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(54) **MOTION COMPATIBLE SENSOR FOR NON-INVASIVE OPTICAL BLOOD ANALYSIS**

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(52) **U.S. Cl.** ..... **600/322**; 600/323

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See application file for complete search history.

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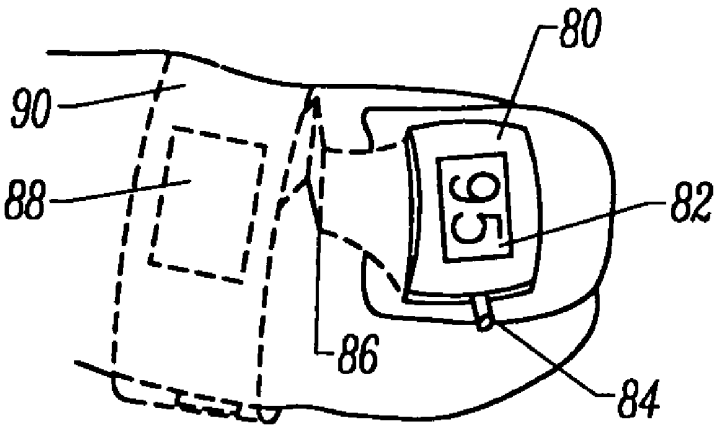
(57) **ABSTRACT**

A non-invasive optical sensor which uses the motion signal to calculate the physiological characteristic being measured. For pulse oximetry, a least squares or a ratio-of-ratios technique can be applied to the motion signal itself. This is made possible by selecting a site on the patient where variations in motion produce signals of two wavelengths which are sufficiently correlated. In particular, it has been determined that a sensor placed on a nail, in particular a thumbnail, exhibits the characteristics of having the red and infrared signals correlated when used for pulse oximetry, and the resulting signals correlate to arterial oxygen saturation.

**9 Claims, 10 Drawing Sheets**



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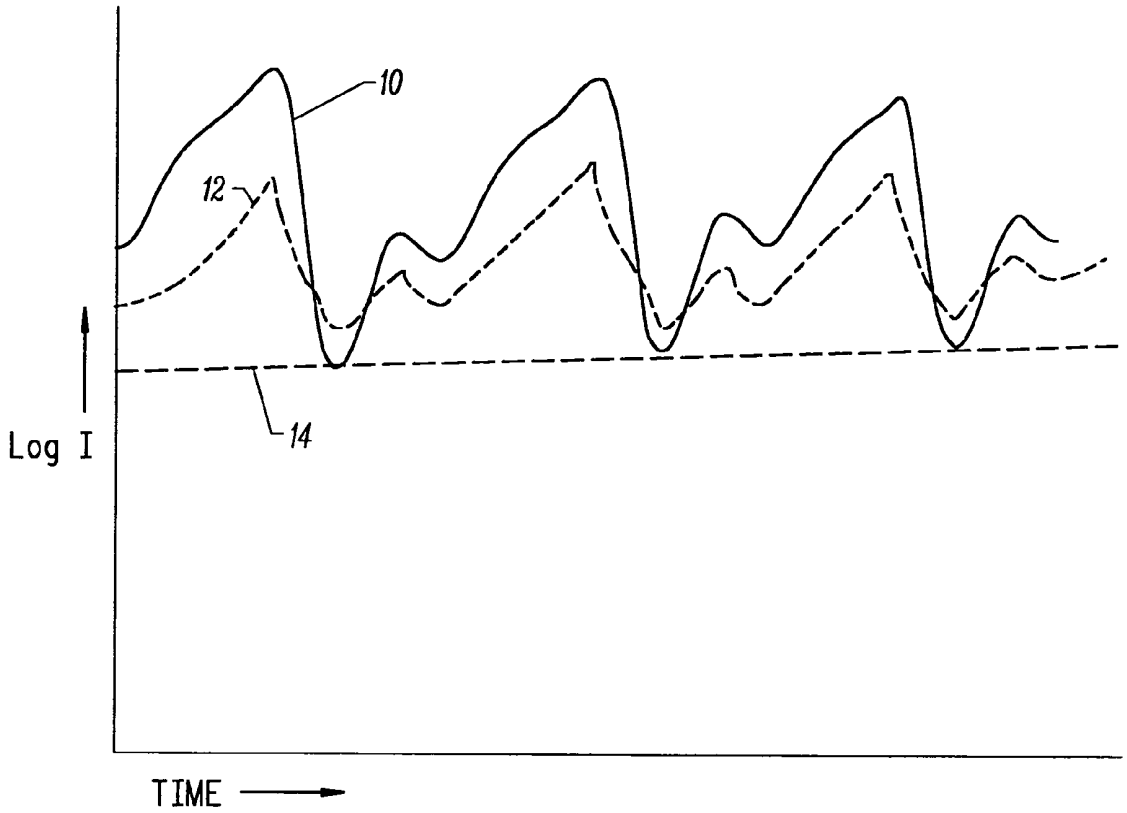


