about a patient based at least in part on the desired slope.

15 18. The system of claim 13, wherein the output is an electronic device.

19. The system of claim 13, wherein the origin point is selected using the mean value or the average value of all of the points in the signal.

20. The system of claim 13, wherein the processor is further capable of generating a confidence measure using the histogram.

20 21. The system of claim 13, wherein the processor is further capable of filtering the signal by performing a noise reduction algorithm.

22. A computer-readable medium for use in determining a slope of a signal on a plot, the computer-readable medium having computer program instructions recorded thereon for:

25 identifying an origin point of the plot;
 determining slopes between the origin point of the plot and at least two points in the signal;

 generating a histogram from the slopes; and
 selecting a desired slope of the signal corresponding to a preferred
30 value in the histogram.

23. The computer-readable medium of claim 22, further having computer program instructions recorded thereon for obtaining the signal using a pulse oximeter.

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24. The computer-readable medium of claim 23, further having computer program instructions recorded thereon for:

determining blood oxygen saturation information based at least in part on the desired slope; and

5 displaying the blood oxygen saturation information.

25. The computer-readable medium of claim 24, wherein the determining blood oxygen saturation information comprises using the desired slope in a look-up table.

10 26. The computer-readable medium of claim 24, wherein the determining blood oxygen saturation information comprises using the desired slope in a calibration equation.

