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(54) **DETERMINATION OF A PHYSIOLOGICAL PARAMETER**

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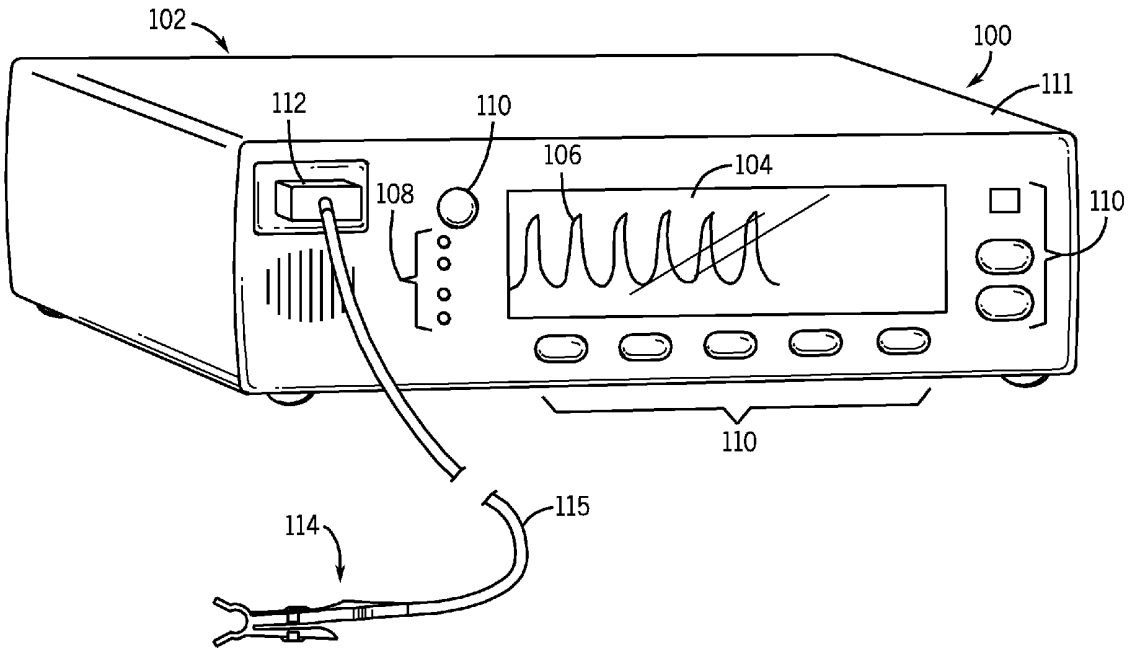
(57) **ABSTRACT**

Methods and systems are provided for transmitting and receiving photon density waves to and from tissue, and processing the received waves using wavelet transforms to identify non-physiological signal components and/or identify physiological conditions. A pulse oximeter may receive the photon density waves from the tissue to generate a signal having phase and amplitude information. A phase signal may be proportional to a scattering by total particles in the tissue, and an amplitude signal may correlate to an absorption by certain particles, providing information on a ratio of different particles in the tissue. Processing the phase and amplitude signals with wavelet transforms may enable an analysis of signals with respect to time, frequency, and magnitude, and may produce various physiological data. For example, non-physiological noise components may be identified, and certain physiological conditions may be identified by processing scalograms of the original signals with patterns corresponding to certain physiological conditions.



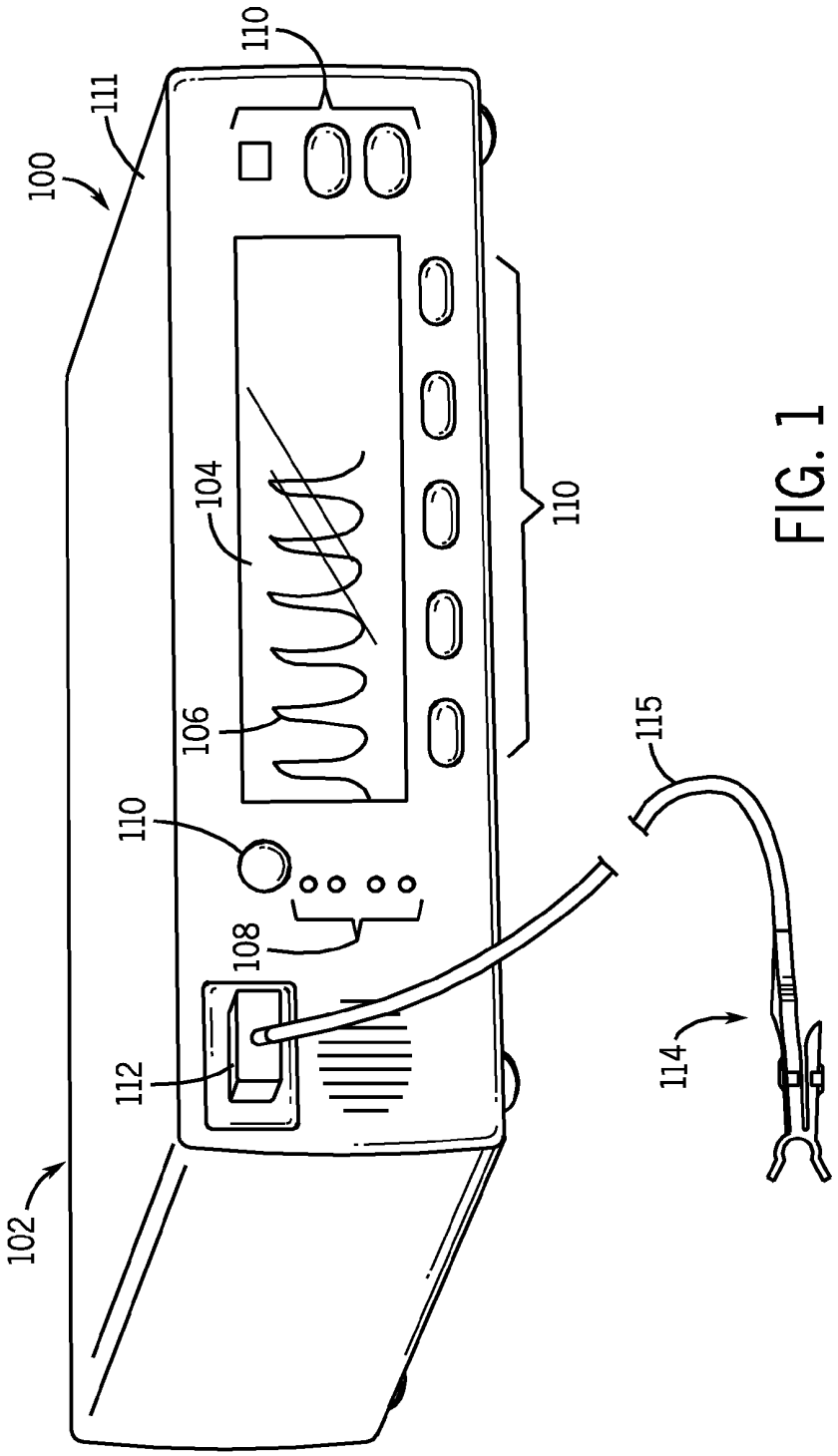


FIG. 1

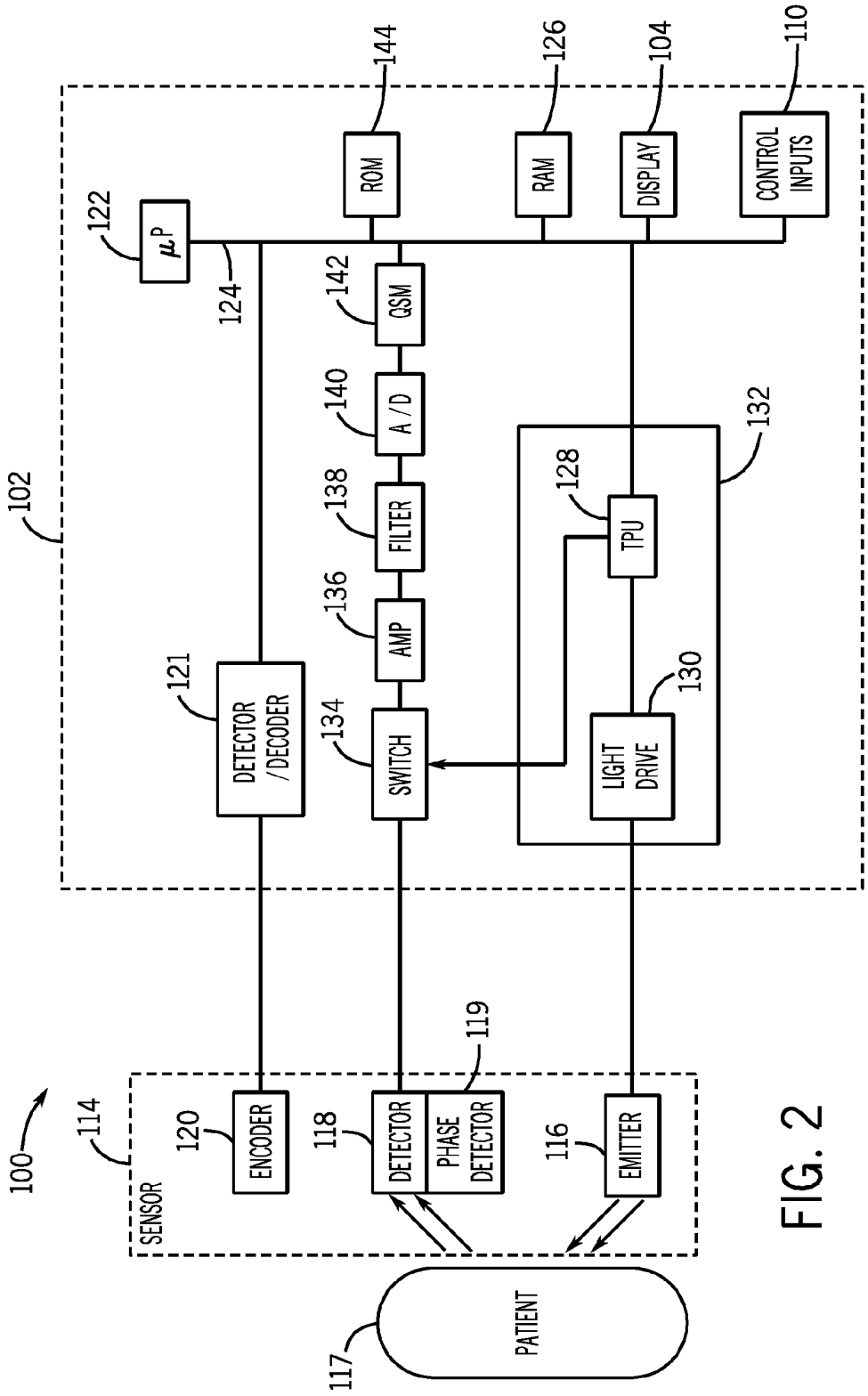

100
102
114
SENSOR
120
ENCODER
118
DETECTOR
119
PHASE DETECTOR
116
EMITTER
117
PATIENT
121
DETECTOR /DECODER
134
SWITCH
136
AMP
138
FILTER
140
A/D
142
GSM
144
ROM
126
RAM
104
DISPLAY
110
CONTROL INPUTS
122
μP
124
132
128
TPU
130
LIGHT DRIVE