FIG. 1

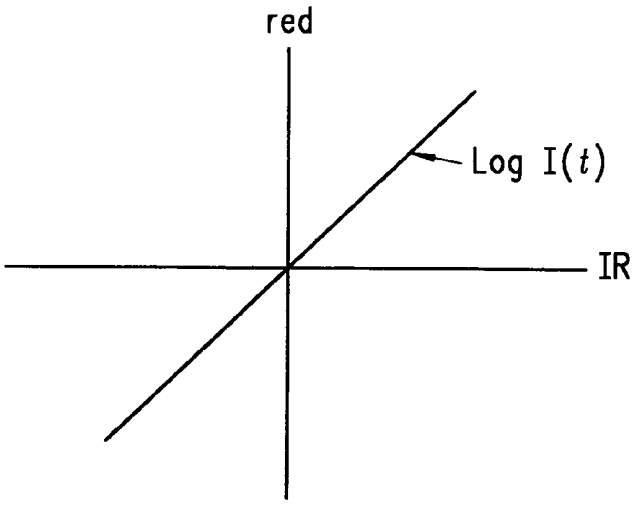


FIG. 2

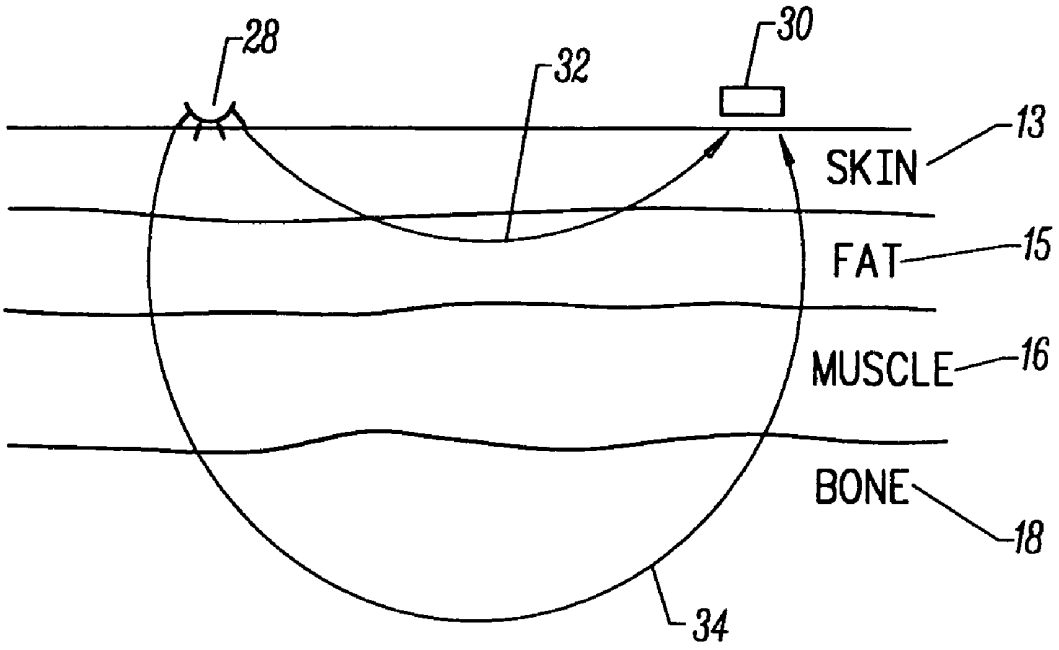


FIG. 3

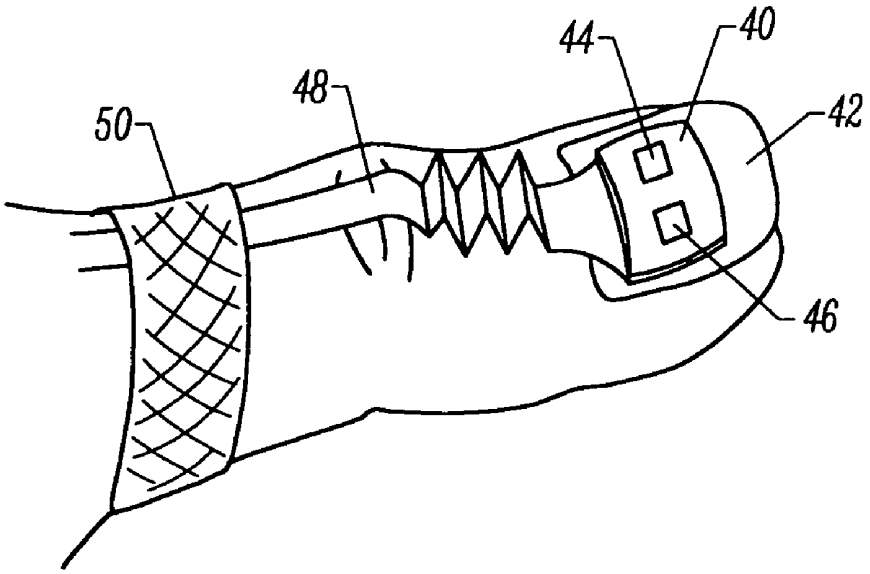


FIG. 4

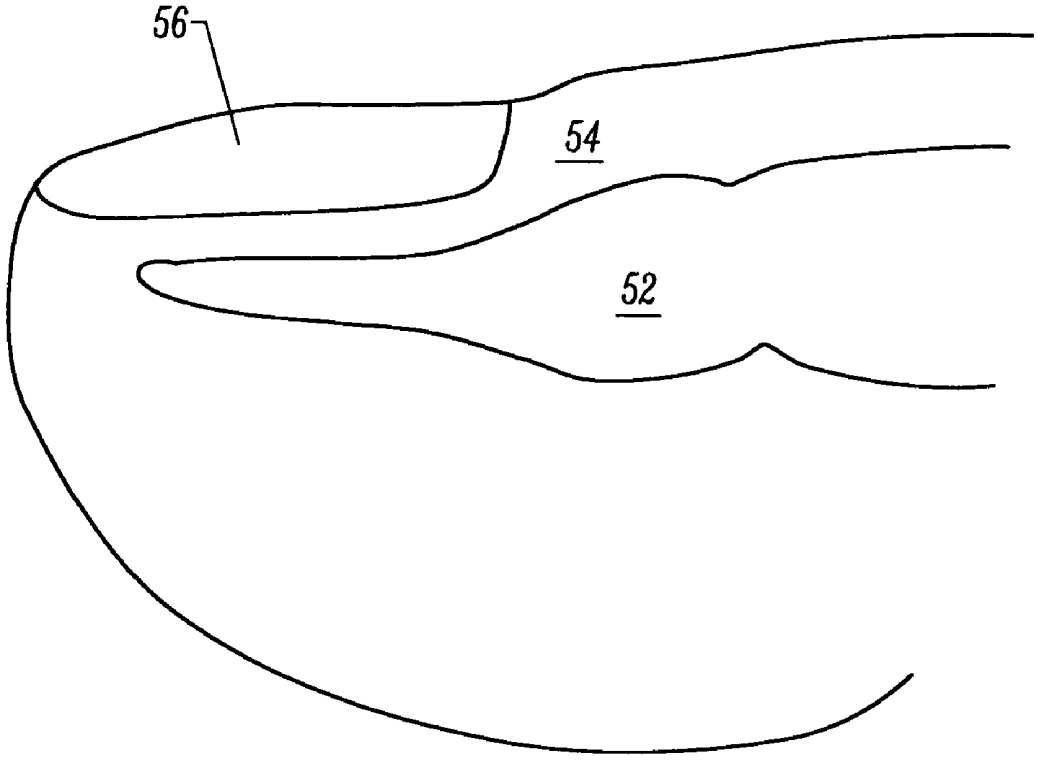


FIG. 5

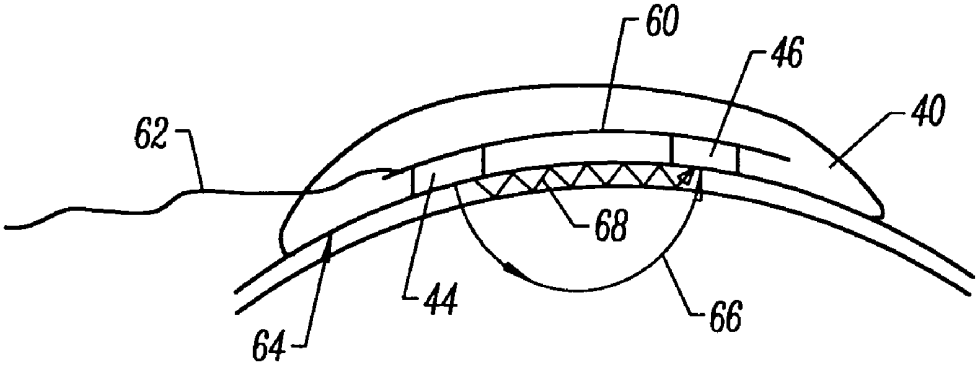


FIG. 6

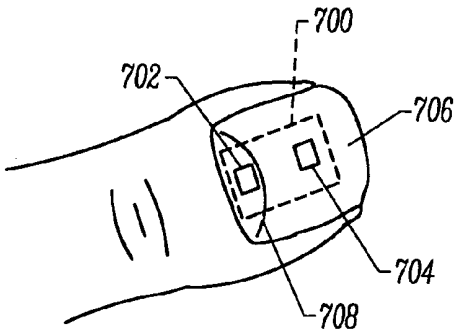