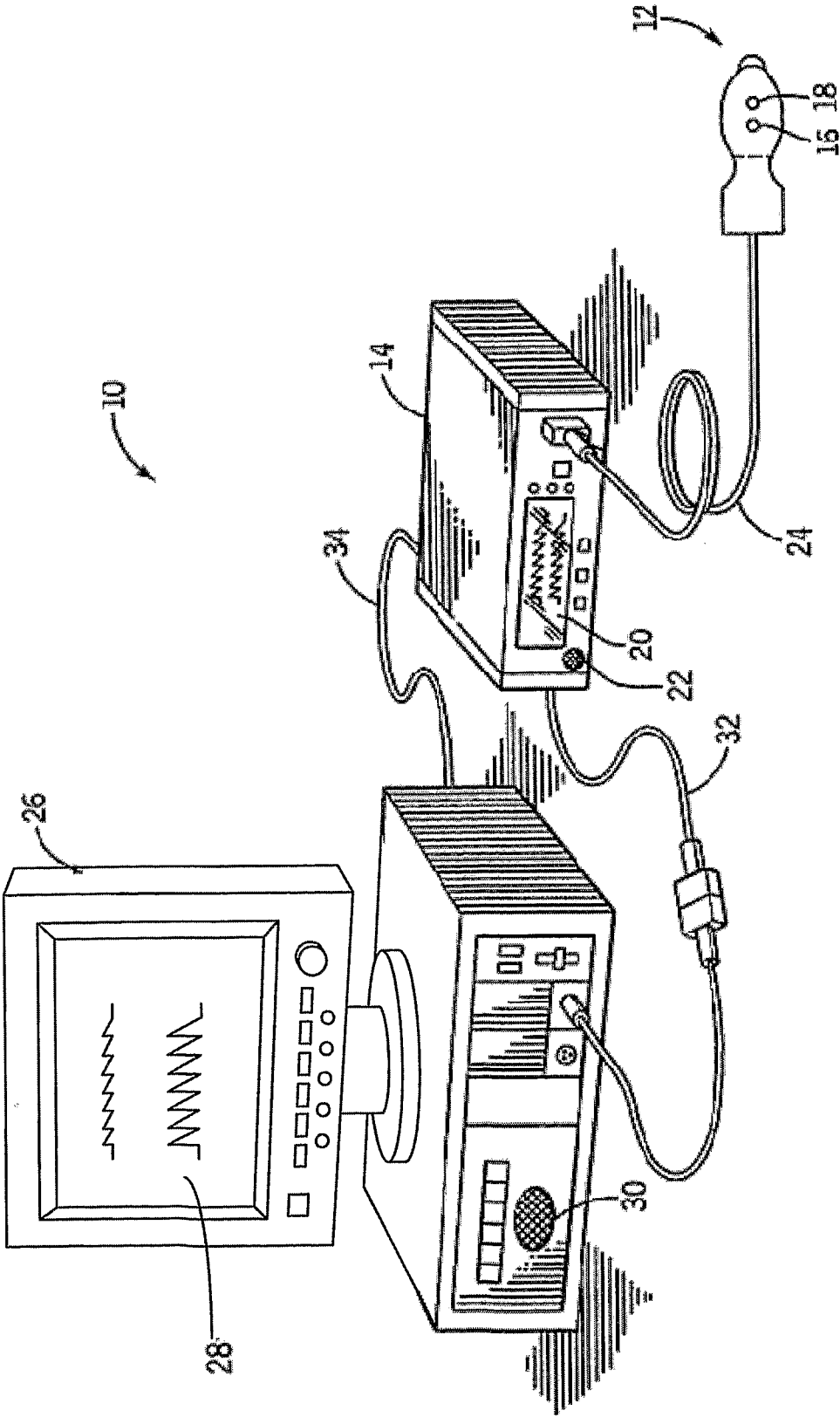


FIG.1

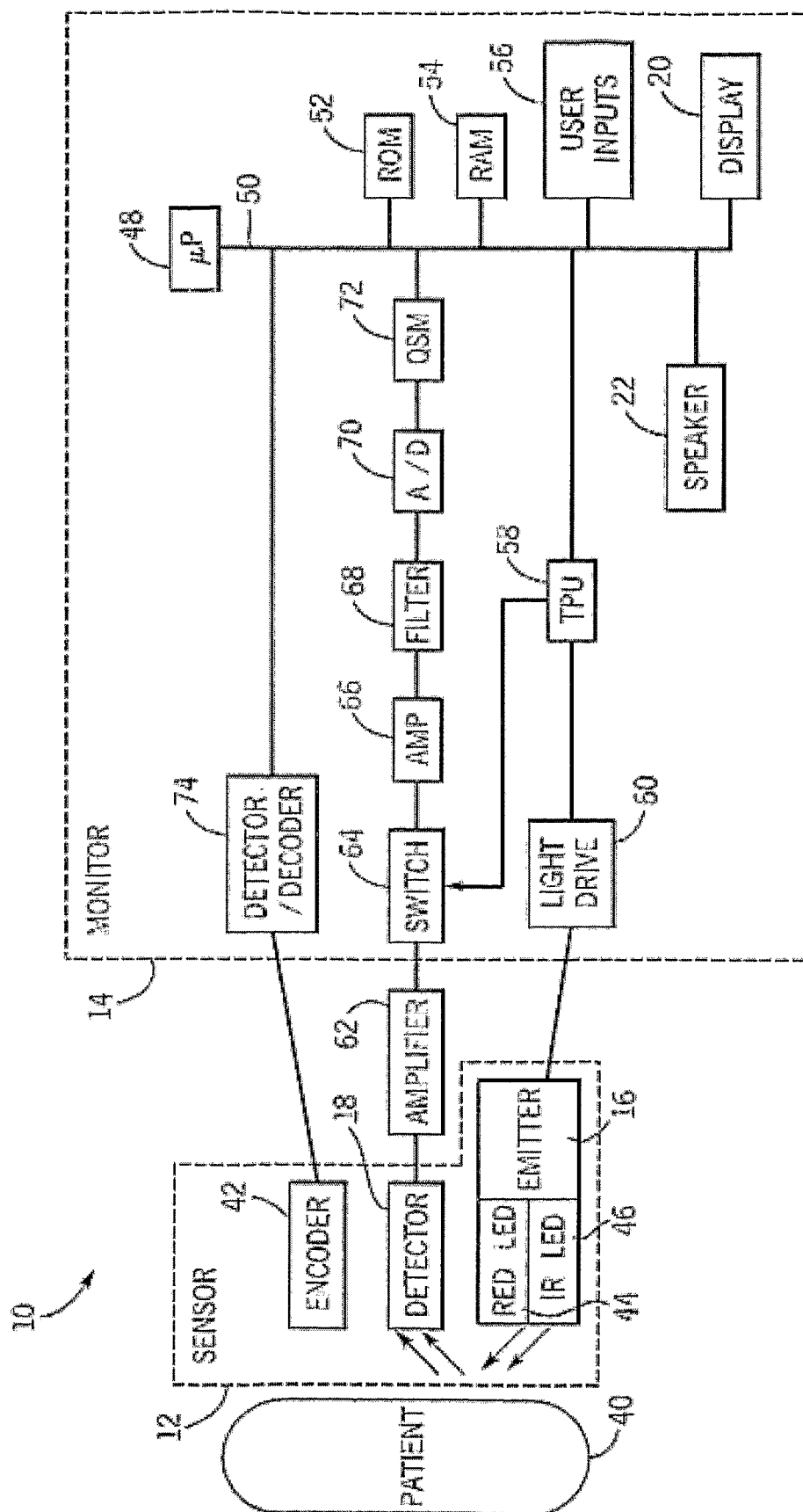


FIG. 2*

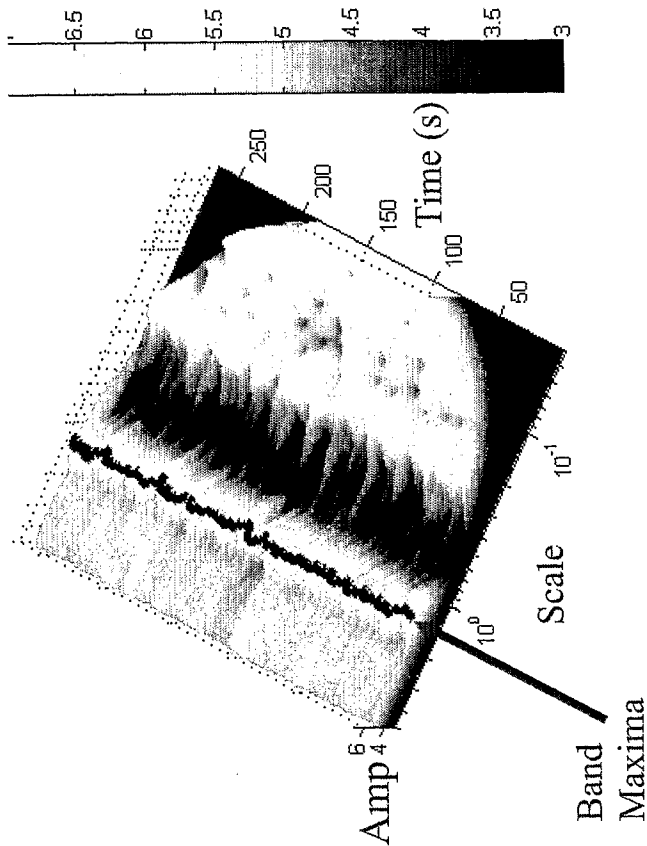