FIG. 2

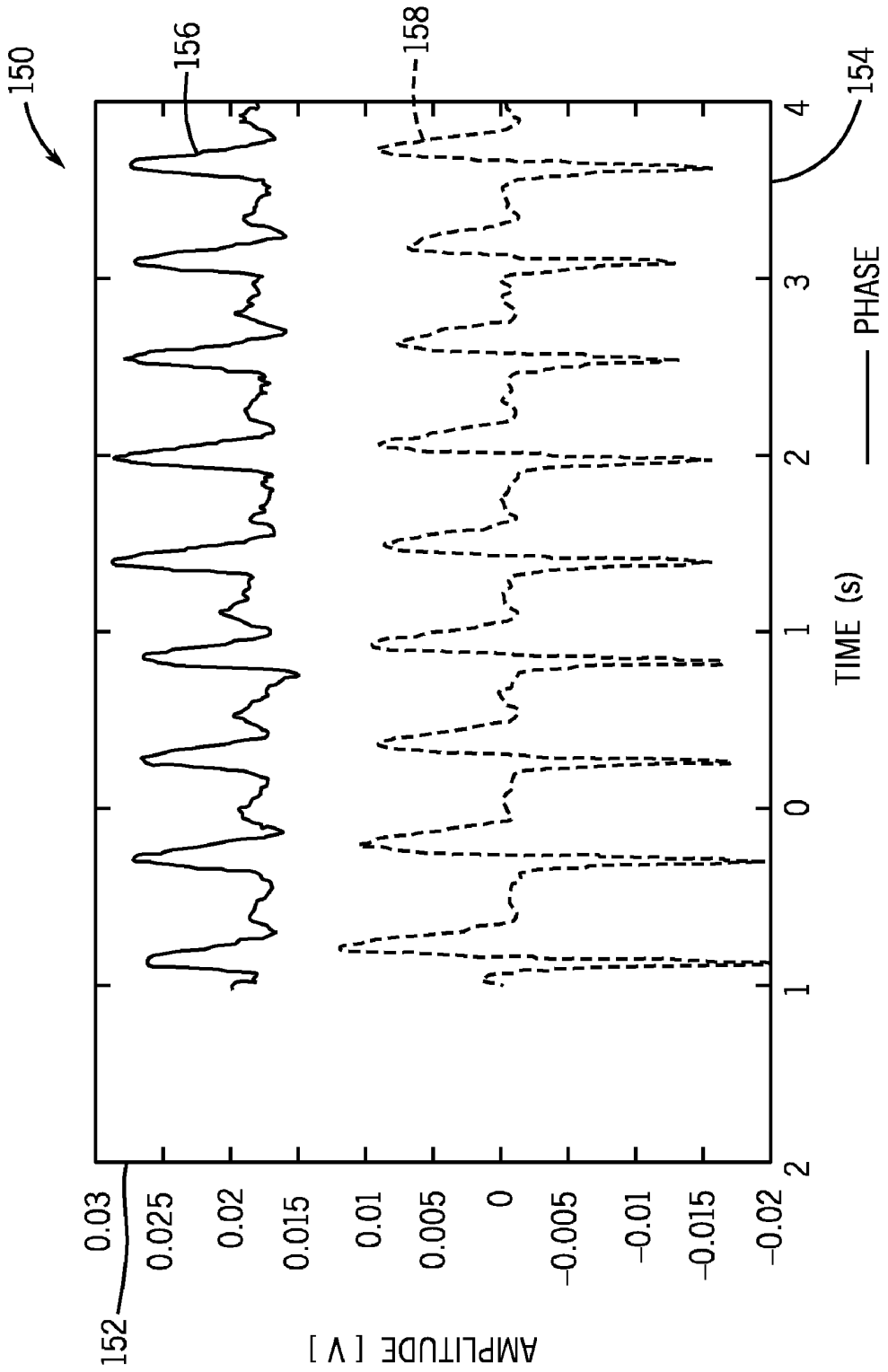
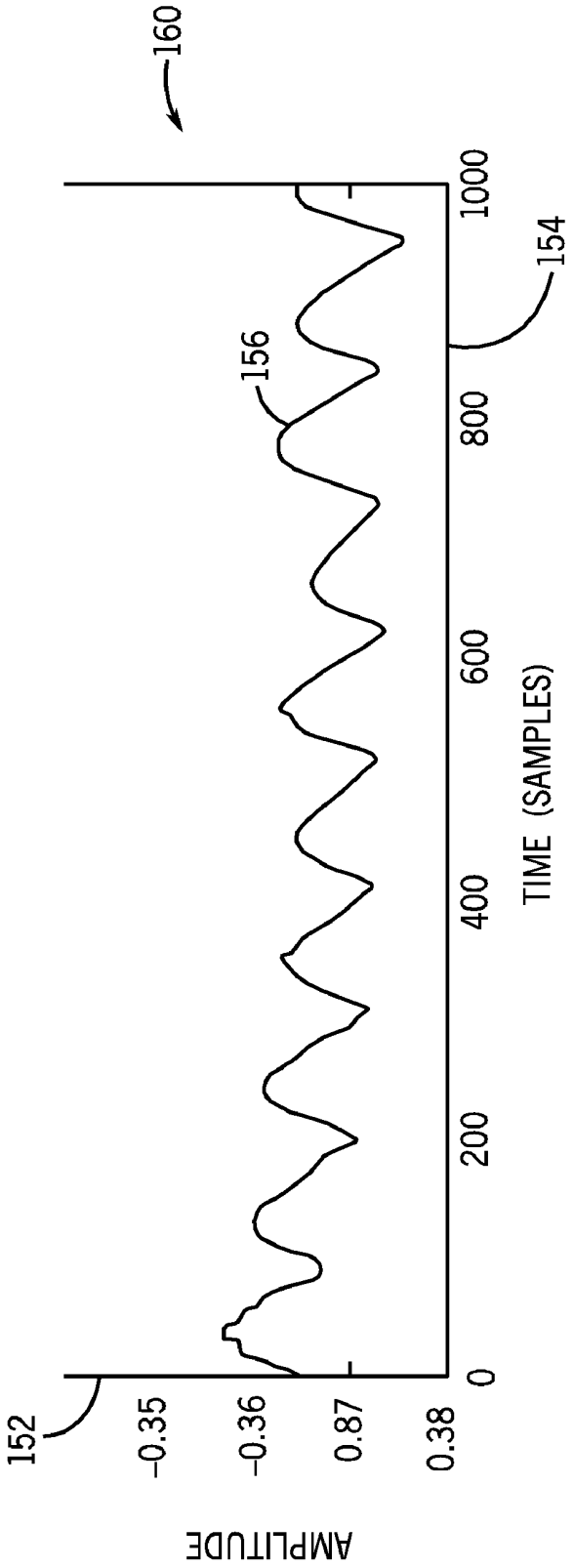

150
156
158
154
152
0.03
0.025
0.02
0.015
0.01
0.005
0
−0.005
−0.01
−0.015
−0.02
AMPLITUDE [V]
2
1
0
1
2
3
4
TIME (s)
PHASE
PLETH

FIG. 3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152
154
156
AMPLITUDE
-0.35
-0.36
0.87
0.38
0
200
400
600
800
1000
TIME (SAMPLES)