FIG. 7

FIG. 8A

FIG. 8B

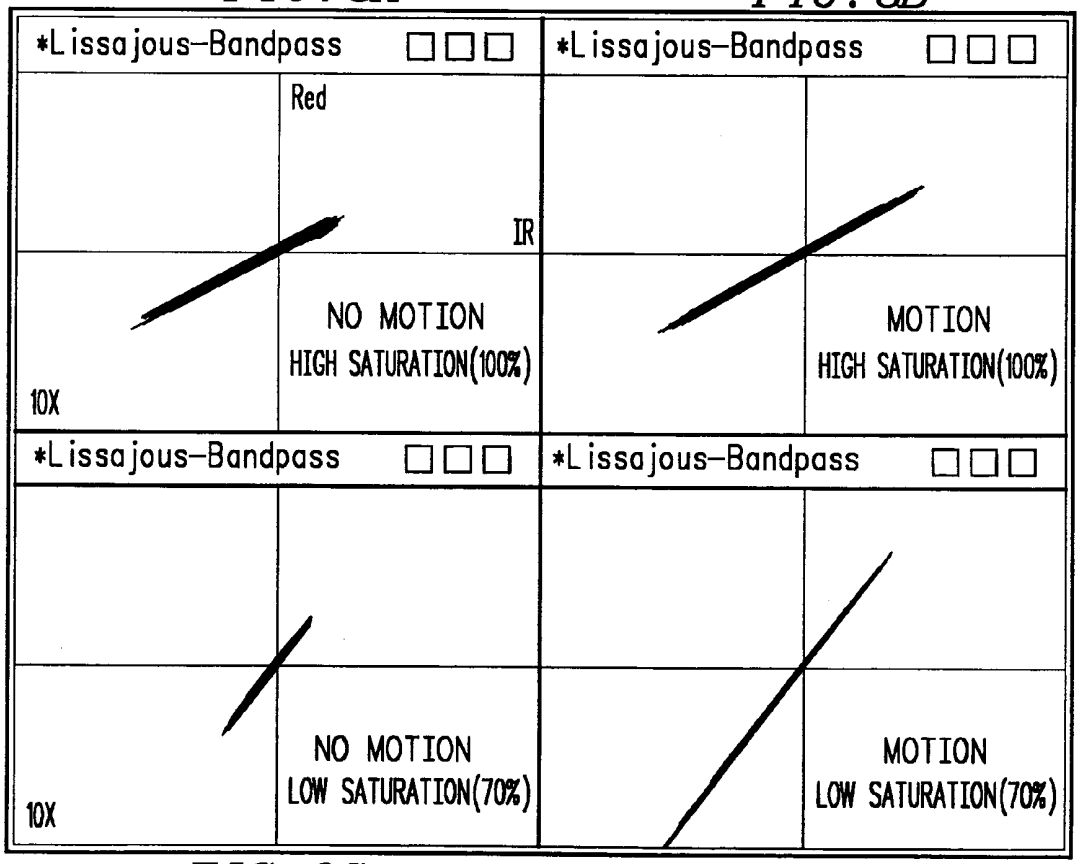


FIG. 8C

FIG. 8D

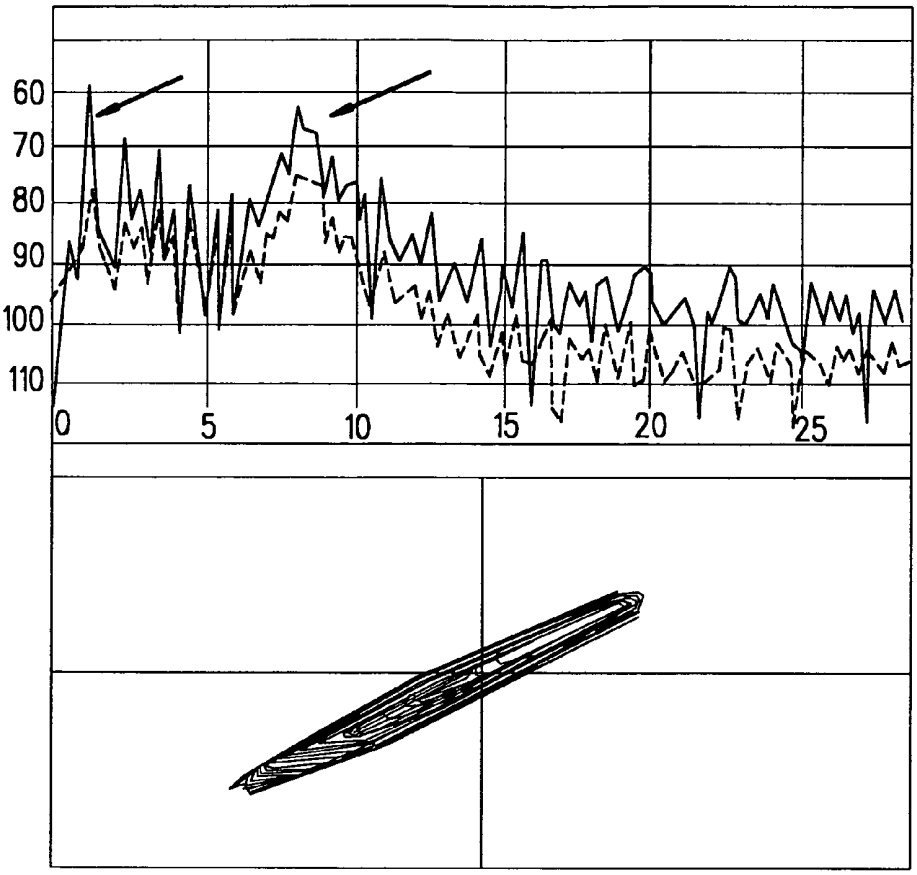


FIG. 9A

FIG. 9B

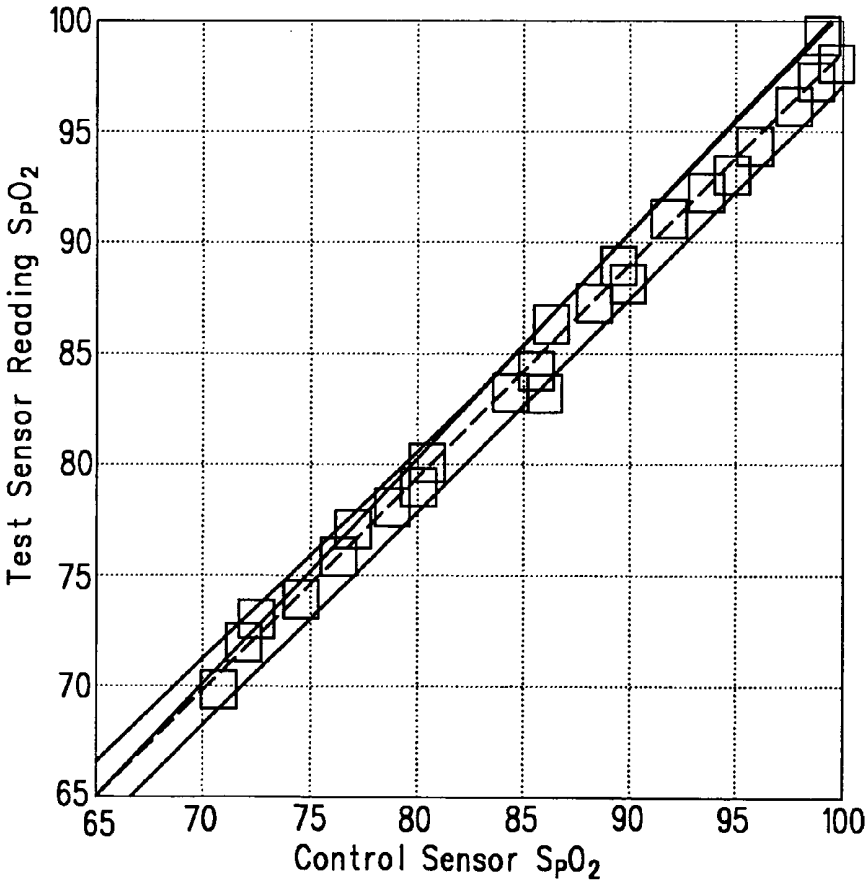


FIG. 10

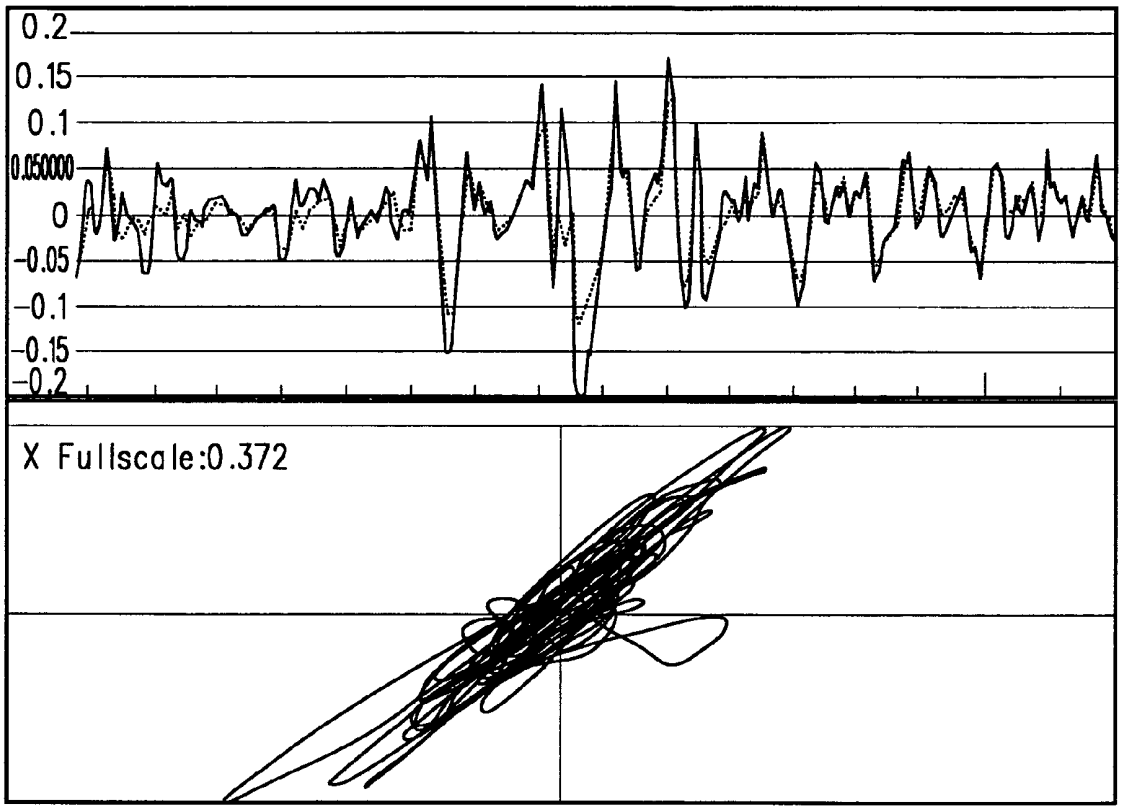


*FIG. 11A*
(PRIOR ART)