FIG. 3(b)

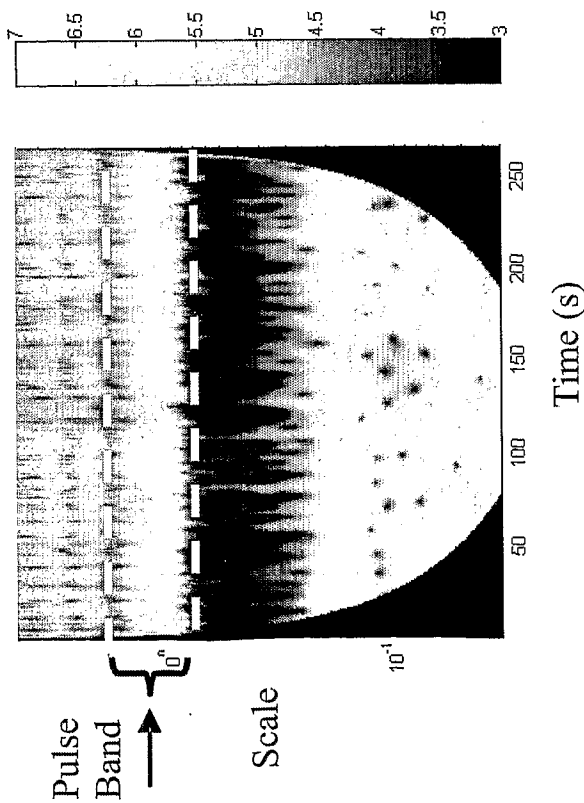


FIG. 3(a)

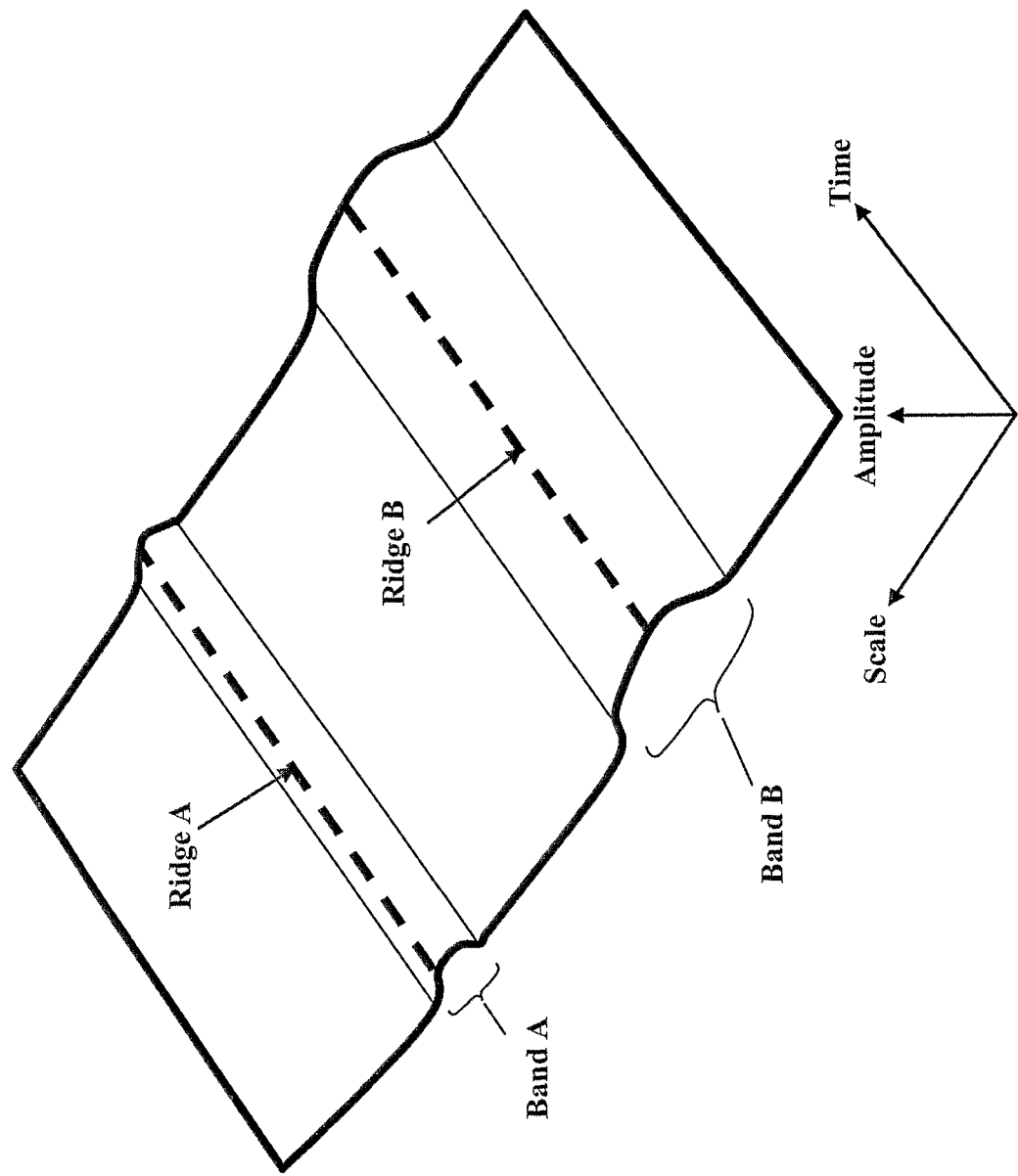


FIG. 3(c)