FIG. 4

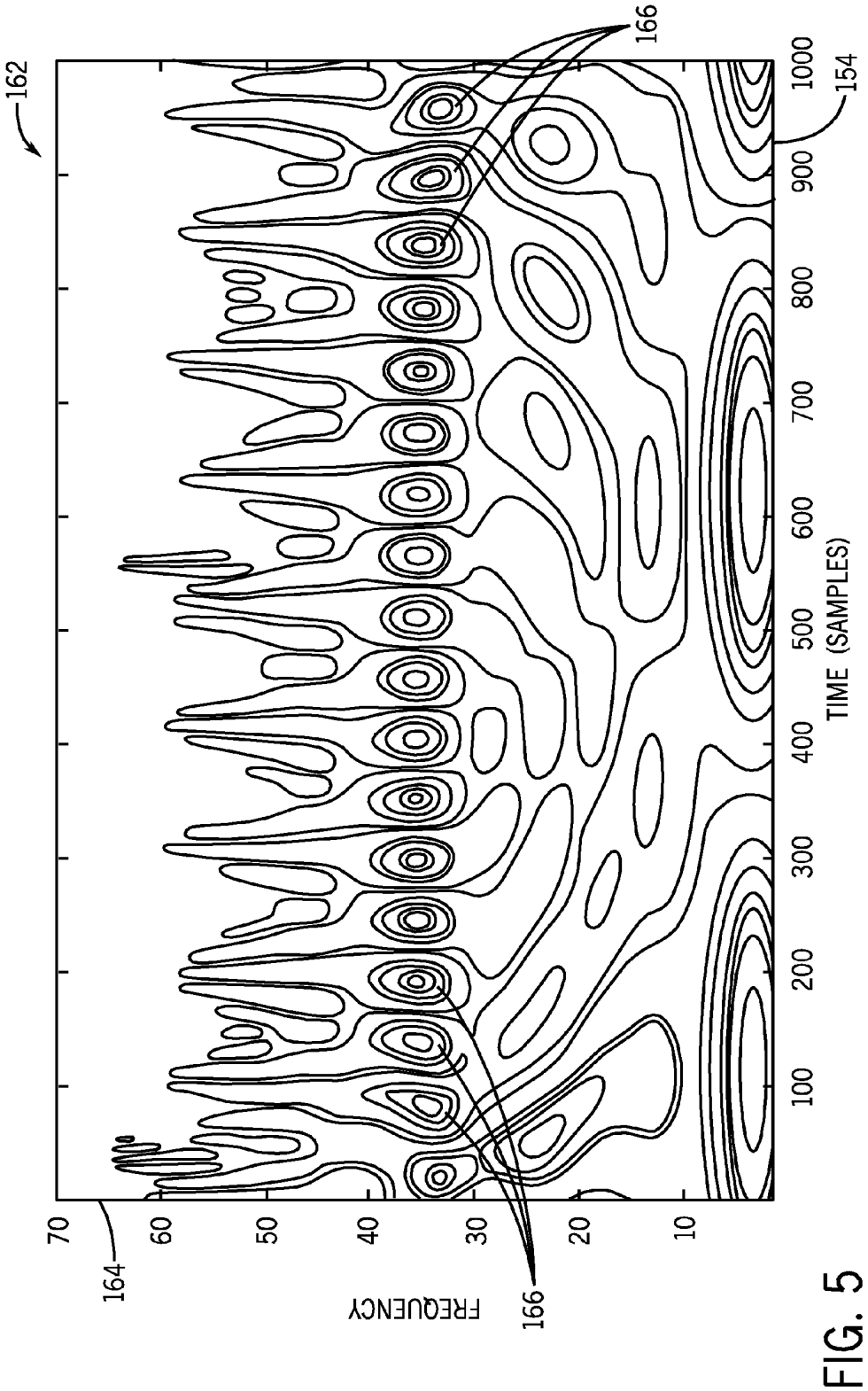

162
166
154
1000
900
800
700
600
500
400
300
200
100
TIME (SAMPLES)
70
60
50
40
30
20
10
FREQUENCY
164
166

FIG. 5

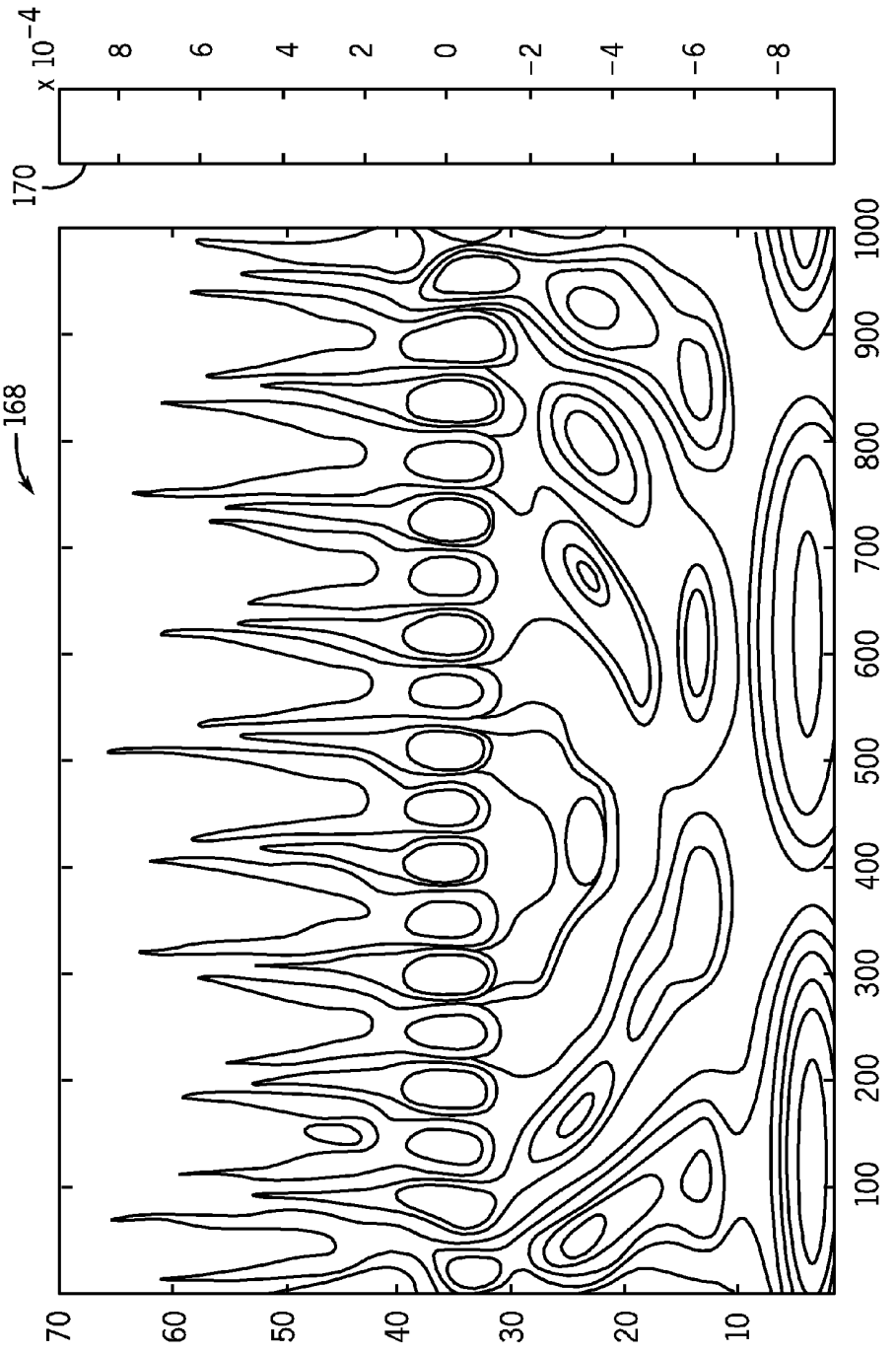

x 10^-4
8
6
4
2
0
-2
-4
-6
-8
170
168
70
60
50
40
30
20
10
100
200
300
400
500
600
700
800
900
1000

FIG. 6

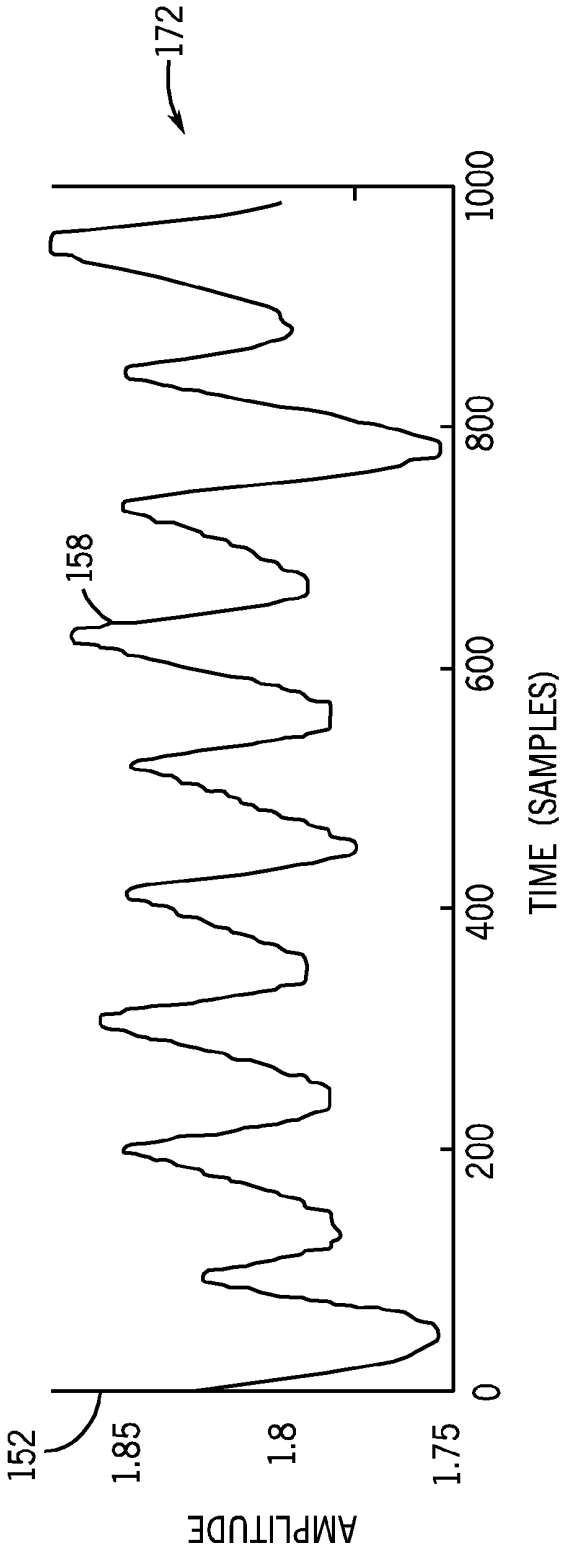
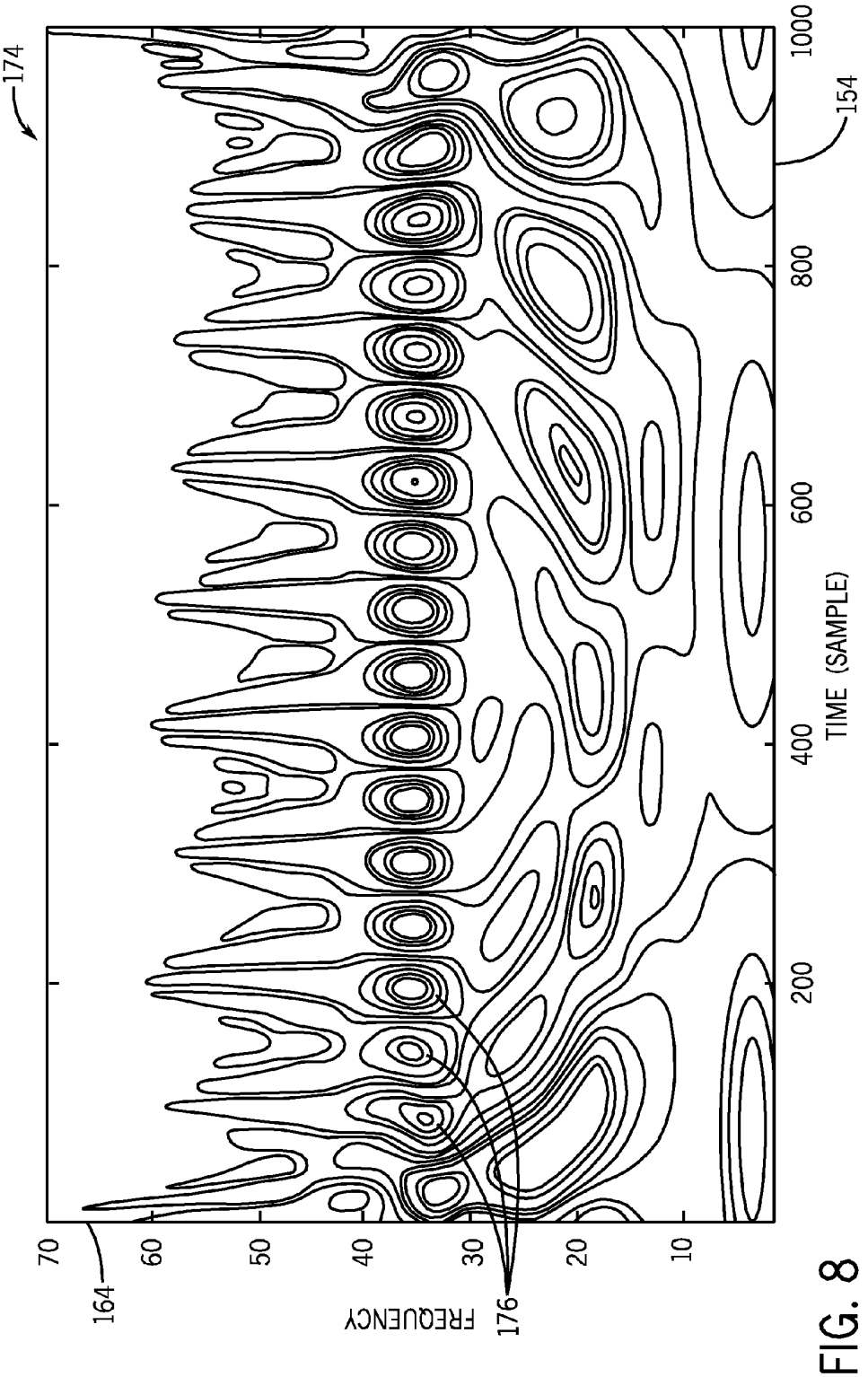