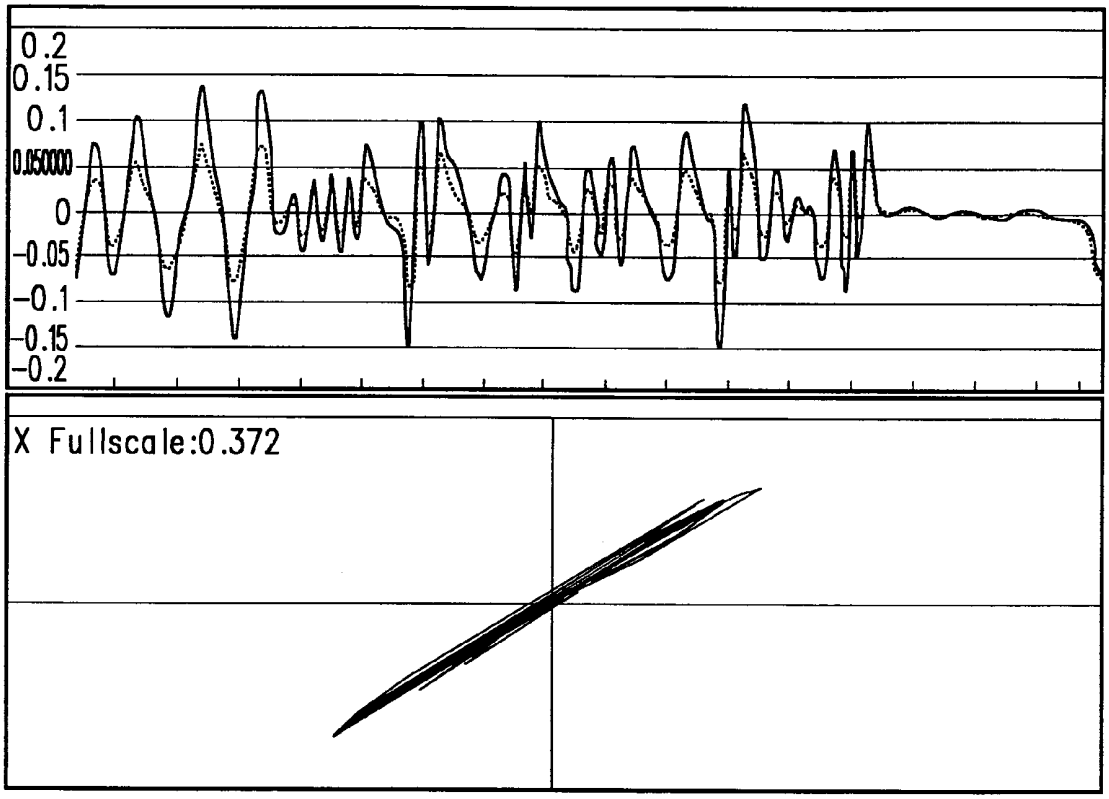


FIG. 11B

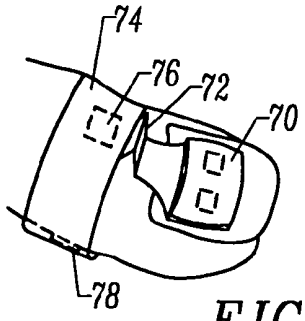


FIG. 12

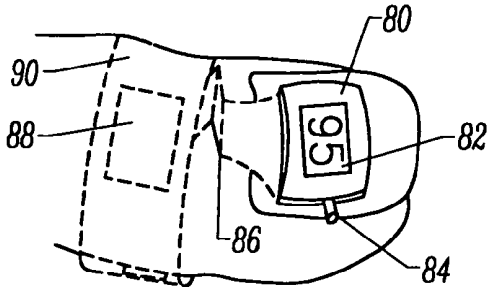


FIG. 13

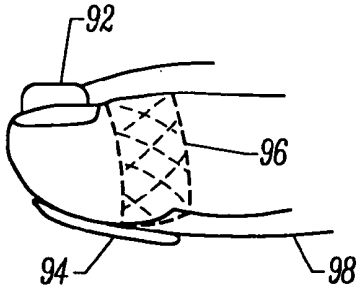


FIG. 14

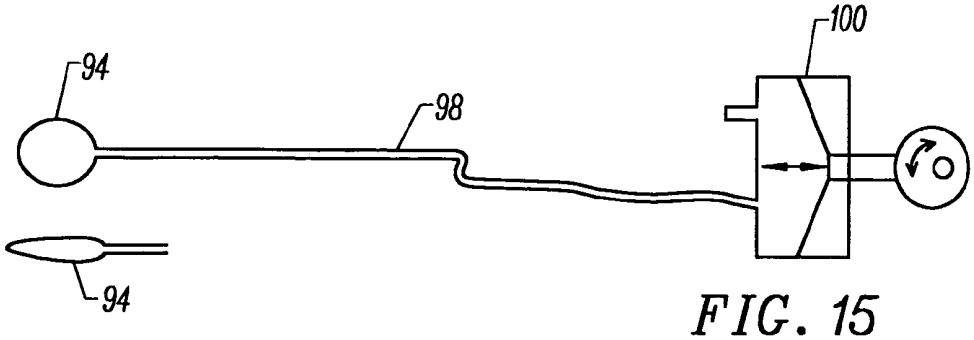


FIG. 15

FIG. 16

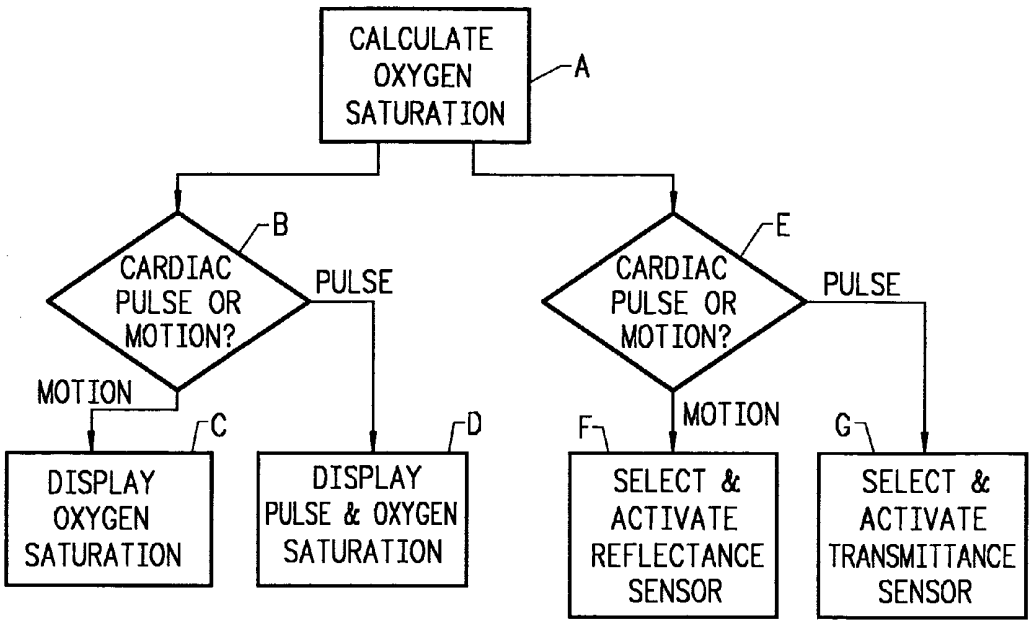
CALCULATE OXYGEN SATURATION
A
CARDIAC PULSE OR MOTION?
B
PULSE
MOTION
C
DISPLAY OXYGEN SATURATION
D
DISPLAY PULSE & OXYGEN SATURATION
CARDIAC PULSE OR MOTION?
E
PULSE
MOTION
F
SELECT & ACTIVATE REFLECTANCE SENSOR
G
SELECT & ACTIVATE TRANSMITTANCE SENSOR