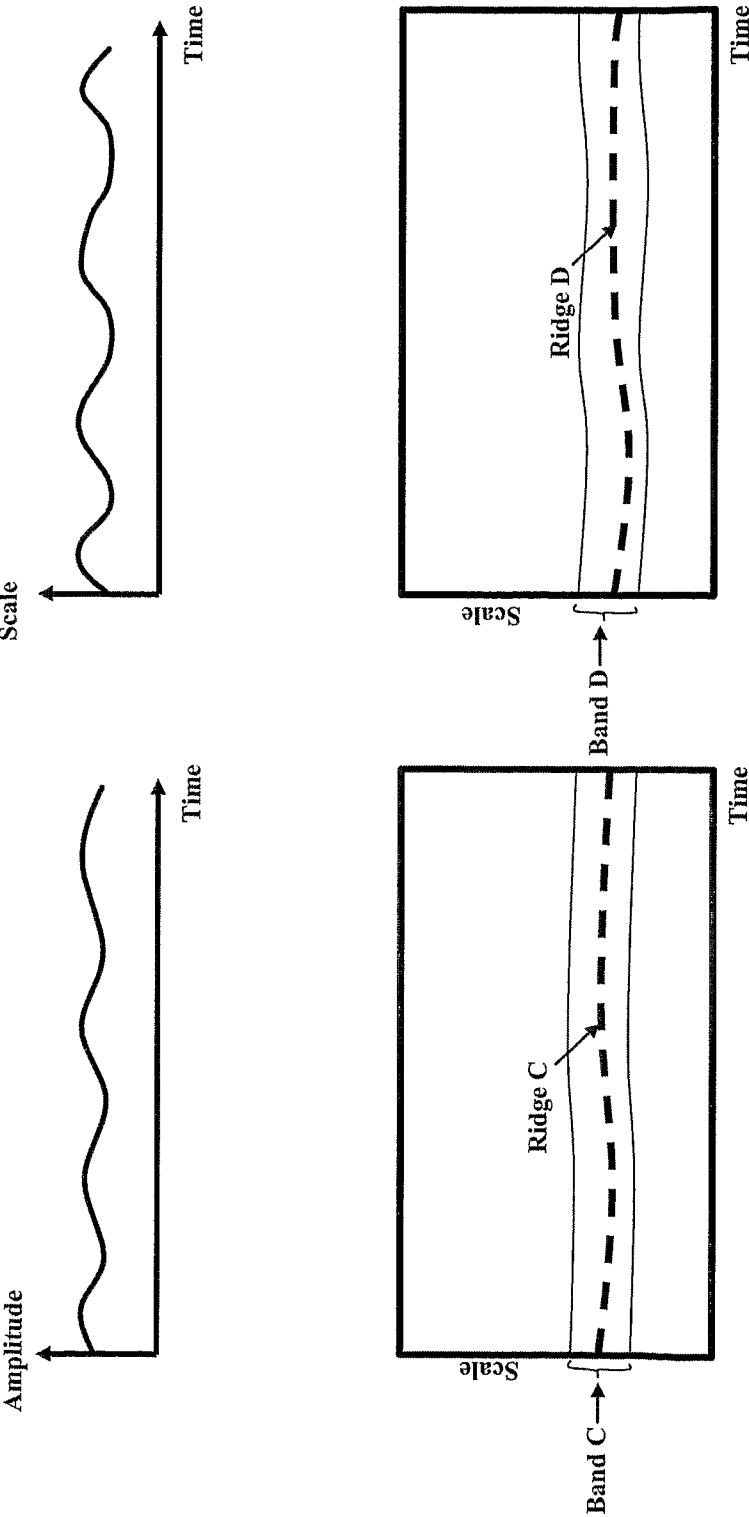


FIG. 3(d)

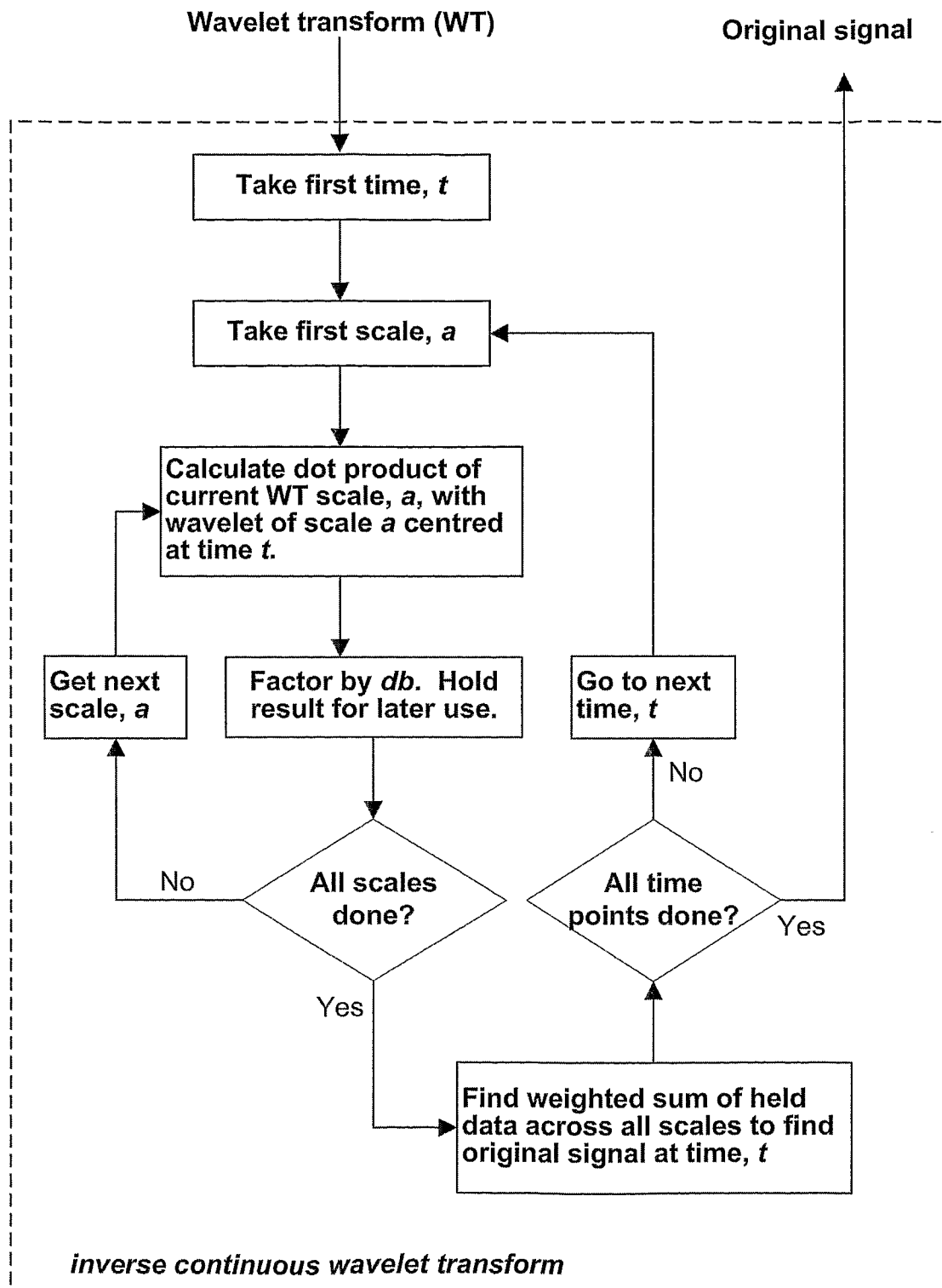
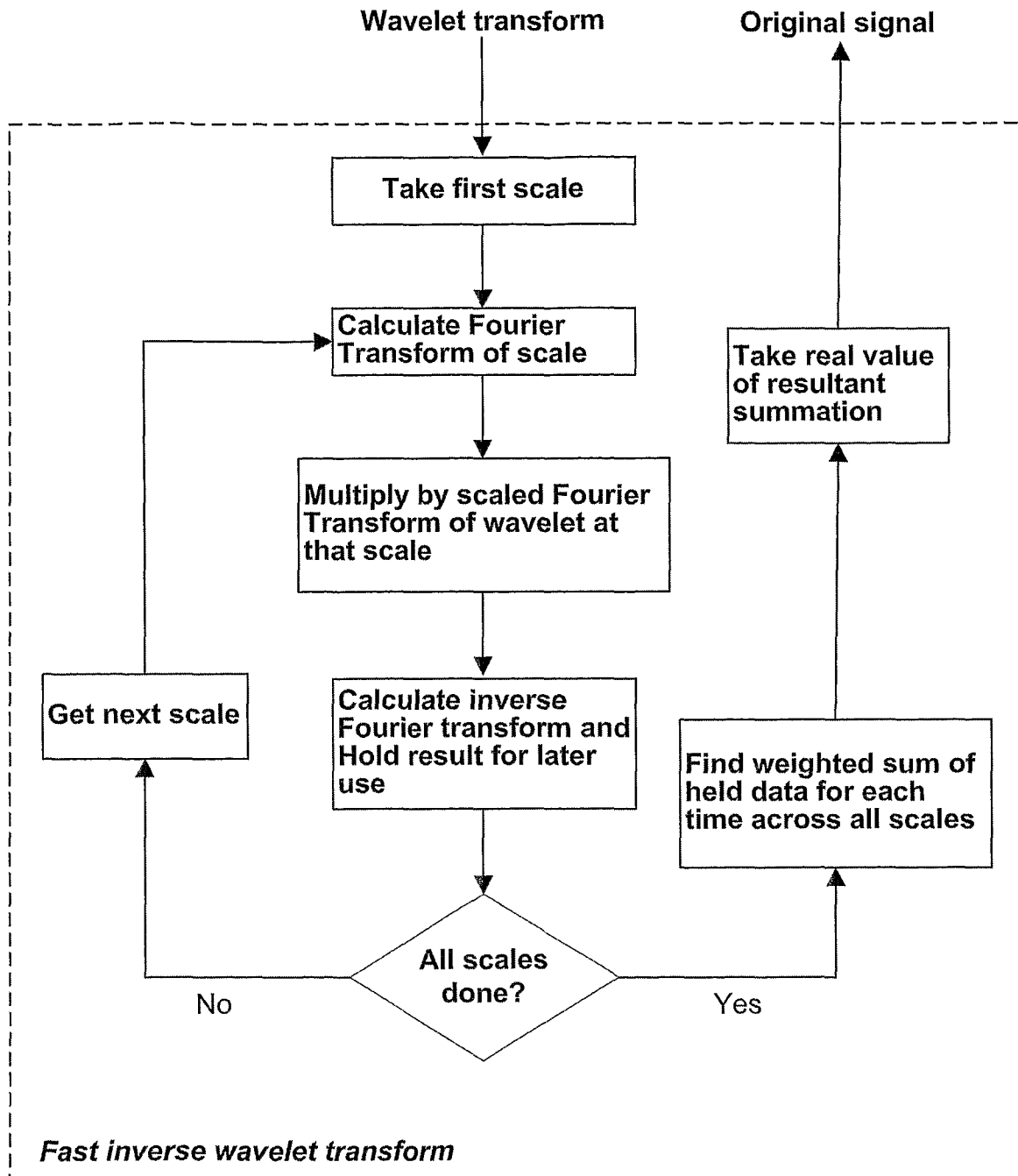