172
158
152
AMPLITUDE
1.85
1.8
1.75
0
200
400
600
800
1000
TIME (SAMPLES)

FIG. 7


174
154
164
176
FREQUENCY
TIME (SAMPLE)
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60
50
40
30
20
10
200
400
600
800
1000

FIG. 8

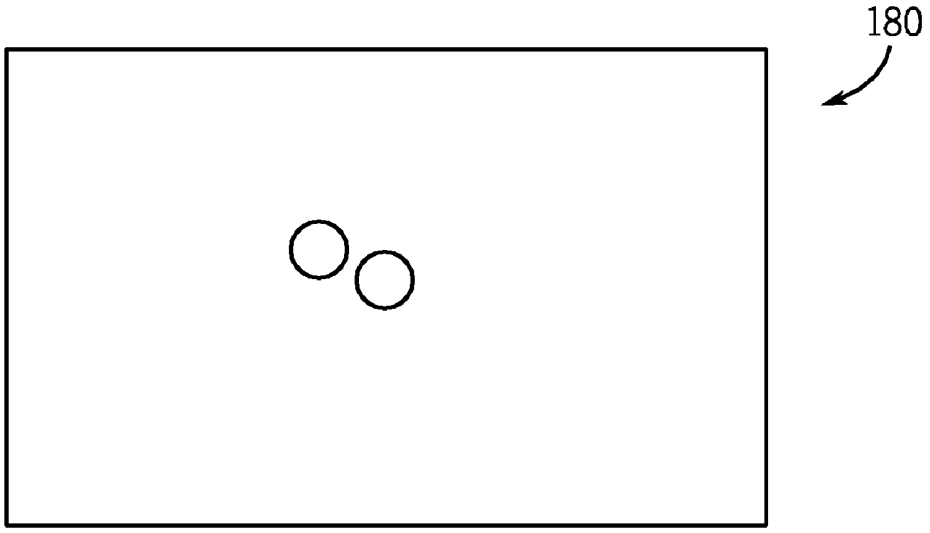


FIG. 9

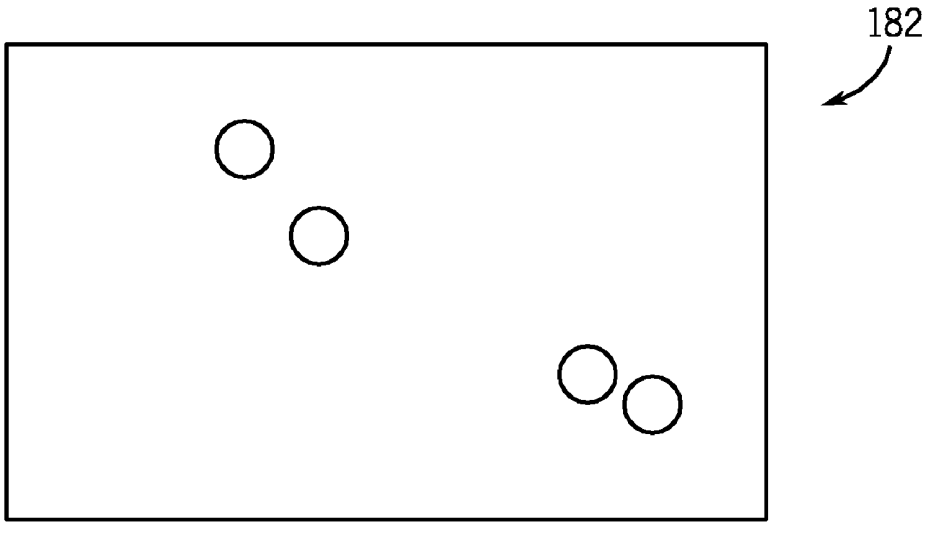
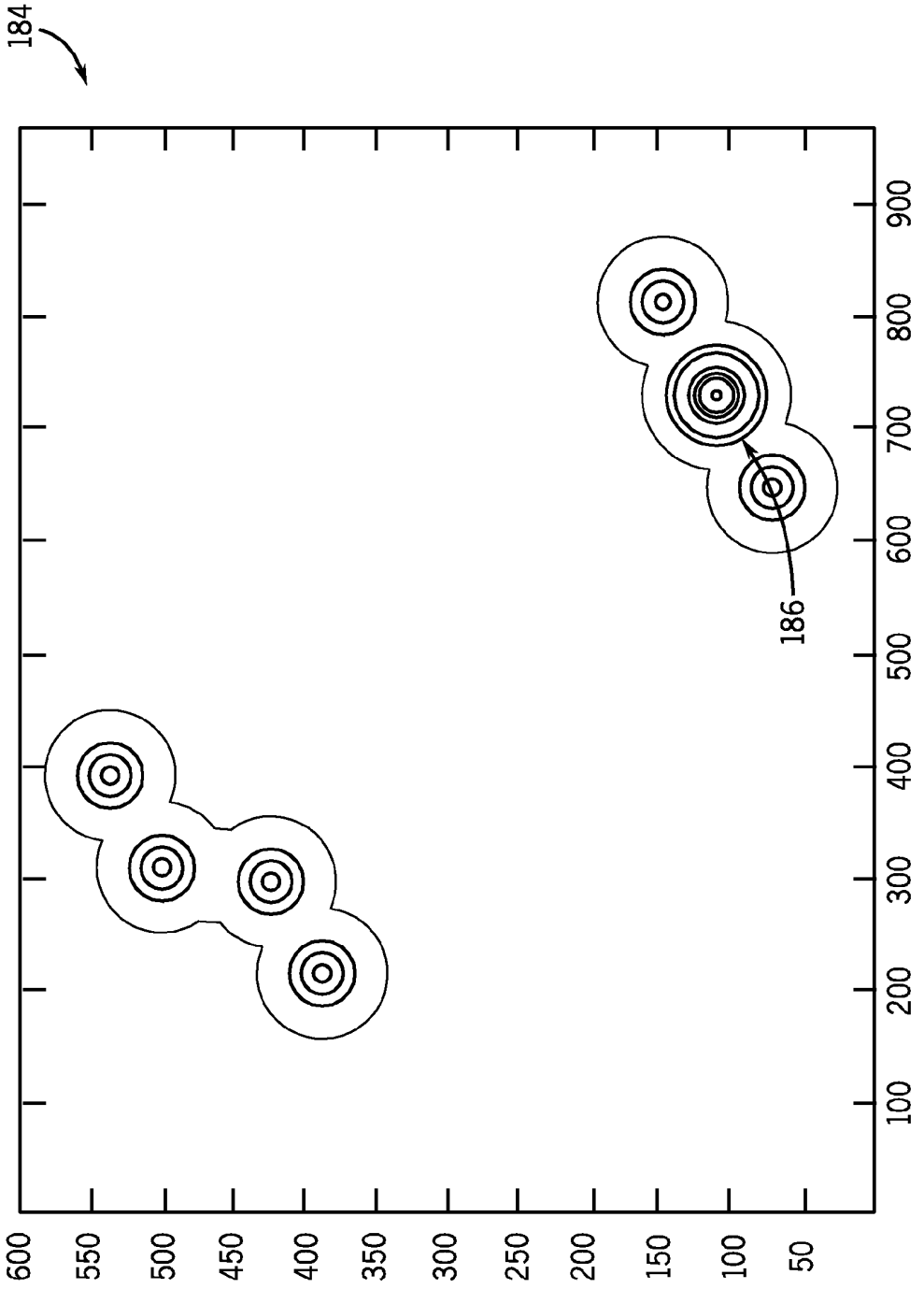