*FIG. 17*

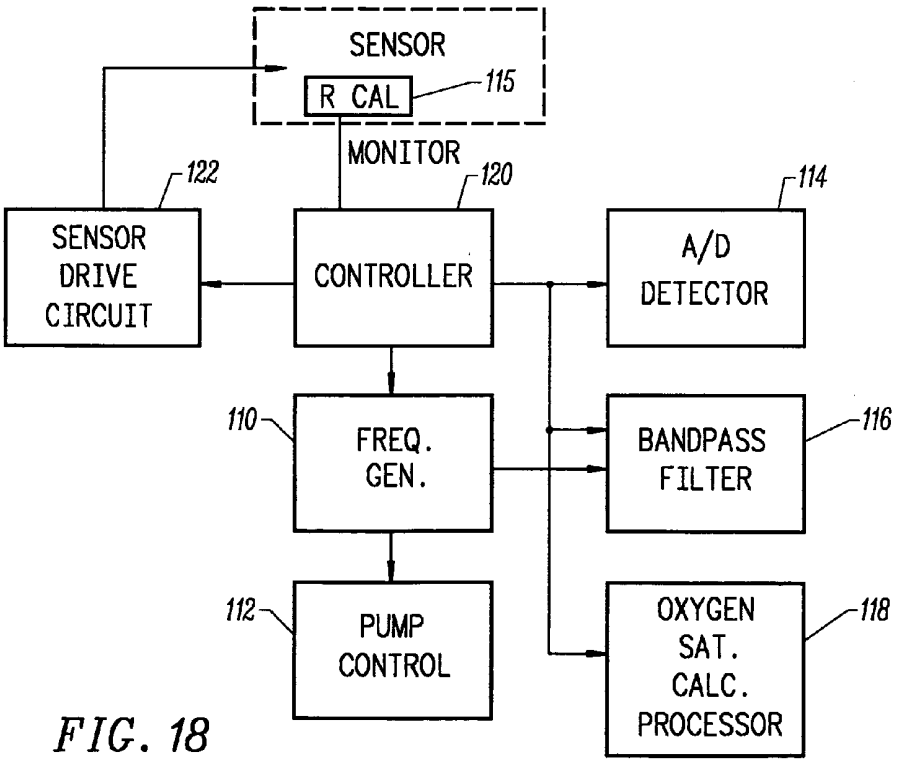
SENSOR
R CAL
115
MONITOR
122
120
114
SENSOR DRIVE CIRCUIT
CONTROLLER
A/D DETECTOR
110
FREQ. GEN.
BANDPASS FILTER
116
112
PUMP CONTROL
OXYGEN SAT. CALC. PROCESSOR
118

*FIG. 18*

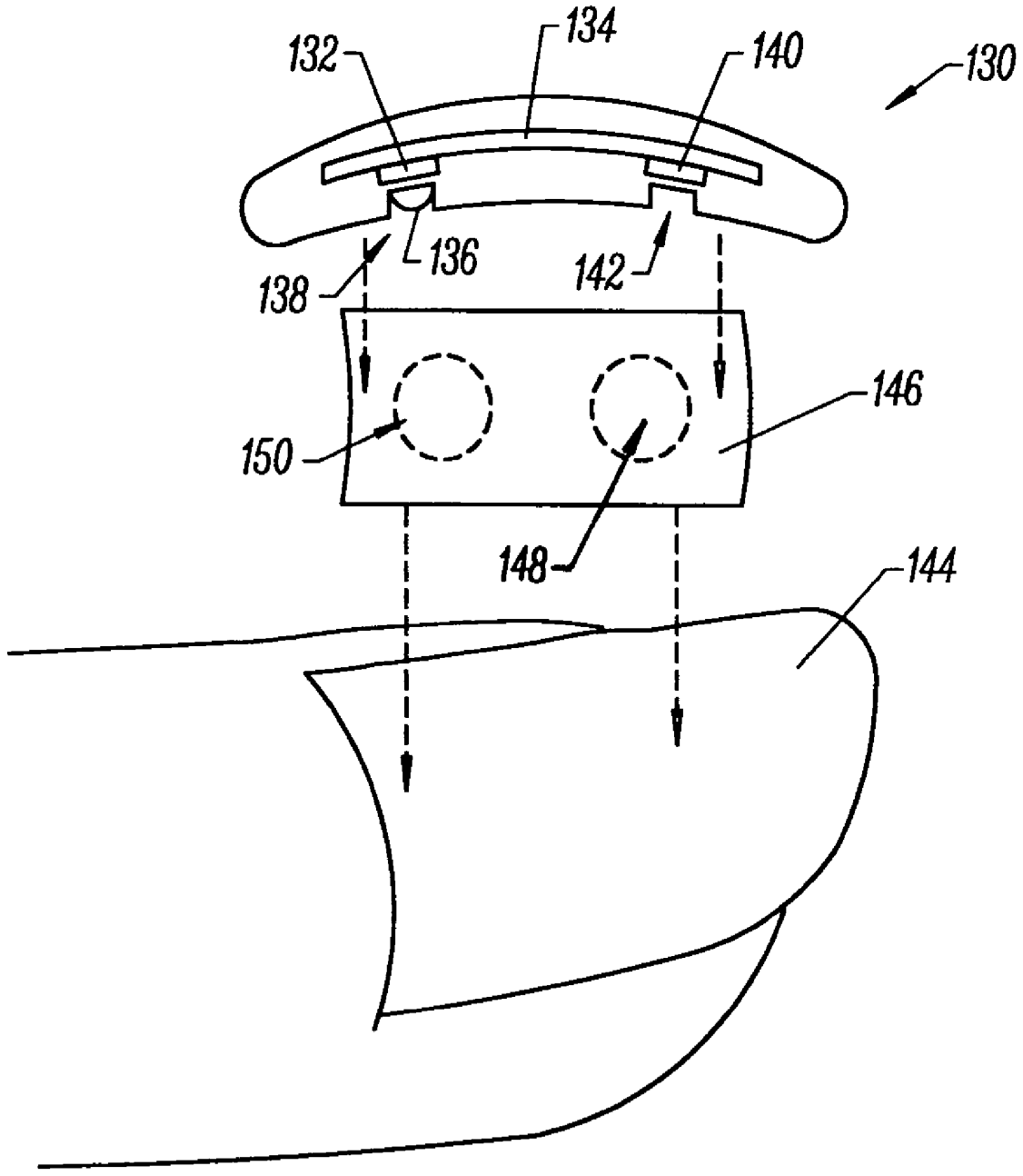


FIG. 19

# MOTION COMPATIBLE SENSOR FOR NON-INVASIVE OPTICAL BLOOD ANALYSIS

## CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 10/080,433, filed Feb. 21, 2002, now U.S. Pat. No. 6,845,256, which is a division of U.S. application Ser. No. 09/348,437, filed Jul. 7, 1999, now U.S. Pat. No. 6,374,129, which is a division of U.S. application Ser. No. 08/722,443, filed Oct. 10, 1996, now U.S. Pat. No. 6,018,673, which disclosures are incorporated by reference for all purposes.

## STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

NOT APPLICABLE

## REFERENCE TO A "SEQUENCE LISTING," A TABLE, OR A COMPUTER PROGRAM LISTING APPENDIX SUBMITTED ON A COMPACT DISK

NOT APPLICABLE

## BACKGROUND OF THE INVENTION

The present invention relates to optical sensors for non-invasive determination of physiological characteristics, and in particular to sensors for making such determinations in the presence of motion.

Many types of optical sensors are used to measure physiological characteristics of a patient. Typically, an optical sensor provides emitted light which is then scattered through tissue and detected. Various characteristics of a patient can be determined from analyzing such light, such as oxygen saturation, pulse rate, pH, etc.

Pulse oximetry is typically used to measure various blood characteristics including, but not limited to, the blood-oxygen saturation of hemoglobin in arterial blood, the volume of individual blood pulsations supplying the tissue, and the rate of blood pulsations corresponding to each heartbeat of a patient. Measurement of these characteristics has been accomplished by use of a non-invasive sensor which scatters light through a portion of the patient's tissue where blood perfuses the tissue, and photoelectrically senses the absorption of light in such tissue. The amount of light absorbed is then used to calculate the amount of blood constituent being measured.

The light scattered 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 transmitted light scattered through the tissue will vary in accordance with the changing amount of blood constituent in the tissue and the related light absorption. For measuring blood oxygen level, such sensors have typically been provided with a light source that is adapted to generate light of at least two different wavelengths, and with photodetectors sensitive to both of those wavelengths, in accordance with known techniques for measuring blood oxygen saturation.

Known non-invasive sensors include devices that are secured to a portion of the body, such as a finger, an ear or the scalp. In animals and humans, the tissue of these body portions is perfused with blood and the tissue surface is readily accessible to the sensor. A photoelectric pulse transducer from World Precision Instruments is described as even recording signals through the fingernail.



Optical sensors are typically either reflective or transmissive. Transmissive sensors have the emitter and detector on opposite sides of a finger, toe, nose or other tissue. They measure light transmitted through the tissue from one side to the other. Reflectance sensors, on the other hand, have the emitter and detector side-by-side, such as placement on the forehead, or on a fetus where it is difficult to position a sensor over a finger, etc. Reflectance sensors detect light which is scattered back to the same surface.

In pulse oximetry, the goal is to determine the amount of oxygen in arterial blood, as distinguished from venous blood or the tissue itself. The light emitted can be absorbed by all three, however, and they need to be distinguished among. FIG. **1** illustrates a plot of the logarithm of the detected intensity signal versus time. Solid line **10** is the detected infrared signal in a pulse oximeter, shown varying with time. Dotted line **12** is the detected red wavelength signal. As can be seen, the value moves up and down with the heartbeat frequency, due to the pulsing of the blood through the arteries. The portion of the signal below line **14** is representative of light absorbed by the tissue, venous blood, and a baseline component of the arterial blood.