FIG. 3(e)

**FIG. 3(f)**

400

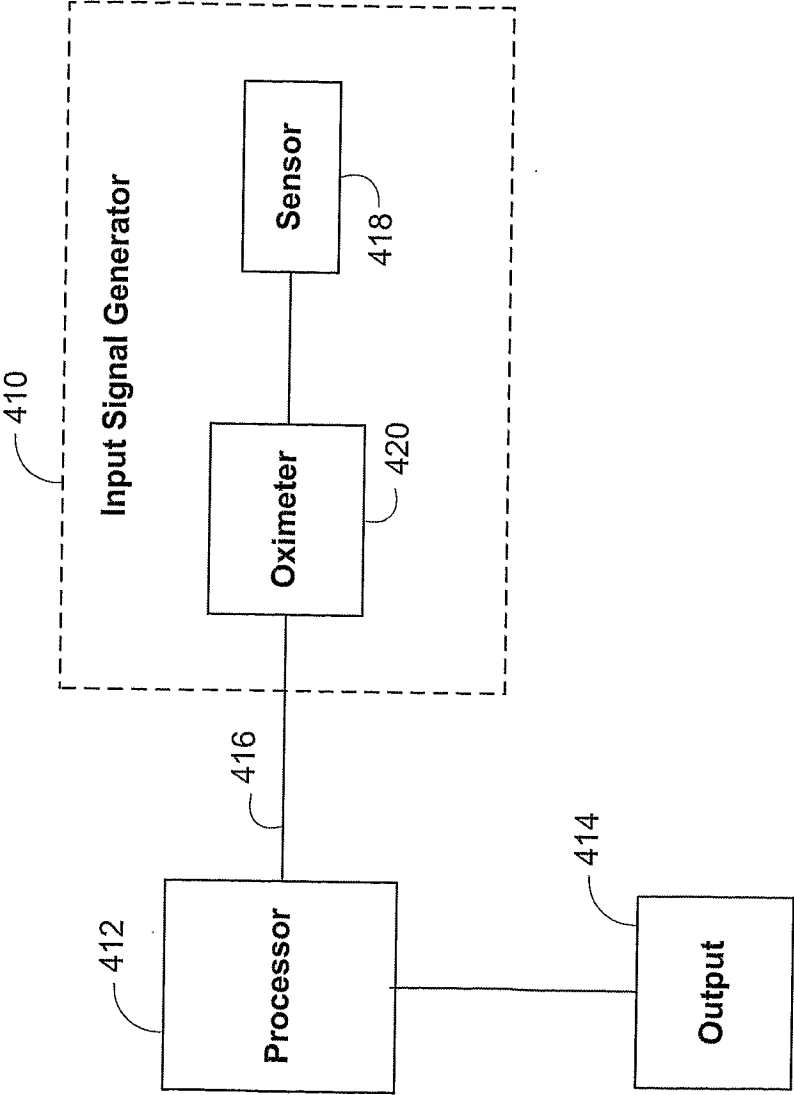


FIG. 4

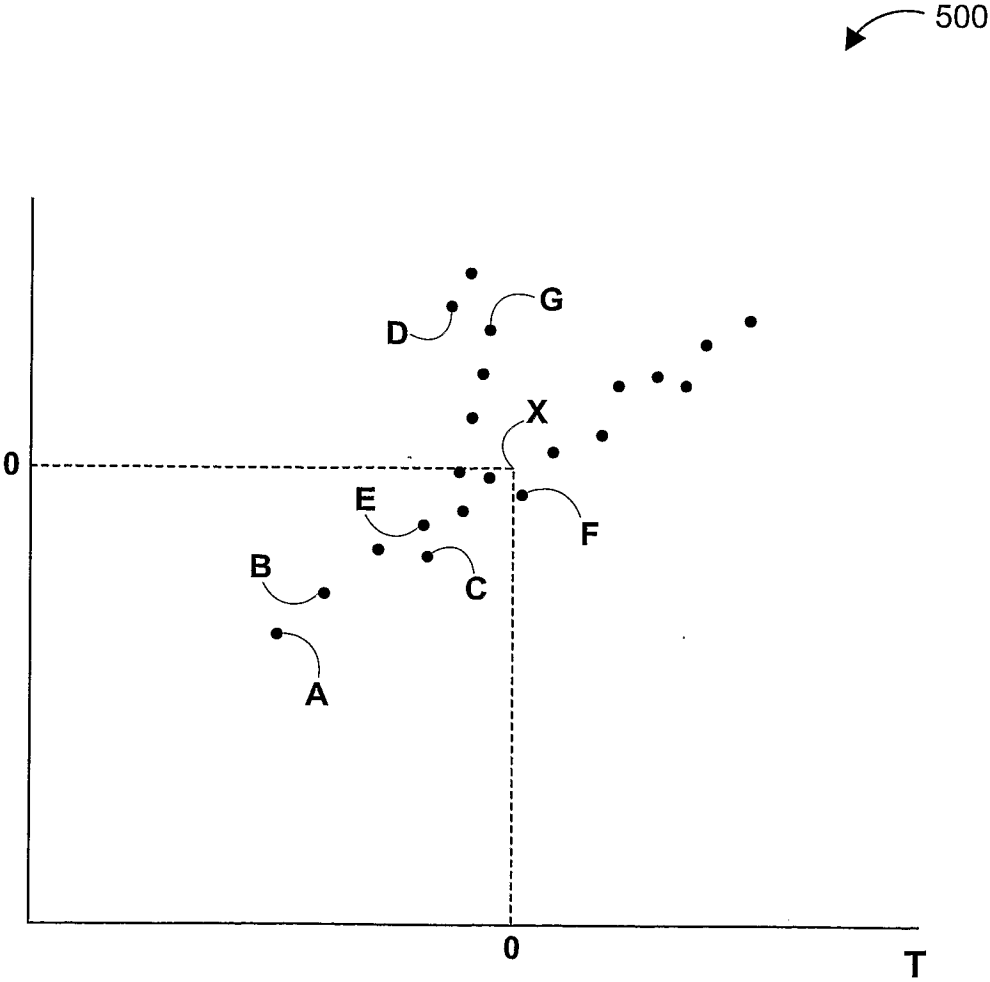
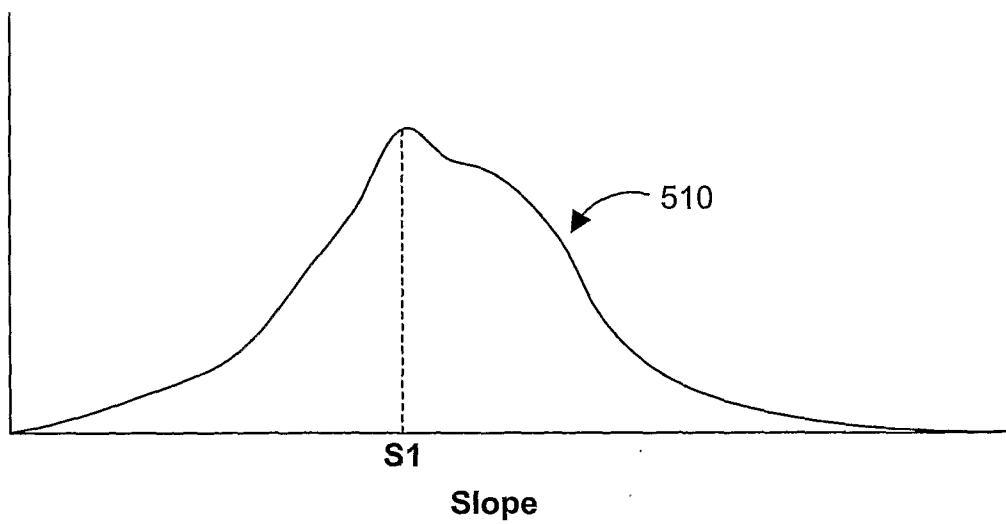