FIG. 10


184
186
600
550
500
450
400
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200
150
100
50
100
200
300
400
500
600
700
800
900

FIG. 11

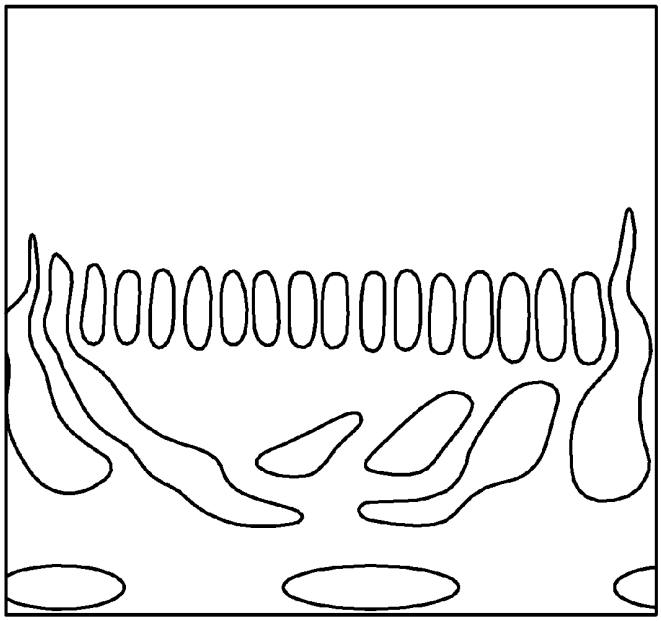


FIG. 12

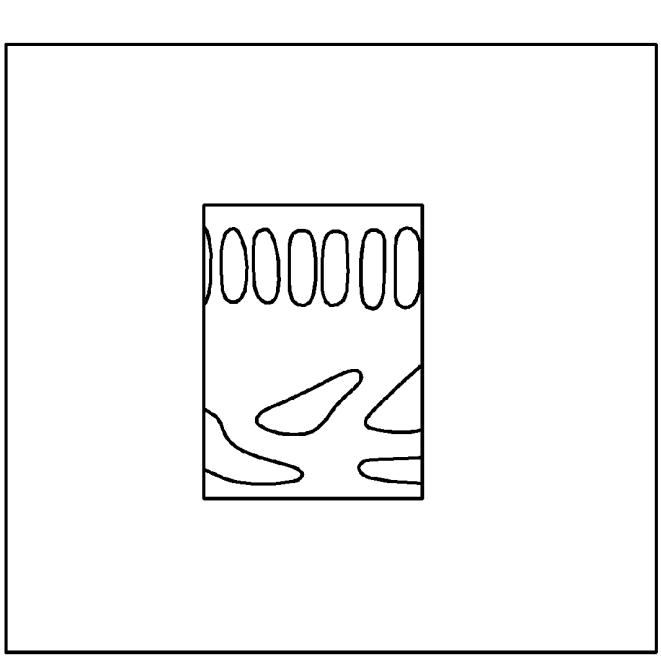
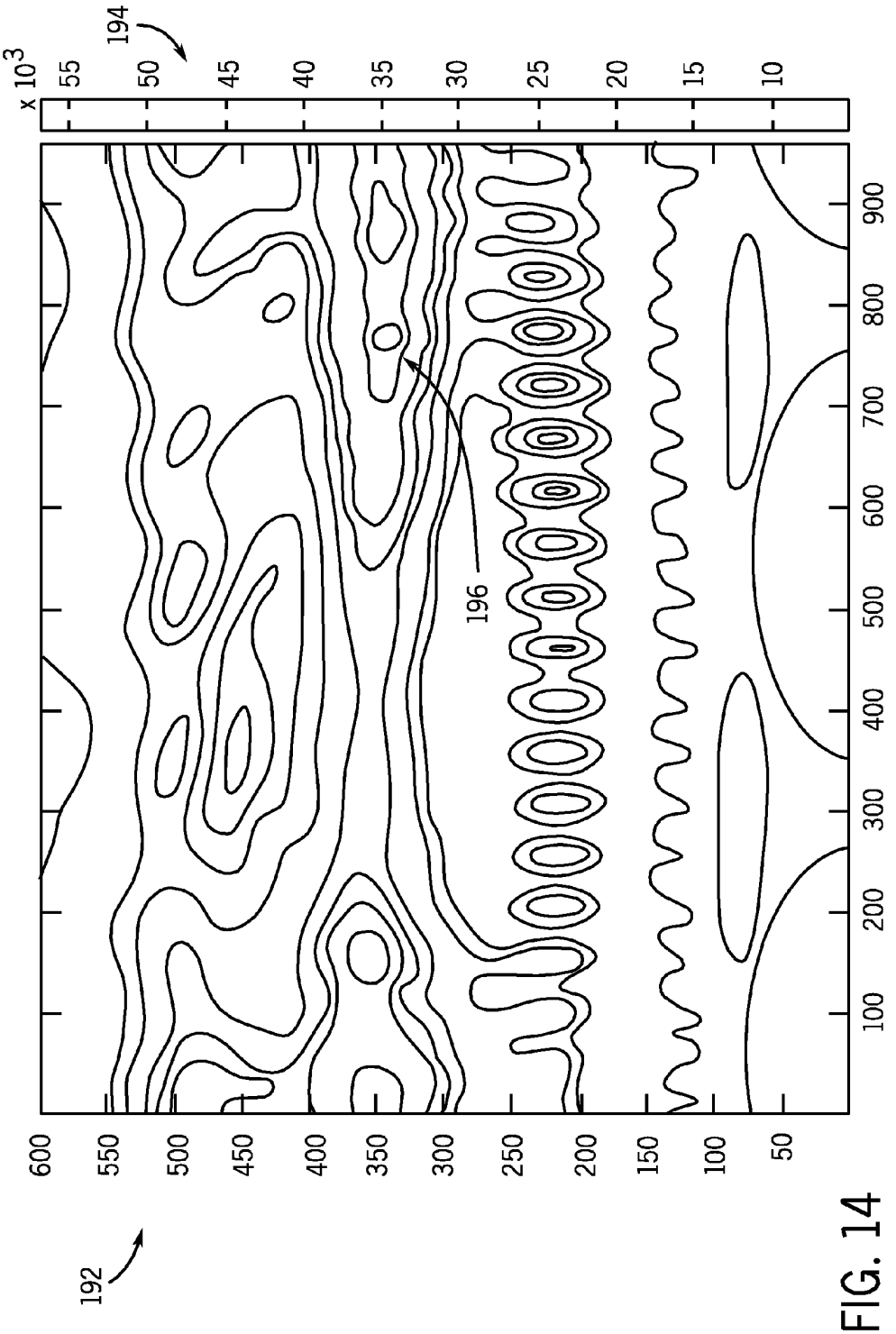


FIG. 13


194
x 10^3
55
50
45
40
35
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25
20
15
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196
600
550
500
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300
250
200
150
100
50
100
200
300
400
500
600
700
800
900
192

FIG. 14

DETERMINATION OF A PHYSIOLOGICAL PARAMETER

RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/245,573, filed Sep. 24, 2009, which application is hereby incorporated by reference.

BACKGROUND

[0002] The present disclosure relates generally to medical devices and, more particularly, to methods of analyzing physiological parameters using photon density waves.

[0003] This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present disclosure, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

[0004] In the field of medicine, doctors often desire to monitor certain physiological characteristics of their patients. Accordingly, a wide variety of devices have been developed for monitoring many such physiological characteristics. Such devices provide doctors and other healthcare personnel with the information they need to provide the best possible healthcare for their patients. As a result, such monitoring devices have become an indispensable part of modern medicine.

[0005] One technique for monitoring certain physiological characteristics of a patient is commonly referred to as pulse oximetry, and the devices built based upon pulse oximetry techniques are commonly referred to as pulse oximeters. Pulse oximetry may be used to measure various blood flow characteristics, such as the blood-oxygen saturation of hemoglobin in arterial blood, the volume of individual blood pulsations supplying the tissue, and/or the rate of blood pulsations corresponding to each heartbeat of a patient. In fact, the "pulse" in pulse oximetry refers to the time varying amount of arterial blood in the tissue during each cardiac cycle.

[0006] Pulse oximeters typically utilize a non-invasive sensor that transmits light through a patient's tissue and that photoelectrically detects the absorption of the transmitted light in such tissue. Such techniques, however, may not fully leverage the information that may be acquired. In particular, while analyses based on light absorption may provide useful measurements, other information that is not based on absorption of light in the tissue may be uncollected and unused, thereby depriving a caregiver of potentially useful information.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] Advantages of the disclosed techniques may become apparent upon reading the following detailed description and upon reference to the drawings in which:

[0008] FIG. **1** illustrates a perspective view of a pulse oximeter in accordance with an embodiment;

[0009] FIG. **2** illustrates a simplified block diagram of a pulse oximeter, according to an embodiment;

[0010] FIG. **3** is a graph depicting time-based phase and photoplethysmography (pleth) signals acquired using a photon density wave pulse oximeter, according to an embodiment;

[0011] FIGS. **4** and **5** depict, respectively, a graph of a phase signal and a corresponding scalogram resulting from a wavelet transformation of the phase signal, according to an embodiment;

[0012] FIG. **6** depicts an analysis of a scalogram based on an intensity scale, according to an embodiment;

[0013] FIGS. **7** and **8** depict, respectively, a graph of a pleth signal and a corresponding scalogram resulting from a wavelet transformation of the pleth signal, according to an embodiment;

[0014] FIGS. **9-11** illustrate a method of comparing a pattern with an image and using a threshold detection method to detect instances of the pattern, according to an embodiment; and

[0015] FIGS. **12-14** illustrate a method of applying a wavelet signature to photon density wave data and determining whether a pattern is present in the wavelet transformation of the photon density wave data.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

[0016] One or more specific embodiments of the present techniques will be described below. In an effort to provide a concise description of these embodiments, not all features of an actual implementation are described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0017] Present embodiments relate to measuring physiologic parameters corresponding to blood flow in a patient by emitting into the patient's tissue light that is modulated to generate photon density waves, detecting the light after it has passed through the patient's tissue, and processing a signal generated in response to the detected light using wavelet transforms to identify physiological information. More specifically, the signal generated in response to the detected light may contain phase and amplitude information of the photon density waves that are transmitted towards the patient's tissue and scattered and absorbed by hemoglobin in the tissue. This signal, referred to herein as the PDW signal, may be processed using wavelet analysis, such that the phase and amplitude information may be analyzed in both frequency and time domains. Various physiological parameters may be determined based on the time-frequency analyses of the transformed PDW signal.