Using appropriate signal analysis, the DC portion can be eliminated, leaving an extracted AC portion which is due to absorption by arterial blood. As can be seen in FIG. **1**, and more clearly in FIG. **2**, the red and infrared signals, although varying by different amounts, are in phase. FIG. **2** illustrates a plot over an epoch of time of the red logarithmic signal versus the infrared logarithmic signal, and is commonly referred to as a Lissajous plot. As can be seen, a line is formed, indicating they are in phase.

This characteristic of the red and infrared signals allows the determination of oxygen saturation through two methods. In a first method, the "ratio of ratios" is calculated, which is the ratio, between red and infrared, of the logarithms of the quotients obtained by dividing the maximum signal intensity and the subsequent minimum signal intensity. This ratio-of-ratios is then used in a predetermined formula to calculate arterial oxygen saturation. This is described more fully in U.S. Pat. No. 4,653,498.

In a second method, referred to here as "least squares," a least squares regression analysis is performed on the above-mentioned Lissajous plot to determine the slope of the ensemble of data points taken during an epoch of time. This slope is then used in a predetermined formula to determine arterial oxygen saturation. Other techniques are set forth in a co-pending application entitled "Method and Apparatus for Estimating Physiological Parameters Using Model-Based Adaptive filtering," filed Jun. 7, 1996, Ser. No. 08/660,510, the disclosure of which is hereby incorporated by reference.

In some cases, it is desirable to measure the oxygen saturation of the venous blood in order to get an indication of how much oxygen is being used by the body. The arterial blood, on the other hand, gives an indication of how much oxygen is being delivered to the body. In Shiga U.S. Pat. No. 4,927,264, the oxygen saturation in venous blood is determined by inducing a venous pressure with a pressure cuff. This effectively varies line **14** of FIG. **1** at a frequency different from the heart rate, so that it can be separately filtered and isolated and compared to the arterial pulse. The non-varying portion is then assumed to be the tissue absorption and can be distinguished from the slowly varying pressure induced venous blood absorption. An alternate approach can be used in extra-corporeal monitoring where the blood is actually pumped out of the body and then back in. Such a technique is set forth in

an article by Odell et al., entitled "Use of Pulse Oximetry to Monitor Venous Saturation During Extracorporeal Life Support" Critical Care Medicine, vol. 22, no. 4 (Apr. 4, 1994). In Odell, the venous blood being pumped out of the body passes the sensor, and the pumping mechanism provides an artificial pulse allowing the use of pulse oximetry techniques.

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

In one oximeter system described in U.S. Pat. No. 5,025,791, an accelerometer is used to detect motion. When motion is detected, readings influenced by motion are either eliminated or indicated as being corrupted. In a typical oximeter, measurements taken at the peaks and valleys of the blood pulse signal are used to calculate the desired characteristic. Motion can cause a false signal peak and valley, resulting in a measurement having an inaccurate value and one which is recorded at the wrong time. In U.S. Pat. No. 4,802,486, assigned to Nellcor Puritan Bennett, the assignee of the present invention, an EKG signal is monitored and correlated to the oximeter reading to provide synchronization to limit the effect of noise and motion artifact pulses on the oximeter readings. This reduces the chances of the oximeter locking onto a periodic motion signal. Still other systems, such as the one described in U.S. Pat. No. 5,078,136, assigned to Nellcor Puritan Bennett, use signal processing in an attempt to limit the effect of noise and motion artifact. The '136 patent, for instance, uses linear interpolation and rate of change techniques to analyze the oximeter signal. U.S. Pat. No. 5,337,744 sets forth sensor modifications used to improve the immunity of the signal from motion artifacts.

The motion signal impedes the measurement because it obscures the cardiac signal. The motion signal can have many components, such as, for example, the emitter or detector physically moving away from the body, or a volume of venous and arterial blood sloshing around in response to the motion, or the signal path being shortened or lengthened by expansion or compression of the tissue due to motion.

Contrary to conventional practice, signal analysis might be able to directly use the time-varying motion signal to calculate oxygen saturation. Under some conditions, the ratio-of-ratios (or least squares) resulting from a motion-induced signal has the same value as the ratio-of-ratios (or least squares) for the cardiac induced signal. The red and infrared intensity signals are often not in phase, and can limit the use of the motion signal for calculating oxygen saturation. One of the factors that may cause this is illustrated in FIG. **3**. As FIG. **3** illustrates, light from emitter **28** can pass through skin **13**, fat **15**, muscle **16**, and bone **18**, on its way to a detector **30**. Light of one wavelength may, on average, take path **32**, while light of another wavelength may penetrate deeper and take path **34**. Motion will cause disproportionate variances in the path lengths of the two wavelengths of light, resulting in out-of-phase signals of the detector.

## BRIEF SUMMARY OF THE INVENTION

The present invention provides a non-invasive optical sensor which uses the motion signal to calculate the physiological characteristic being measured. For pulse oximetry, a least squares or a ratio-of-ratios technique can be applied to the slope of the motion signal itself. This is made possible by selecting a site on the patient where motion produces signals at two wavelengths which are adequately correlated with each other. Adequately correlated signals have a "closed" or "nearly closed" Lissajous. In particular, it has been determined that a sensor placed on a nail, in particular a thumbnail, exhibits the characteristics of having the red and infrared signals in phase when used for pulse oximetry.

The present invention also provides an optical sensor which fits entirely on a nail. No adhesive or other securing mechanism around the rest of the finger is necessary, resulting in the entire sensor moving with the nail. The use of the nail site reduces the likelihood of out-of-phase motion signals for red and infrared wavelengths, and takes advantage of the predominantly arterial blood saturation characteristic of the blood present beneath the nail. In addition, the nail is an advantageous surface for adhering the sensor to, and at this location the method of attachment allows a low profile, low mass sensor to be used which further limits differential phase errors due to motion.

Preferably, the sensor on a nail of the present invention is a reflectance-type sensor. In one embodiment, a closer spacing is used than in typical prior art sensors, preferably less than 5 mm, more preferably approximately 4 mm. It has been empirically determined that the physiological characteristics at a nail site produce an improved signal with closer spacing. In addition, the sensor preferably has a curvature which conforms to the shape of the nail, and is attached with an adhesive.

In alternate embodiments of the invention, artificial motion may be induced with an air bag or otherwise to produce a motion signal which can be used with the sensor of the invention. In particular, this could be used for patients with low perfusion, a weak heartbeat or no heartbeat such as is the case during heart bypass surgery.

For a further understanding of the nature and advantages of the invention, reference should be made to the following description taken in conjunction with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a graph of the log of the infrared and red intensity signals for pulse oximeters.

FIG. **2** is a graph of the red and IR signals showing correlation.

FIG. **3** is a diagram of the different average paths of different wavelength light through a patient.

FIG. **4** is a perspective view of a nail sensor according to the present invention on a thumb.

FIG. **5** is a cross-sectional, cutaway view of a thumb showing its components.

FIG. **6** is a end, cutaway view of one embodiment of a conformable nail sensor according to the present invention.

FIG. **7** is a diagram of a sensor according to the present invention placed longitudinally to span the lunula of the nail.

FIGS. **8**A-**8**D are Lissajous plots of the output of a sensor according to the invention with and without motion, and at low and high saturation.

FIG. **9**A is a plot of the red and infrared frequency distribution (FFT of time signals) showing experimental results from a thumbnail sensor according to the invention.

FIG. **9**B is a plot of the Lissajous for the results of FIG. **9**A.

FIG. **10** is a graph showing a plot of oxygen saturation readings of a sensor according to the present invention compared to a standard prior art sensor.

FIGS. **11**A and **11**B compare the prior art sensor and the present invention. The output waveforms and Lissajous plot are shown for each.

FIG. **12** is a diagram of an alternate embodiment of the invention showing a combination reflective and transmissive sensor.

FIG. **13** is a diagram of an alternate embodiment of the invention showing a self-contained nail sensor with its own display.

FIG. **14** is a diagram of a nail sensor with a motion inducing mechanism according to the present invention.

FIGS. **15** and **16** are top and side views of the motion stimulating mechanism of FIG. **14**.

FIG. **17** is a flowchart of one embodiment of a program for responding to whether motion or a cardiac pulse is used for calculating saturation.

FIG. **18** is a block diagram of one embodiment of portions of an oximeter using controlled generation of motion.

FIG. **19** is a diagram of an embodiment of the sensor using a cylindrical lens and a tinted adhesive.