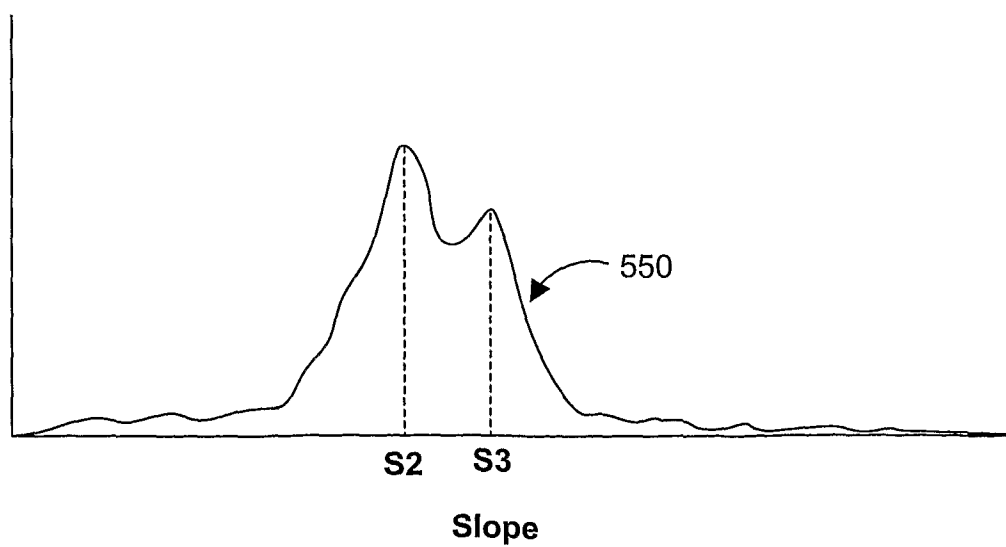
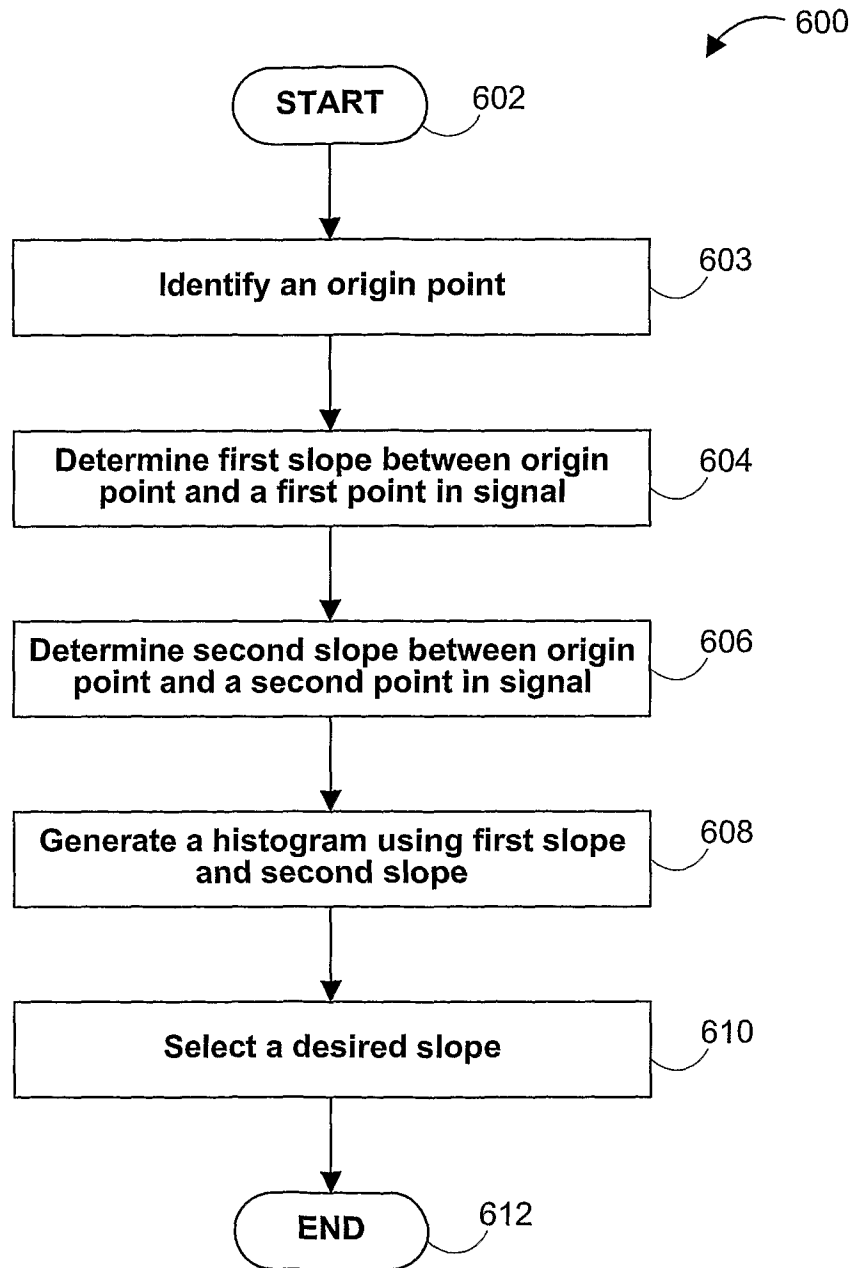
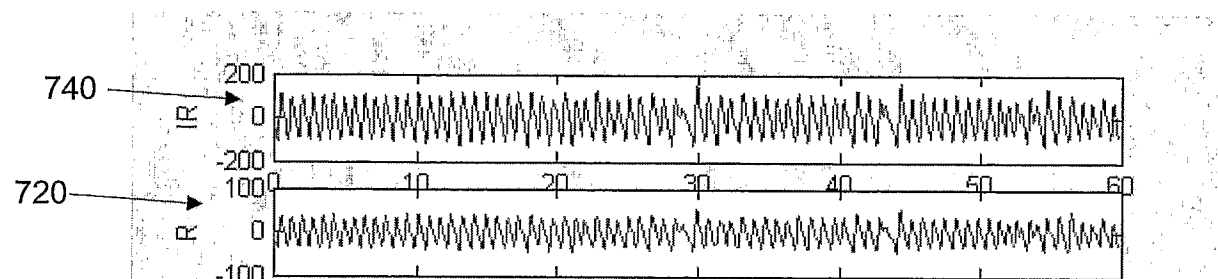
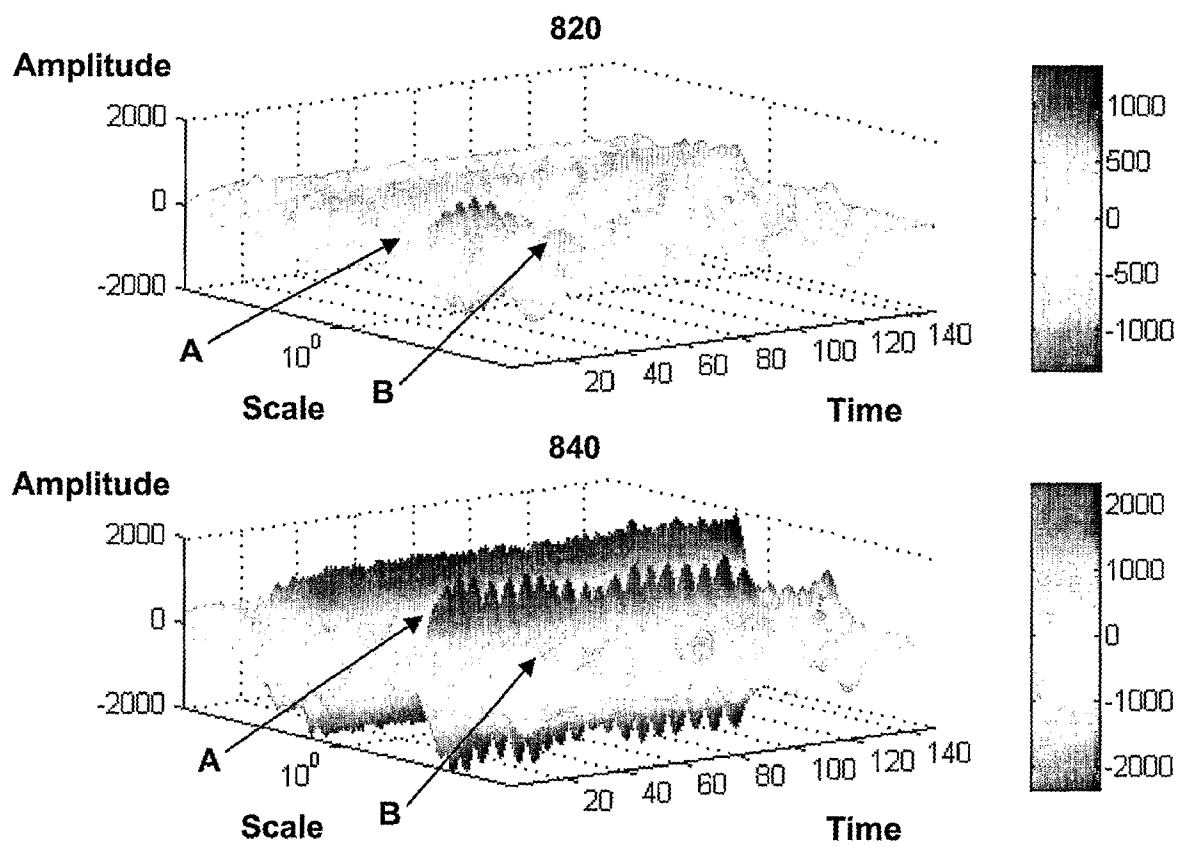