[0018] Photon density waves may be described as progressively decaying waves of intensity. Photons generated by a light source generally make random migrations in a scattering medium, and may, at a given modulation frequency, collectively form a photon density wave that moves away from the light source. Photon propagation is generally dictated by scattering and absorption in the medium through which the waves are moving. Like other waves, photon density waves undergo refraction, diffraction, interference, dispersion, attenuation, and so forth. The photons of the photon density wave may propagate through the medium (i.e., the tissue) to be detected

at a photodector, and the phase changes and amplitude changes of the detected waves may facilitate measurement of changes in the total scattering particles as well as the absorber concentration. The phase of the detected waves may be used to determine photon scattering while the amplitude of such waves may indicate the absorption of photons by the tissue.

[0019] In particular, changes in phase of a PDW signal may correspond to a total number of scattering particles (e.g., total hemoglobin) in the observed medium. For example, since the scattering coefficient of the tissue may change depending on the total number of hemoglobin particles in the tissue, variations in the phase changes may correspond to variations in the total hemoglobin in the tissue. Thus, changes in the phase of a PDW signal may be predominately due to the total number of scattering hemoglobin particles, rather than to the ratio of different particles (e.g., oxygenated and deoxygenated hemoglobin) in the tissue.

[0020] On the other hand, changes in the amplitude of the photon density waves may correspond to the absorption of specific light frequencies (e.g. red or infrared light) in the observed volume, and, thus, a ratio of different types of particles in the probed medium. Oxygenated and deoxygenated hemoglobin particles may both scatter the photons of modulated photon density waves, but may absorb different frequencies of light. By analyzing the changes in amplitude in the PDW signal, a ratio of different types of particles in the tissue may be estimated. Data acquired using photon density waves may thus provide additional physiological information to what is typically provided in a pulse oximetry signal.

[0021] When the photon density waves transmitted and/or scattered through the tissue are received at a detector in the pulse oximeter, the detector (e.g., a photodiode) may produce a current proportional to the intensities of the received photon density waves. The produced current may be processed to determine certain physiological characteristics. In some pulse oximetry systems, Fourier analysis may be used to process the signal. Fourier transforms, however, may return a globally averaged energy value without information regarding the temporal location of signal components. Therefore, in one or more embodiments of the present disclosure, wavelet transforms may instead be used for processing and analyzing the signal generated in response to the photon density waves. One advantage that may be provided by the use of wavelet transforms is that wavelet transforms may allow a signal to be decomposed such that the frequency characteristics may be analyzed with respect to the temporal location of the frequency characteristics in a PDW signal.

[0022] Furthermore, as the PDW signal is obtained by emitting photon density waves into tissue, the PDW signal may contain information regarding both the absorption (e.g., amplitude) and scattering (e.g., phase) of the measured tissue. Thus, wavelet transforms may be used to identify differences between the absorption and scattering of the photon density waves by the tissue, and may enable an analysis of such wave characteristics with respect to time and frequency. As will be further discussed, wavelet analysis of PDW signals may enable a pulse oximeter to determine whether signal changes result from physiological changes or non-physiological interferences, and may also enable the detection of certain physiological conditions. For example, in one embodiment, wavelet analysis may enable a pulse oximeter to determine whether absorption and scattering are temporally correlated, and may determine that changes in absorption may be due to non-physiological interferences (e.g., motion) rather than physiological changes based on this temporal correlation. Thus, if changes in observed amplitude (e.g., the absorption of oxygenated or deoxygenated hemoglobin) do not correlate with a corresponding change in phase (e.g., scattering of total hemoglobin particles in tissue), the observed changes in absorption may be attributed to patient motion as opposed to changes in the physiological parameter being measured. In some embodiments, non-physiological signal components (e.g., patient motion) may be removed from the PDW signal to improve the accuracy of physiological data calculated from the PDW signal.

[0023] Turning to FIG. **1**, a perspective view of a medical device is illustrated in accordance with an embodiment. The medical device may be a pulse oximeter **100**. The pulse oximeter **100** may include a monitor **102**, such as those available from Nellcor Puritan Bennett LLC. The pulse oximeter **100** may be utilized to observe the blood constituents of a patient's arterial blood to facilitate estimation of the state of oxygen exchange in the patient's body by emitting light into tissue and detecting the light after dispersion and/or reflection by the tissue. The amount of light that passes through the tissue and other characteristics of the light may vary in accordance with the changing amount of certain blood constituents in the tissue and the related light absorption and/or scattering. As with conventional pulse oximeter systems, the pulse oximeter **100** may emit light from two or more LEDs or lasers into pulsatile tissue and then detect the transmitted light with a light detector (e.g., a photodiode or photo-detector) after the light has passed through the pulsatile tissue. Such measurements may be utilized to estimate a percentage of blood oxygen saturation in the probed volume of blood. Additionally, in one embodiment, the pulse oximeter **100** may modulate the emitted light to generate photon density waves at a high frequency to detect phase shifts that correlate predominantly to scattering particles in the probed volume of blood.

[0024] The monitor **102** may be configured to display calculated parameters on a display **104**. As illustrated in FIG. **1**, the display **104** may be integrated into the monitor **102**. However, the monitor **102** may also be configured to provide data via a port to an external display or secondary monitor. The display **104** may be configured to display computed physiological data including, for example, an oxygen saturation percentage, a pulse rate, and/or a plethysmographic waveform **106**. The oxygen saturation percentage may be a functional arterial hemoglobin oxygen saturation measurement in units of percentage SpO_2, while the pulse rate may indicate a patient's pulse rate in beats per minute. The monitor **102** may also display information related to alarms, monitor settings, and/or signal quality via indicator lights **108**.

[0025] To facilitate user input, the monitor **102** may include a plurality of control inputs **110**. The control inputs **110** may include fixed function keys, programmable function keys, and soft keys. Specifically, the control inputs **110** may correspond to soft key icons in the display **104**. Pressing control inputs **110** associated with, or adjacent to, an icon in the display may select a corresponding option. The monitor **102** may also include a casing **111**. The casing **111** may aid in the protection of the internal elements of the monitor **102** from damage.

[0026] The monitor **102** may further include a sensor port **112**. The sensor port **112** may allow for connection to an external sensor **114**, via a cable **115** which connects to the sensor port **112**. The sensor **114** may be of a disposable or a non-disposable type. Furthermore, the sensor **114** may be

used to obtain readings from a patient, which can be used by the monitor to calculate certain physiological characteristics such as the blood-oxygen saturation of hemoglobin in arterial blood, the volume of individual blood pulsations supplying the tissue, and/or the rate of blood pulsations corresponding to each heartbeat of a patient.

[0027] Turning to FIG. **2**, a simplified block diagram of a pulse oximeter system **100** is illustrated in accordance with an embodiment. Specifically, certain components of the sensor **114** and the monitor **102** are illustrated in FIG. **2**. The sensor **114** may include an emitter **116**, a detector **118**, and an encoder **120**. The emitter **116** may receive modulated drive signals from the monitor **102**, and may activate and deactivate a light emitting device at certain intervals. Thus, the monitor **102** may activate and deactivate the light emitted by the emitter **116** at high frequencies to generate photon density waves. The photon density waves may facilitate measurements relating to scattering in the probed medium based on phase changes in the emitted photon density waves.

[0028] The emitter **116** may be capable of emitting one or more wavelengths of light, e.g., RED and infrared (IR) light, into the tissue of a patient **117**, where 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 mm. The emitter **116** may include a single emitting device, for example, with two light emitting diodes (LEDs) or the emitter **116** may include a plurality of emitting devices with, for example, multiple LED's at various locations. Regardless of the number of light emitting devices, the emitter **116** may be used to measure, for example, blood oxygen saturation, water fractions, hematocrit, or other physiologic parameters of the patient **117**, as discussed herein. It should be understood that, as used herein, the term "light" may refer to one or more of radio, microwave, millimeter wave, infrared, visible, ultraviolet, gamma ray or X-ray electromagnetic radiation, and may also include any wavelength within the radio, microwave, infrared, visible, ultraviolet, or X-ray spectra, and that any suitable wavelength of light may be appropriate for use with the present disclosure. Further, in one or more embodiments, the light may refer to photon density waves, or light emitted in response to modulated drive signals.

[0029] In one embodiment, the detector **118** may be an array of detector elements that may be capable of detecting light at various intensities and wavelengths. In operation, light enters the detector **118** after passing through the tissue of the patient **117**. The detector **118** may convert the light at a given intensity, which may be directly related to the absorbance and/or reflectance of light in the tissue of the patient **117**, into an electrical signal. That is, when more light at a certain wavelength is absorbed or reflected, less light of that wavelength is typically received from the tissue by the detector **118**. For example, the detector **118** may include one or more photodiodes, or any other element capable of generating a current or voltage in response to the light incident on the detector **118**. After converting the received light to an electrical signal, the detector **118** may send the signal to the monitor **102**, where physiological characteristics may be calculated based at least in part on the absorption of light in the tissue of the patient **117**.

[0030] In some embodiments, in addition to the emitter **116** and the detector **118**, the sensor **114** may also contain various other features. For example, the sensor **114** may include a phase detector **119** capable of detecting phase shifts in photon density waves observed by the detector **118**. While the phase detection feature **119** is positioned within the sensor **114** in the illustrated embodiment, in other embodiments, the phase detection feature **119** may also be located within the monitor **102**.