## DETAILED DESCRIPTION OF THE INVENTION

FIG. **4** illustrates a sensor **40** according to the present invention preferably mounted on a nail **42** (a thumbnail or any other digit may be used). The sensor is held on with adhesive, and has an emitter **44** and a detector **46**. A flexible circuit **48** provides the electrical connections to the emitter and detector, and may be accordion-shaped between the sensor and a securing band **50** to provide additional strain relief. This isolates the sensor from tugging or pulling on the electrical connection cord from either the sensor side or the other direction. Band **50** may be, for instance, an elastic band, cloth wrap secured with Velcro™, or another device. Flexible circuit **48** could be electrical wires or fiber optic cables. The different wavelength light could be premixed using the fiber optic cable.

The placement on the top of the nail allows the cable to extend along the top of the finger or other digit, without the sensor or the cable being on the palmar side of the digit where it would interfere with grasping or other functionality of the hand.

As can be seen, the emitter **44** and detector **46** are arranged laterally across the width of the nail. However, a longitudinal arrangement (discussed more fully below) or any other arrangement on a nail is possible. The spacing of the emitter and detector may be varied, but an optimum spacing was experimentally found to be less than 10 mm, preferably less than 5 mm, more preferably approximately 4 mm.

The nailbed makes a good site for the sensor because it has been observed that motion generates artifact signals for the red and infrared wavelengths that are largely correlated to one another. The inventors have observed that this results in a ratio-of-ratios (or least squares) which correlates well with the arterial oxygen saturation.

Referring to FIG. **5**, a cross-sectional view of the thumb is shown. As can be seen, the thumb includes a bone **52** with a thin layer of connective tissue **54** between the bone and thumbnail **56**. A number of characteristics may contribute to the improved signal and the motion induced artifact being in phase. The different wavelength paths illustrated in FIG. **3** may be limited by the presence of bone **52**, preventing one of the wavelengths from going deeper into tissue and having a different distance to travel. This effect is provided by the selection of the thumbnail as a site, and the use of reflectance oximeter sensor as opposed to a transmissive sensor. In a transmissive sensor, light would have to travel around the bone deep through the tissue, and the red and infrared may travel different lengths and be affected differently by motion.

Connective tissue layer **54** is thin and apparently strongly connective. Thus, the expansion and compression of tissues, particularly fatty tissues, which may cause out of phase motion artifacts for other sites and types of sensors, is apparently greatly reduced here. Because the thumbnail **56** itself provides a strong mounting platform, the sensor can be securely attached to it with adhesive, avoiding the emitter and detector from separating from the patient and causing gaps that may cause corrupt ratio-of-ratio values.

The region beneath nail **56** also provides a region which appears to be concentrated with oxygen saturated blood similar to the saturation of arterial blood. Oxygen consumption beneath the nail appears to be small relative to the circulation there, or the relative volume of venous blood may be negligibly small.

The presence of many small capillaries, rather than large vessels, makes the region more homogeneous, and thus lessens the likelihood that two different light wavelengths would be affected differently by passing through differing regions. In the absence of motion, the high perfusion allows a normal pulse oximetry reading to be made. During the occurrence of motion, the large amount of blood present allows a strong motion signal to be obtained, since a lot of blood is moved around by the motion. In experiments conducted by the inventors, motion artifact signals greater than 50 times that of a normal pulsatile plethysmogram signal have been observed. The nail site also appears to have a nailbed-tissue boundary that is optically phase-matched for the wavelengths of the sensor.

In addition to measuring oxygen saturation, the nailbed is a good site for other optical sensors. For example, glucose detection which requires the use of a near infrared wavelength could be used. Among the blood properties or constituents that can be measured are blood gases ($CO_2$, $O_2$), pH, glucose, drug concentrations, or other analytes (THb, Hct, lactate, $K^+$, $Na^+$, $Ca_2^+$, etc.).

FIG. **6** is an end, cutaway view of one embodiment of a sensor **40** according to the present invention. Emitter **44** and detector **46** are shown mounted on a flexible circuit board **60**. An electrical cord **62** provides the connection to the electrical components of circuit board **60**. The body of the sensor is preferably a semi-rigid piece of black poron foam. A metal strip could be imbedded to give extra rigidity. An adhesive is attached to underside **64** of the sensor to attach it securely to the nail. The underside is also curved to conform to the shape of the nail, but is slightly flexible to allow adaptation to differing nail shapes. Different curvature sensors could be provided for different sizes and shapes of nails to provide optimum fit, or the bottom surface could be fabricated from a softer, more conforming material.

One characteristic of the nail as a site is that the nail itself could act as a light pipe, shunting light between the emitter and the detector. Preferably, the light travels through the tissue beneath the nail along a path **66**. However, some light could bounce back and forth through the nail itself on a path **68** between the emitter and detector in a manner not unlike a waveguide. To limit this shunting, the sensor body is made to absorb light, or at least the region between the emitter and detector is made at least partially absorbing to the wavelengths of interest. In this way, each time light strikes the side of the nail adjacent the absorbing layer, it will be absorbed, rather than propagating along the nail.

Shunting can also be limited by recessing the emitter and detector and providing a narrow numerical aperture. Because of the rigidity of the sensor body, recessing will not produce variations in distance during motion. By limiting the numerical aperture of the emitter and detector to values less than 0.9,

preferably to values less than 0.5, the emitter will not directly launch light into the nail "waveguide," and light which does potentially travel path **68** will be outside the acceptance angle of the detector.

The nail also provides advantages for adhering the sensor to the patient since the nail does not have the quantity of oils or sweat as present on the skin.

FIG. **7** is a diagram of a sensor **700** arranged longitudinally along a nail **706**. The sensor has an emitter **702** and a detector **704** which are not both on the lunula of the nail. The lunula is the light colored area of the nail below line **708** in FIG. **7**. It is believed that if both the emitter and detector are located on the lunula, more undesirable shunting of light will occur.

FIG. **8** has FIGS. **8**A-**8**D which show the Lissajous plots and calculated saturations for a sensor according to the present invention during four conditions: motion and no motion at high and low saturation. As can be seen in FIGS. **8**A and **8**B at high saturation, the calculated saturation 100% is equivalent with or without motion. In FIG. **8**B, the motion signal is seen to be more than 10 times larger than the cardiac signal of FIG. **8**A (FIGS. **8**A and **8**C are magnified by 10). Similar results occur at low saturation as seen in FIGS. **8**C and **8**D where the saturation values are calculated to be 70% under both conditions.

FIG. **9**A is a graph of the frequency distribution of the detected red and infrared signals for a sensor of the present invention in an experiment with an 8 Hz artificial motion pulse applied. The cardiac signature can be seen at the lower frequencies below 5 Hz, while the 8 Hz driven motion signal is also visible. FIG. **9**B is a graph of the red versus infrared intensity signals for the experiment illustrating that both signals are correlated and representative of the same saturation.

FIG. **10** illustrates the oxygen saturation readings of a sensor according to the present invention in experimental tests without motion comparing it with a standard prior art transmissive sensor at another site. A close agreement was noted, indicating the calibration of this sensor on the nailbed site is similar to a conventional transmission sensor.

FIGS. **11**A and **11**B show a comparison of the output waveform and Lissajous, in the presence of motion, of a sensor according to the present invention (FIG. **11**B) with a standard prior art transmissive sensor at another site (FIG. **11**A).

FIG. **12** illustrates an alternate embodiment of the present invention in which a nail sensor **70** according to the present invention is attached via a flexible circuit **72** to a transmissive sensor **74** which wraps around the finger and has an emitter **76** and detector **78** positioned on top and on the bottom of the finger. Such a combination sensor could allow the oximeter monitor with its program to choose between the sensors depending upon motion conditions. When motion is present, nail sensor **70** could be used, and when motion is not present, sensor **74**, which may be more sensitive to the cardiac pulse signal, could be used. Alternately, a single pair of red and infrared emitters could be used, with a reflectance detector on the nail, and a transmissive detector off the nail. Depending on the mode, a switch in the sensor, or in an intermediate amplifier module, or in the oximeter monitor could select between the detectors. In another embodiment, a single detector is used, with one pair of emitters on the nail, and another pair of emitters off the nail. Alternately, a completely separate transmissive sensor could be used.

In some patients, in particular those with low blood perfusion, it may be difficult to lock onto a pulse waveform. The additional transmissive sensor could be used to enable locking on for such patients. In addition, a transmissive sensor could be used to calibrate the nail sensor "on-the-fly." Because of shunting and other unique aspects of the nail site, a predetermined calibration may be off. A measurement of saturation using the transmissive and the nail reflectance sensors could be done in the absence of motion, with a correction factor applied to the reflectance sensor. The correction could be a constant which is added or a multiplicative factor, or both. If measurements are done at different saturations, a calibration line or curve could be determined by the oximeter to allow adjustments anywhere along the calculated curve. Subsequently, in the presence of motion, the nail sensor will be more accurately calibrated.