FIG. 5(a)

**FIG. 5(b)****FIG. 5(c)**

**FIG. 6**

**FIG. 7**

**FIG. 8**

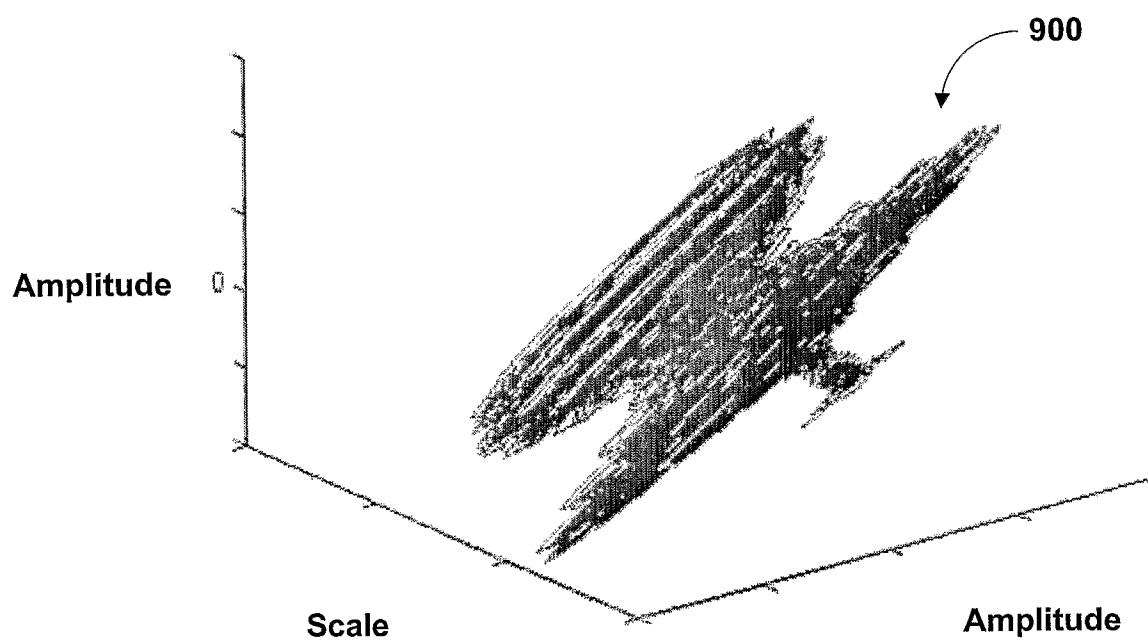


FIG. 9

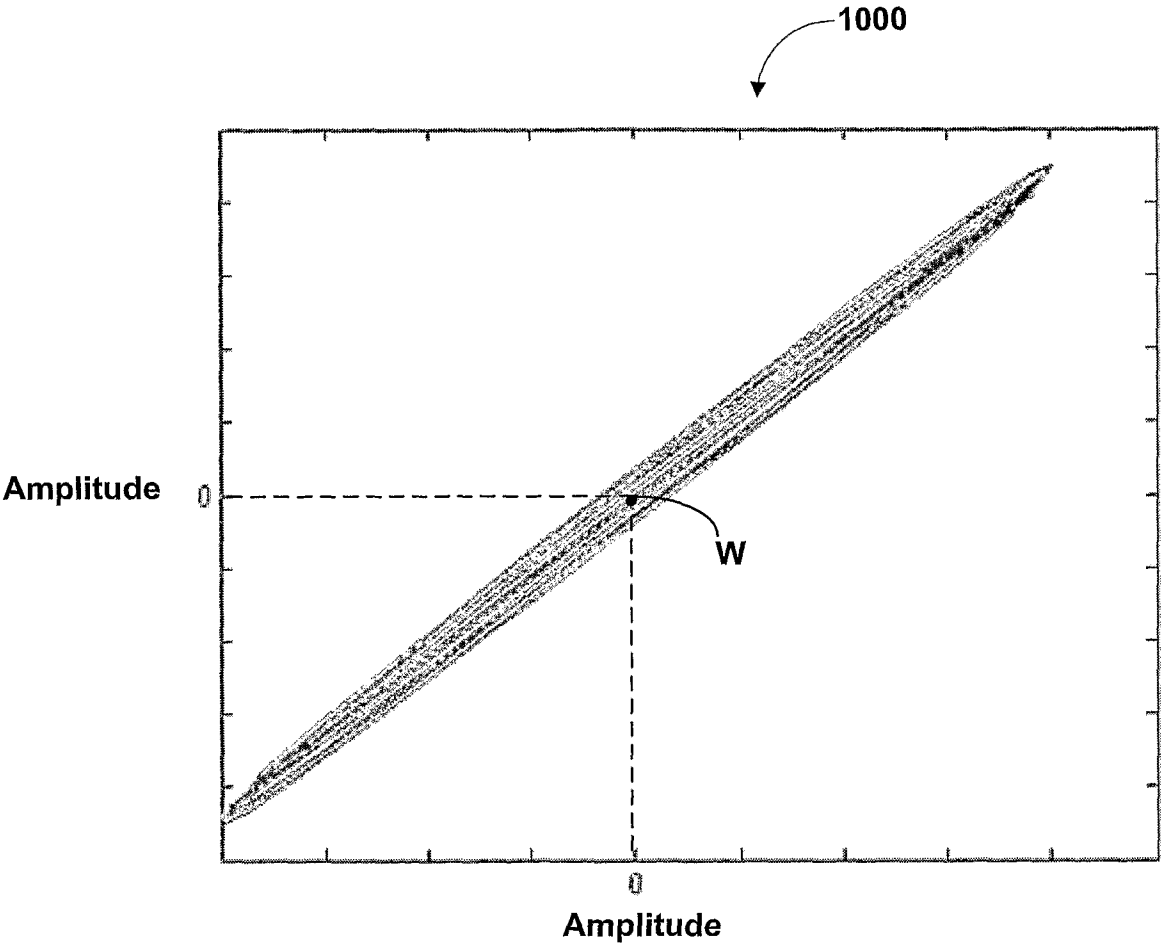


FIG. 10

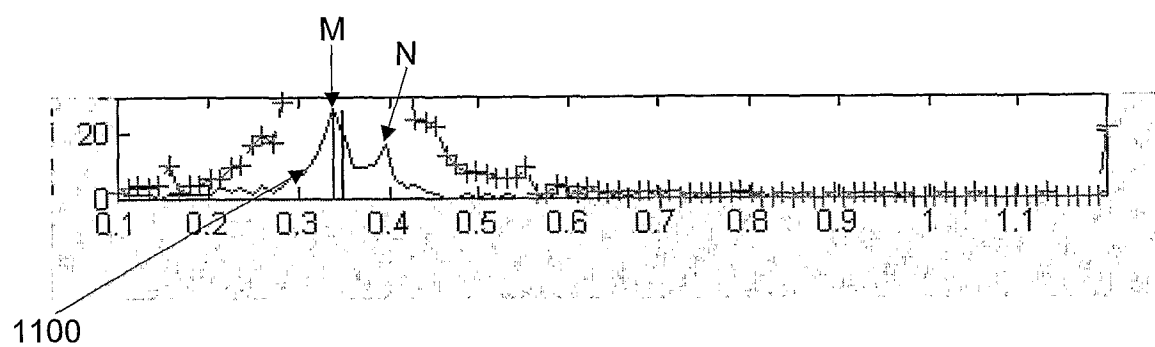


FIG. 11

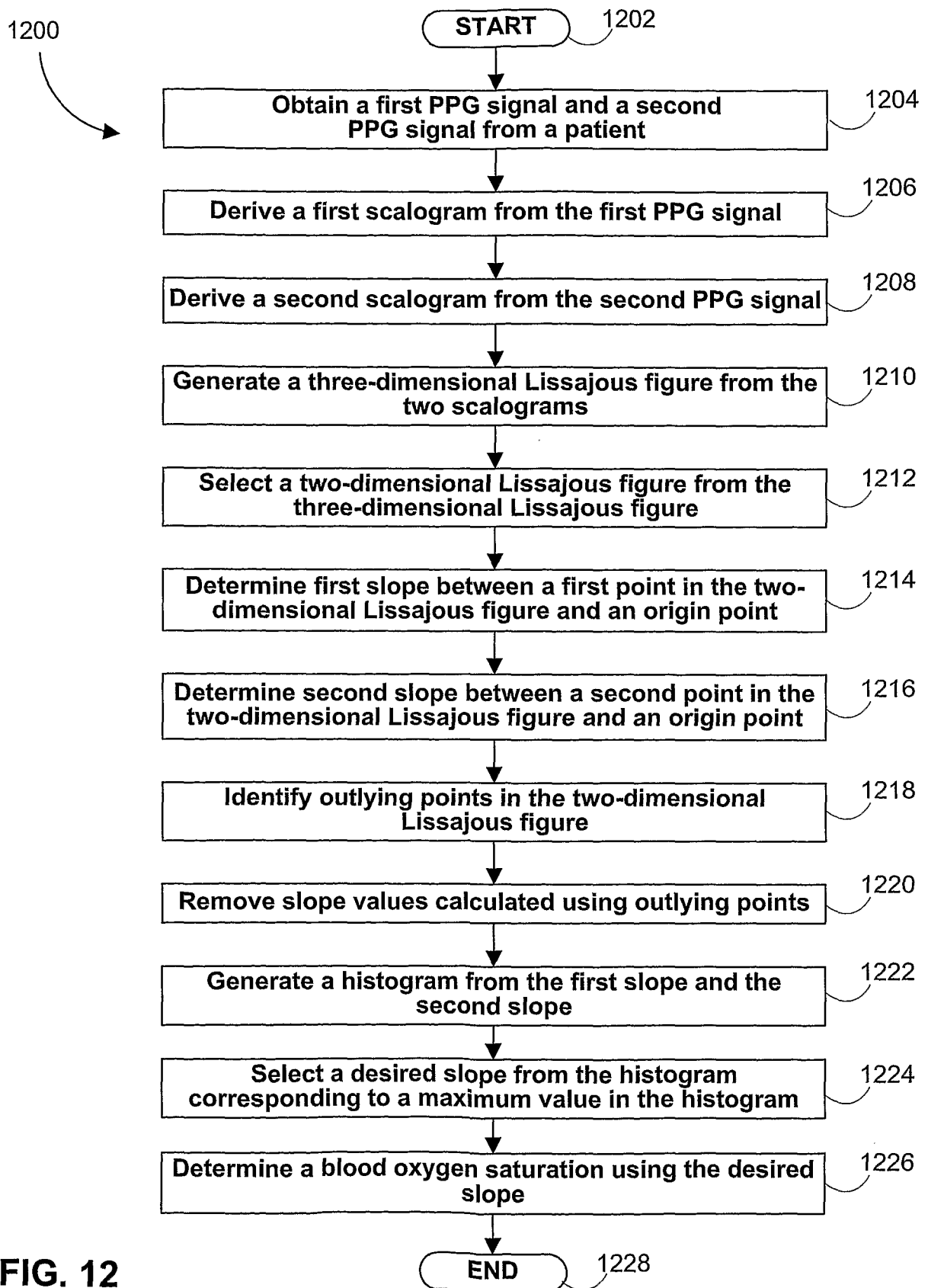
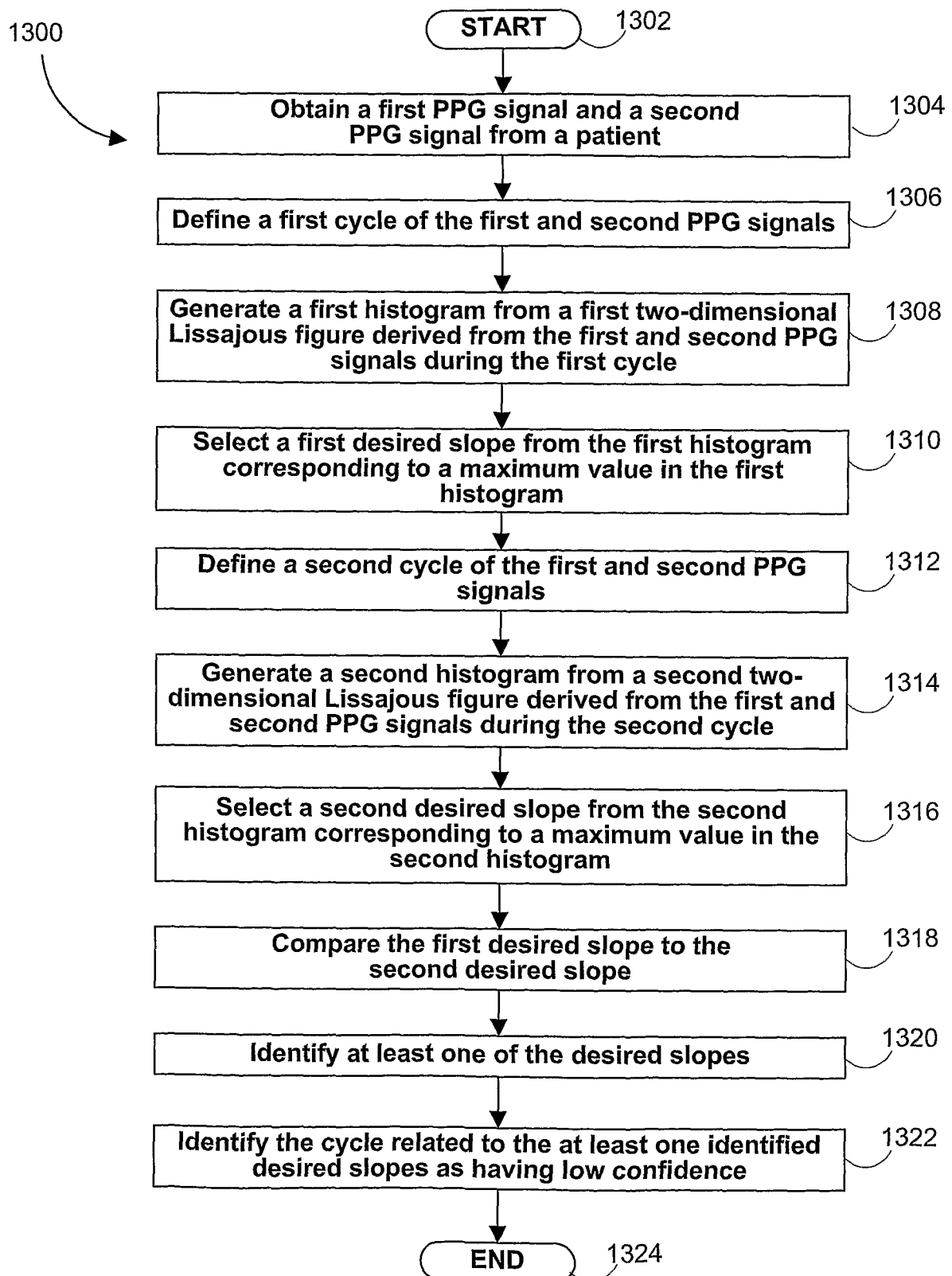


FIG. 12

**FIG. 13**

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2009/006138

A. CLASSIFICATION OF SUBJECT MATTER
INV. 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

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2001/018557 A1 (LYNN LAWRENCE A [US] ET AL LYNN LAWRENCE A [US]) 30 August 2001 (2001-08-30) paragraphs [0024] - [0117]; figures 1-14	1-26
A	US 2005/070773 A1 (CHIN RODNEY [US] ET AL) 31 March 2005 (2005-03-31) paragraphs [0018] - [0022] figures 1-10	1-26
A	WO 2004/026132 A (PRO TECH SERVICES INC A WASHIN [US]; RIGGINS MICHAEL [US]; MARGULIES L) 1 April 2004 (2004-04-01) abstract; figures 1-9	1-26
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☒ 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
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- *O* document referring to an oral disclosure, use, exhibition or other means
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- * & * document member of the same patent family

Date of the actual completion of the international search

21 September 2009

Date of mailing of the international search report

06/10/2009