[0031] Additionally the sensor **114** may include an encoder **120**, which may contain information about the sensor **114**, such as what type of sensor it is (e.g., whether the sensor is intended for placement on a forehead or digit) and the wavelengths of light emitted by the emitter **116**. This information may allow the monitor **102** to select appropriate algorithms and/or calibration coefficients for calculating the patient's **117** physiological characteristics. The encoder **120** may, for instance, be a memory on which one or more of the following information may be stored for communication to the monitor **102**: the type of the sensor **114**; the wavelengths of light emitted by the emitter **116**; and the proper calibration coefficients and/or algorithms to be used for calculating the patient's **117** physiological characteristics. In one embodiment, the data or signal from the encoder **120** may be decoded by a detector/decoder **121** in the monitor **102**.

[0032] Signals from the detector **118** and the encoder **120** may be transmitted to the monitor **102**. The monitor **102** may include one or more processors **122** coupled to an internal bus **124**. Also connected to the bus **124** may be a RAM memory **126** and a display **104**. The monitor **102** may also include a modulator **132**, which may include a time processing unit (TPU) **128** and light drive circuitry **130**. The modulator **132** may modulate the drive signals that activate the LEDs or other emitting structures of the emitter **116**. The modulator **132** may be hardware-based, a software-based, or some combination thereof. For example, a software aspect of the modulator **132** may be stored on the memory **126** and may be controlled by the processor **122**. The TPU **128** may include a sine wave generator, and may provide timing control signals to light drive circuitry **130**, which controls when the emitter **116** is activated, and if multiple light sources are used, the multiplexed timing for the different light sources. TPU **128** may also control the gating-in of signals from detector **118** through a switching circuit **134**. These signals are sampled at the proper time, depending at least in part upon which of multiple light sources is activated, if multiple light sources are used.

[0033] The modulator **132** may be configured to modulate light emitting devices in the emitter **116** at sufficiently high frequencies (e.g., approximately 50 MHz to 3.0 GHz) to generate resolvable photon density waves to propagate through the tissue of the patient **117**. While a traditional pulse oximeter may conduct measurements at low frequencies (e.g., 1.5 KHz) to return a DC signal, in some embodiments, the modulator **132** may be configured to modulate between 100 MHz and 1 GHz or between 600 MHz and 1 GHz, for example. While the modulator **132** is depicted as in the monitor **102**, in some embodiments, the modulation function may be performed by a modulator disposed in the sensor **114**. In one embodiment, the modulation and detection features may both be located within the sensor **114** to reduce the distance traveled by the signals, and to reduce potential interferences.

[0034] The received signal from the detector **118** may be processed to provide certain physiological data. In one embodiment, the received signal may be passed through an amplifier **136**, a low pass filter **138**, and an analog-to-digital converter (ADC) **140** for amplifying, filtering, and digitizing the electrical signals the from the sensor **114**. The digital data may then be stored in a queued serial module (QSM) **142**, for

later downloading to RAM **126** as QSM **142** fills up. There may also be multiple parallel paths for separate amplifiers, filters, and A/D converters for multiple light wavelengths or spectra received. Further, the processor **122** may calculate the oxygen saturation or some other physiological parameter of interest based on the received signals corresponding to the light received by the detector **118**. For example, the processor may execute instructions or algorithms stored on the memory **144**, and may be configured to perform calculations to determine a value related to the quantity of scattering particles in the probed tissue.

[0035] As discussed, the pulse oximeter **100** may emit and detect light waves to facilitate non-invasive measurement of a patient's physiological characteristics. In embodiments, the pulse oximeter **100** may generate resolvable photon density waves and identify physiological and/or non-physiological signal components of PDW signal detected after the photon density waves have passed through a medium (e.g., a patient's tissue). The wave characteristics used to analyze the PDW signal and identify signal components may include characteristics relating to the absorption of the light at the emitted wavelengths in the probed medium (e.g., amplitude change) and characteristics relating predominantly to scattering in the probed medium (e.g., phase shift).

[0036] The correlation between certain wave characteristic (e.g., amplitude and phase) and certain medium characteristics (e.g., absorption and scattering) may be based on the high frequency modulation of the light emitted by the pulse oximeter **100**, which generate the resolvable photon density waves. In some embodiments, the pulse oximeter **100** may emit light that is modulated at a high frequency (e.g., 50 MHz to 3.0 GHz), and then measure the phase shift of these high frequency waves to facilitate estimation of a total number of scattering particles in the observed medium. Similarly, the pulse oximeter **100** may be utilized to measure wave characteristics that relate predominantly to absorption in an observed volume. For example, the pulse oximeter **100** may detect changes in AC and DC amplitudes of the resolvable photon density waves to facilitate detection of a ratio of certain constituents in the blood (e.g., a ratio of oxygenated to deoxygenated hemoglobin).

[0037] The graph **150** of FIG. **3**, depicts the amplitude **152** over time **154** of a phase signal **156** and a plethysmographic (pleth) signal **158** from a pulse oximeter **100** (as in FIGS. **1** and **2**). The phase signal **156** and the pleth signal **158** may also each be derived from a respective PDW signal, as discussed above. In one embodiment, a sensor **114** of the pulse oximeter **100** may be configured to modulate emitted light to generate photon density waves, and may detect waves containing both phase and amplitude data (e.g., the phase signal **156** and the pleth signal **158**).

[0038] The phase signal **156** may vary proportionally to the intensity of light received at the detector **118** having a phase change from the emitted photon density wave. As discussed, the phase change characteristic of the received light may indicate a total number of particles (e.g., total hemoglobin), as the scattering coefficient in the medium (e.g., the tissue) may vary proportionally with the variation of total hemoglobin in the tissue. The pleth signal **158** may vary proportionally to the intensity of light received at the detector **118**. As different particles in the tissue may absorb different wavelengths of light, the intensity of light received at the detector **118** may indicate a ratio of different types of particles in the tissue (e.g., deoxygenated or oxygenated hemoglobin).

[0039] Each of the phase signal **156** and pleth signal **158** may be processed to enable the identification of certain physiological parameters of the patient **117**. In one embodiment, a pulse oximeter **100** that is capable of generating photon density waves and receiving/detecting the returns may use wavelet transforms to process the returned signal. For example continuous wavelet transforms may be applied to the PDW signals. In some embodiments, the PDW signals may also be digitized, such that discrete or complex wavelet transforms may be applied.

[0040] Using continuous wavelet transformation in one example, the detector **118** may produce a phase signal **156** and a pleth signal **158** in response to the received light. Wavelet transforms may be applied to produce an energy map having both time and frequency information. In one embodiment, algorithms or instructions may be implemented or performed by the monitor **102** (e.g., by the processor **122**) to transform PDW signals, such that the signals may be analyzed with respect to time, frequency, and/or magnitude. For example, the wavelet transform of a signal x(t) may be defined in the equation below:

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

[0041] In eq. (1), $\psi^{*}(t)$ is the complex conjugate of the wavelet function $\psi(t)$. The variable a is the dilation parameter of the wavelet, and b is the location parameter of the wavelet. In one or more embodiments, any suitable wavelet function, including a Morelet wavelet, may be used to obtain a time-frequency representation of the PDW signals (e.g., the phase signal **156** and the pleth signal **158**). The transform of eq. (1) may be regarded as a time-frequency representation where the characteristic frequency associated with the wavelet is inversely proportional to the scale a, and can be used to construct a representation of a signal on a transform surface. The energy density function of the wavelet transform, also referred to as the scalogram, may be defined by the equation below:

$$S_{R}(a,b)=\frac{|T(a,b)|^{2}}{a} \qquad \text{eq. (2)}$$

[0042] where "| |" is the modulus operator. Thus, by applying the wavelet transform on a time-based signal for the time-frequency representation of the signal, and then applying the energy density function of the wavelet transform, a scalogram may be produced. The scalogram, which may also be interpreted as a spectral density of frequency over time, may be a three dimensional model (having time, frequency, and magnitude) from which certain physiological information may be obtained. A comparison of a time-based phase signal (e.g., phase signal **156** in FIG. **3**) and its corresponding scalogram are presented in FIGS. **4** and **5**.

[0043] In FIG. **4**, the graph **160** displays a time-based phase signal **156**, which changes in amplitude **152** over time **154**. As discussed, generating and emitting photon density waves and receiving the photon density waves that are transmitted and/or scattered through the tissue may result in additional phase information, such as the phase signal **156**, which may not be available using a typical unmodulated light source. In one

embodiment, light modulated at high frequencies (e.g., 50 MHz to 3 GHz) generate resolvable photon density waves from which phase changes may be detected. The variations in scattering hemoglobin particles that may occur with each cardiac cycle correspond with variations in phase change, as depicted in the variations in amplitude **152** of the phase signal **156** in the graph **160**.

[0044] In addition to the phase information which may be received by using photon density waves in a pulse oximeter **100**, wavelet transformations may provide further information by enabling the analyses of phase information in both the time and frequency domains. The scalogram **162** in FIG. **5** provides a time-frequency representation of the phase signal **156**. The phase signal **156** and the time-frequency representation of the signal **156** may be represented over the same time **154** in the graph **160** and the scalogram **162**. The scalogram **162** may provide a relationship between frequency **164** and amplitude, which may be depicted as a spectral density in the scalogram **162**. Different features may be seen at different frequencies of the transformed signal **156**, and may match temporally with the original time-based signal **156**. For example, the features **166** may correspond to some physiological parameter (e.g., oxygen saturation, pulse rate, breathing rate, etc.) within a frequency band of the wavelet-transformed signal **156**.

[0045] Variations in the spectral density of the scalogram **162** may be based on the changes in the amplitude of the phase, or changes in the total number of hemoglobin. Patterns and ridges in the scalogram **162** may be the locus of points of local maxima in the plane, and may provide information concerning the location of temporal features, including the instantaneous frequency of the signal at that temporal location. Thus, both the magnitude of phase change, as well as the instantaneous frequency of phase change, may be available for any temporal location of the scalogram **162**. As some transformations (e.g., a typical Fourier transformation) may return a globally averaged energy value without information regarding the temporal location of signal components, the temporal location of certain phase signal characteristics may not be available. Thus, applying wavelet transforms may be particularly useful in identifying certain non-physiological signal components (e.g., peaks or spikes) within the phase signal **156**.