FIG. **13** illustrates an alternate embodiment of the invention in which a self-contained sensor **80** according to the present invention includes the processing circuitry on one or more semiconductor chips inside, and has its own display **82**, which may be a liquid crystal display, for instance. In one embodiment, a button **84** allows switching between modes, such as between displaying a pulse and oxygen saturation. In an alternate embodiment, a flex connection **86** to a module **88** attached on a band **90** may be used. Module **88** might contain the battery, or alternately the processing circuitry, or the display. Additionally, either embodiment could be used for a wireless transmission to an oximeter, with the transmitting circuit either being in module **88** or sensor body **80**.

FIG. **14** illustrates another embodiment of the present invention in which a stimulator is used to generate an artificial pulse. A stimulator could electrically stimulate the nerves to cause motion of an appendage, or could use a pneumatic pressure cuff to stimulate an artificial pulse, or use electromechanical stimulation or any other mechanism which generates a pulse characteristically different (e.g., amplitude, frequency, shape, etc.) than the cardiac pulse so that the cardiac pulse need not be used. Such an apparatus would be particularly advantageous for patients with low blood perfusion or a weak heartbeat. FIG. **14** is one embodiment showing a sensor **92** mounted on a thumbnail, with an airbag **94** mounted to the bottom of the thumb and held in place with a band **96**. A hose **98** to the airbag periodically inflates and deflates it, causing a pressure wave through the thumb, giving artificially induced motion. This pressure induced motion provides the variation needed for sensor **92** to measure the oxygen saturation using either the ratio-of-ratios or a least squares technique. If the motion is in the frequency range of a heartbeat, the sensor can be backward compatible with existing oximeter monitors, even those that look for a cardiac signal.

FIG. **15** illustrates airbag **94** in a top view, showing hose **98** connected to a diaphragm pump **100**. FIG. **16** shows a side view of the airbag **94** of FIG. **15**, showing that it is wide but flat.

FIG. **17** is a flowchart of one embodiment of a portion of a program for operating an oximeter so that either cardiac pulses or motion pulses can be used to calculate oxygen saturation. The oxygen saturation is calculated in a known manner (step A). In a first alternative, the signal is analyzed to determine if it is a cardiac pulse or a motion pulse (step B). This can be done using any of the pulse qualification or motion detection techniques known to those of skill in the art. If a motion signal is present and used for the oxygen saturation calculation, then in step C only the oxygen saturation signal is displayed, and not a pulse rate (which would be a motion pulse rate, and not the patient's heart rate). If a cardiac pulse is used, the pulse rate is also displayed (step D).

Alternately, a pulse determination step E could be used where the sensor includes both a reflectance sensor and a transmittance sensor. If motion is present above a predetermined threshold (such as at least twice the arterial pulse

signal), the reflectance sensor is used, which uses the motion signal, and alters any motion filtering or motion reduction techniques (step F). If the motion signal is below the threshold, the transmittance sensor is used (step G), with standard motion reduction techniques being employed (either hardware or software or both).

Both sensors could be energized in an ongoing manner, and the saturation and rate could be chosen to come from the sensor considered most reliable, depending on the instrument's assessment of motion. Simultaneous computation may further allow improved processed signal estimates of cardiac rate in the presence of motion given knowledge of estimated saturation.

FIG. **18** is a block diagram of a portion of a pulse oximeter monitor used in conjunction with an artificial pulse generator, such as shown in FIGS. **14-16**. A frequency generator **110** produces a desired frequency for the motion pulse. This could be varied to give a frequency which is not interfered with by other noise, or frequency hopping could be used to isolate the signal from other sources of motion or noise. A pump controller **112** activates a pump or motor **100** (FIG. **12**) at the generated frequency. Since the driven frequency is known, optionally other frequencies could be filtered out to reduce noise. After a signal is captured and converted to digital form by a circuit **114**, a bandpass filter **116** is used to reduce other frequency signals. A control signal from frequency generator **110** could vary the bandpass frequency. A circuit or processor **118** then calculates the oxygen saturation. A central controller **120** controls the rest of the circuitry, including a sensor driver circuit **122**, which could selectively activate different reflectance and transmittance emitters in one embodiment. Controller **120** could also analyze the signals for the presence of motion to alternate between motion and cardiac pulse modes in one embodiment. Alternately, a separate motion sensor could provide an input to controller **120**. Note that other physical implementations are possible, such as using a single processor to do the filtering, the frequency generation and the oxygen saturation calculation.

A calibration resistor (or other active or passive element) **115** encodes the mean wavelength of at least one LED, and provides it to a calibration reader circuit or CPU **120**. The wavelength indicated is used to select coefficients stored in the monitor. Such a calibration technique is described in more detail in U.S. Pat. No. 4,621,643, the disclosure of which is incorporated herein by reference.

FIG. **19** is a cut-away view of an embodiment of a sensor **130** according to the invention. An emitter **132** is mounted on a circuit **134** inside the sensor housing. A cylindrical lens **136** is mounted in an aperture **138**. The lens directs the light down through the nail, minimizing the light which hits the nail at an angle and can be shunted to the detector. An aperture itself can perform the same function, but the lens insures that more of the light is used, maintaining a higher intensity at a given power, or allowing less power to be used. Detector **140** is recessed in an aperture **142** to avoid shunted light on the receiving end.

The sensor is secured to a nail **144** using an adhesive layer **146**. The adhesive layer can act as a shunt path itself. Accordingly, the adhesive layer may be tinted to be opaque to the wavelengths used, with preferably transparent windows **148** and **150** for the detector and emitter apertures.

As will be understood by those of skill in the art, the present invention could be embodied in other specific forms without departing from the spirit or essential characteristics thereof. For example, a sensor could be placed on a fingernail other than the thumb nail, and could be placed on toenails. Alternately, a sensor could be placed on the cuticle or the live nail fold skin extending over the beginning of the nail. The sensor could be attached with a clip-type sensor, or an elastic wrap, bandage or adhesive which encircles the appendage could be used. The sensor could be placed at locations other than the nailbed where signals at the multiple wavelengths in the presence of motion are still adequately correlated. The emitter in the sensor could be fabricated using an optical fiber to carry the light from a source remotely located, and equivalently the detector could be an optical light guide to pipe the light to a remote detector. Accordingly, reference should be made to the following claims which set forth the scope of the invention.

What is claimed is:

**1**. A photometric processing device for processing detector signals from a radiation detector in a patient sensor also having a radiation emitter, comprising:

a first processing unit configured to determine a blood parameter from a cardiac signal derived plethysmogram from the detector;

a second processing unit configured to determine the blood parameter from a motion artifact waveform from the detector; and

a control unit configured to utilize the first and second processing units responsive to a motion artifact content of the detector signals.

**2**. The photometric processing device of claim **1** further comprising a processor and a memory, wherein the first and second processing units and the control unit are first, second and third programs stored in the memory.

**3**. The photometric processing device of claim **1** further comprising a selector configured to select between a reflectance mode and a transmittance mode of the sensor.

**4**. The photometric processing device of claim **3** wherein the control unit is further configured to switch between the first and second processing units in accordance with a selection of the selector.

**5**. The photometric processing device of claim **4** wherein the selector is responsive to the motion artifact content of the detector signals.

**6**. The photometric processing device of claim **1** wherein the radiation emitter emits and the radiation detector detects radiation at two or more wavelengths, wherein the detector signals at the two or more wavelengths are correlated in the presence of motion.

**7**. The photometric processing device of claim **6** wherein the detector signals produce a closed Lissajous.

**8**. The photometric processing device of claim **1** wherein the detector signals are generated in response to at least two wavelengths and are correlated in the presence of non-cardiac pulses.

**9**. The photometric processing device of claim **8** wherein the detector signals include predominately motion-induced variations and the sensor is configured to be placed on a nail on a digit.

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| 专利名称(译) | 运动兼容传感器，用于非侵入式光学血液分析 | | |
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| [标]申请(专利权)人(译) | 内尔科尔普里坦贝内特公司 | | |
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摘要(译)

一种非侵入式光学传感器，其使用运动信号来计算被测量的生理特征。对于脉搏血氧测定法，可以将最小二乘法或比率比技术应用于运动信号本身。这可以通过选择患者的位置来实现，其中运动的变化产生两个充分相关的波长的信号。特别地，已经确定放置在指甲上的传感器，特别是缩略图，表现出当用于脉搏血氧测定时具有相关的红色和红外信号的特性，并且所得到的信号与动脉血氧饱和度相关。