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INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2009/006138

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004/111119 A1 (SARKAR SHANTANU [US] ET AL) 10 June 2004 (2004-06-10) paragraphs [0032] - [0048] paragraphs [0113] - [0133] figures 1-10 -----	1-26

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2009/006138

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2001018557 A1	30-08-2001	US 6223064 B1	24-04-2001
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		DE 10392677 B4	26-04-2007
		DE 10392677 T5	21-07-2005
US 2004111119 A1	10-06-2004	DE 60308725 T2	23-08-2007
		EP 1569719 A2	07-09-2005
		WO 2004050184 A2	17-06-2004

专利名称(译)	用于使用原点确定斜率的信号处理系统和方法		
公开(公告)号	EP2303106A1	公开(公告)日	2011-04-06
申请号	EP2009772896	申请日	2009-06-29
[标]申请(专利权)人(译)	NELLCOR PURITAN BENNETT爱尔兰		
申请(专利权)人(译)	NELLCOR PURITAN BENNETT爱尔兰		
当前申请(专利权)人(译)	NELLCOR PURITAN BENNETT爱尔兰		
[标]发明人	ADDISON PAUL STANLEY WATSON JAMES NICHOLAS		
发明人	ADDISON, PAUL, STANLEY WATSON, JAMES, NICHOLAS		
IPC分类号	A61B5/00		
CPC分类号	A61B5/14551 A61B5/7203 A61B5/7225 A61B5/726		
优先权	61/077079 2008-06-30 US 61/080950 2008-07-15 US		
外部链接	Espacenet		

摘要(译)

本公开涉及信号处理，并且更具体地，涉及确定信号的斜率。在实施例中，可以确定绘图的原点与信号中的至少两个点之间的斜率。斜率可以用于生成直方图，并且可以选择与直方图中的优选值对应的信号的期望斜率。在一个实施例中，可以从三维李萨如图中选择二维李萨如图，并且可以创建所选择的利萨如图中的斜率的直方图以确定期望的斜率。期望的斜率可具有临床相关性（例如，其可用于确定患者的血氧饱和度水平）。三维李萨如图可以从与两个硬度图相关的表面信号导出。每个尺度图可以是对信号执行连续小波变换的结果。可以关于确定期望的斜率生成置信度量。