[0046] As discussed with respect to eq. (1), the characteristic frequency associated with the wavelet is inversely proportional to the scale a. The scalogram **168** of FIG. **6** inverts the magnitudes of the scalogram **162**, and scalogram features may be analyzed with respect to its spectral density. The scale **170** represents how the spectral density may be determined for the scalogram **168**.

[0047] A comparison of the time-based signal of a pleth signal (e.g., pleth signal **158** in FIG. **3**) and its corresponding scalogram are presented in FIGS. **7** and **8**. In FIG. **7**, the graph **172** displays a time-based pleth signal **158**, which changes in amplitude **152** over time **154**. The corresponding pleth signal scalogram **174** in FIG. **8** provides a time-frequency representation of the pleth signal **158**. The pleth signal **158** and the time-frequency representation of the signal **158** may have the same time scale **154** in the graph **172** and the scalogram **174**. In addition, the pleth signal scalogram **174** may provide a relationship between frequency **164** and magnitude of the pleth signal **158**. As discussed with respect to the phase signal **156** and the corresponding phase signal scalogram **162** of FIGS. **4** and **5**, the magnitude of the pleth signal scalogram **174** may be represented in varying spectral density, from which features **176** may be detected. The varying spectral density may correlate to variations in the amplitude of the pleth signal **158**, which may be proportional to the variation of photons absorbed by certain hemoglobins (e.g., oxygenated or deoxygenated hemoglobin). Further, the time-frequency representation provided by the scalogram **174** may facilitate identifying and/or removing non-physiological signal components, and in some embodiments, the scalogram **174** may facilitate in determining certain physiological parameters.

[0048] Furthermore, in some embodiments, the phase signal scalogram **162** and the pleth signal scalogram **174** may be compared or analyzed with respect to one another to determine certain physiological parameters. For example, an increase in frequency or amplitude at one temporal location may be detected on a pleth signal scalogram **174**, possibly indicating a change in the number of photon absorbing hemoglobin. The phase signal scalogram **162** may be analyzed at the same temporal location to determine whether the change in photon absorption corresponds to a change in hemoglobin ratio (e.g., the ratio between oxygenated and deoxygenated hemoglobin), and/or a change in total hemoglobin.

[0049] As certain features in a scalogram may indicate certain physiological conditions, the present techniques may also include methods of determining the presence of patterns in a scalogram which may, due to their repeated or repetitive nature, indicate a physiological condition. That is, ongoing or repeated physiological conditions may be characterized by discernible and repeatable patterns, whereas noise, motion artifacts, and other non-repetitive phenomena cannot typically be characterized by a recurring pattern or signature. FIGS. **9-11** depict one example of how a pattern indicative of a physiological condition may be detected in a scalogram. In one embodiment, a pattern of interest **180** depicted in FIG. **9** may be known to indicate a certain physiological condition. The image **182** of FIG. **10** may represent some portion of a scalogram. Some embodiments may include a method of determining whether the pattern of interest **180** is present in the image **182** by cross correlating the pattern **180** with the image **182**. The resulting image **184** of FIG. **11** may represent the cross correlation. The identification of the pattern **180** may include setting a threshold to identify the pattern **180**. For example, the threshold may be some spectral intensity, and instances in the image **182** that exceed a threshold intensity may indicate that the pattern **180** is present in the image **182**. For example, the presence of the depicted brighter spot **186** may be used to identify the pattern **180** in the example image **182**.

[0050] In one or more embodiments, a pattern may be identified by developing various wavelet signatures with which to compare a PDW signal. FIGS. **12-14** depict one example of how a scalogram **188** (FIG. **12**) of a PDW signal may be analyzed in view of a wavelet signature **190** (FIG. **13**) to determine the presence of some pattern of interest exemplified by the wavelet signature **190**. In some embodiments, a set of wavelet signatures may be developed to enable the identification of various physiological conditions.

[0051] In one embodiment, the scalogram **188** may be cross-correlated with the wavelet signature **190** to determine whether the pattern of interest is present in the scalogram **188**. Various techniques, such as the cross correlation and threshold techniques discussed with respect to FIGS. **9-11**, may be used to determine whether the pattern, as typified by wavelet

signature **190**, is present in the scalogram **188**. Thus, in one embodiment, one or more wavelet signatures **190** may be processed (e.g., cross-correlated) with the scalogram **188** to produce a combined image, as in the image **192** of FIG. **14**. The image **192** may be analyzed (e.g., using various image processing techniques and/or facial recognition technologies) to determine whether the patterns are present. In one embodiment, the intensity throughout the image **192** may be analyzed (e.g., using an intensity scale **194**) to detect instances where the intensity in the image **192** meets or surpasses some threshold. For example, the present techniques may identify a pattern **196** at some threshold intensity, and the presence of the pattern **196** may indicate one or more physiological conditions.

[0052] While the disclosure may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the embodiments provided herein are not intended to be limited to the particular forms disclosed. Rather, the various embodiments may cover all modifications, equivalents, and alternatives falling within the spirit and scope of the disclosure as defined by the following appended claims.

What is claimed is:

1. A method for processing a physiological signal, comprising the acts of:

receiving a signal in response to propagation of photon density waves through tissue;

processing the signal using a wavelet transform to generate two or more multi-dimension components; and

using the two or more multi-dimensional components to distinguish physiological and non-physiological components of the signal.

2. The method, as set forth in claim **1**, wherein the wavelet transform is a Morelet wavelet.

3. The method, as set forth in claim **1**, wherein the two or more multi-dimension components comprise frequency and time.

4. The method, as set forth in claim **1**, comprising representing the two or more multi-dimension components as a scalogram.

5. The method, as set forth in claim **4**, wherein distinguishing physiological and non-physiological components comprises identifying features on the scalogram.

6. The method, as set forth in claim **1**, wherein distinguishing physiological and non-physiological components comprises employing one or more image processing techniques or facial recognition technologies.

7. The method, as set forth in claim **1**, wherein distinguishing physiological and non-physiological components comprises:

cross-correlating an image representation of the two or more multi-dimension components with a known pattern or signature to produce a cross-correlated image; and

determining whether the image representation substantially includes the known pattern or signature based on the cross-correlated image.

8. The method, as set forth in claim **7**, wherein determining whether the image representation substantially includes the known pattern or signature is based on comparing the spectral intensity of the cross correlated image to a threshold intensity.

9. The method, as set forth in claim **1**, comprising removing the non-physiological components from the signal.

10. A monitor, comprising:

a display;

a connector port capable of receiving a signal generated in response to propagation of photon density waves through tissue; and

data processing circuitry capable of applying a continuous wavelet transform to the signal, analyzing an output of the continuous wavelet transform to distinguish between physiological and non-physiological components of the signal, generating patient physiological data based on at least the physiological components of the signal, and displaying the patient physiological data on the display.

11. The monitor, as set forth in claim **10**, wherein the output of the continuous wavelet transform comprises a scalogram comprising a spectral density of the signal with respect to frequency and time.

12. The monitor, as set forth in claim **10**, wherein distinguishing between physiological and non-physiological components of the signal is based on whether a phase component and an amplitude component of the signal correlate.

13. The monitor, as set forth in claim **10**, wherein generating patient physiological data is based on a comparison of the output with a pattern corresponding to a physiological condition.

14. The monitor, as set forth in claim **13**, wherein the comparison comprises cross-correlating the output with the pattern and determining whether the cross correlation meets a threshold.

15. A monitoring system, comprising:

a sensor suitable for acquiring photon density wave data when situated on a patient; and

a monitor in communication with the sensor, wherein the monitor distinguishes between physiological and non-physiological aspects of the photon density wave data based on a continuous wavelet transformation of the photon density wave data.

16. The monitoring system of claim **15**, wherein the photon density wave data comprises information relating to a total number of particles at a tissue site where the sensor is situated on the patient and information relating to a ratio of different types of particles at the tissue site.

17. The monitoring system of claim **15**, wherein the monitor distinguishes between the physiological and the non-physiological aspects based substantially on whether a phase component of the photon density wave data correlates with an amplitude component of the photon density wave data.

18. The monitoring system of claim **15**, wherein the monitor is configured to identify a physiological condition based on at least the physiological aspect of the photon density wave data.

19. The monitoring system of claim **18**, wherein the monitor identifies the physiological condition based on a continuous wavelet transformation of the photon density wave data.

20. The monitoring system of claim **18**, wherein the monitor identifies the physiological condition based on a comparison of the continuous wavelet transformation with a pattern corresponding to the physiological condition.

* * * * *

专利名称(译)	生理参数的确定		
公开(公告)号	US20110071366A1	公开(公告)日	2011-03-24
申请号	US12/880303	申请日	2010-09-13
[标]申请(专利权)人(译)	内尔科尔普里坦贝内特公司		
申请(专利权)人(译)	NELLCOR PURITAN BENNETT LLC		
当前申请(专利权)人(译)	COVIDIEN LP		
[标]发明人	MCKENNA EDWARD M		
发明人	MCKENNA, EDWARD M.		
IPC分类号	A61B5/00 G06F19/00 G06T11/20		
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摘要(译)

提供了用于向组织发送光子密度波和从组织接收光子密度波，以及使用小波变换处理接收的波以识别非生理信号分量和/或识别生理状况的方法和系统。脉冲血氧计可以从组织接收光子密度波以产生具有相位和幅度信息的信号。相位信号可以与组织中的总颗粒的散射成比例，并且振幅信号可以与某些颗粒的吸收相关，提供关于组织中不同颗粒的比率的信息。利用小波变换处理相位和幅度信号可以实现关于时间，频率和幅度的信号分析，并且可以产生各种生理数据。例如，可以识别非生理噪声分量，并且可以通过利用对应于某些生理条件的模式处理原始信号的尺度图来识别某些生理条件。