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(54) **APPARATUS FOR REMOVING MOTION ARTIFACTS FROM MEASUREMENTS OF BODILY PARAMETERS**

APPARAT ZUR ENTFERNUNG VON BEWEGUNGS-ARTEFAKTEN VON
KÖRPERPARAMETERMESSUNGEN

APPAREIL D'ELIMINATION D'ARTEFACTS DUS AU MOUVEMENT A PARTIR DE MESURES DE
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Description

TECHNICAL FIELD

[0001] This invention relates to the field of signal processing. More particularly, this invention relates to processing measured signals to remove unwanted signal components caused by noise and especially noise caused by motion artifacts.

BACKGROUND

[0002] The measurement of physiological signals can often be difficult because the underlying physiological processes may generate very low level signals. Furthermore, interfering noise is inherent in the body and the interface between the body and sensors of physiological processes. Examples of physiological measurements include: measurement of electrocardiogram (ECG) signals based on the electrical depolarization of the heart muscle, blood pressure, blood oxygen saturation, partial pressure of CO₂, heart rate, respiration rate, and depth of anesthesia. ECG signals, for example, are typically detected by surface electrodes mounted on the chest of a patient. ECG signals are weak at the signal source (*i.e.*, the heart) and are even weaker at the surface of the chest. Furthermore, electrical interference from the activity of other muscles (*e.g.*, noise caused by patient breathing, general movement, etc.) causes additional interference with physiological signals such as an ECG. Thus, considerable care must be taken in the design and use of physiological processors to enhance the quality of the true signal and reduce the effects of interfering noise signals.

[0003] It is convenient to characterize a measured signal as being a composite signal composed of a true signal component and a noise signal component. The terms "measured signal" and "composite signal" will be used interchangeably hereinafter. Signal processors are frequently used to remove noise signal components from a composite measured signal in order to obtain a signal that closely, if not identically, represents the true signal. Conventional filtering techniques such as low pass, band pass, and high pass filtering can be used to remove noise signal components from the measured composite signal where the noise signal component occupies a frequency range outside the true signal component. More sophisticated techniques for conventional noise filtering include multiple notch filters, which are suitable for use where the noise signal component exists at multiple, distinct frequencies, all outside the true signal frequency band.

[0004] However, it is often the case that the frequency spectrum of the true and noise signal components overlap and that the statistical properties of both signal components change with time. More importantly, there are many cases where little is known about the noise signal component. In such cases, conventional filtering techniques may be ineffective in extracting the true signal.

[0005] The measurement of oxygen saturation in the blood of a patient is a common physiological measurement, the accuracy of which may be compromised by the presence of noise. Knowledge of blood oxygen saturation can be critical during surgery. There are means of obtaining blood oxygen saturation by invasive techniques, such as extracting and testing blood removed from a patient using a co-oximeter. But, such invasive means are typically time consuming, expensive, and uncomfortable for the patient. Fortunately, non-invasive measurements of blood oxygen saturation can be made using known properties of energy attenuation as a selected form of energy passes through a bodily medium. Such non-invasive measurements are performed routinely with a pulse oximeter.

[0006] The basic idea behind energy attenuation measurements as employed in pulse oximetry is as follows. Radiant energy is directed toward a bodily medium, where the medium is derived from or contained within a patient, and the amplitude of the energy transmitted through or reflected from the medium is then measured. The amount of attenuation of the incident energy caused by the medium is strongly dependent on the thickness and composition of the medium through which the energy must pass, as well as the specific form of energy selected. Information about a physiological system can be derived from data taken from the attenuated signal of the incident energy transmitted or reflected. However, the accuracy of such information is reduced where the measured signal includes noise. Furthermore, non-invasive measurements often do not afford the opportunity to selectively observe the interference causing the noise signal component, making it difficult to remove.

[0007] A pulse oximeter is one example of a physiological monitoring system that is based upon the measurement of energy attenuated by biological tissues and substances. More specifically, a pulse oximeter measures the variable absorption caused by blood volume changes, primarily arterial in origin. Pulse oximeters transmit electromagnetic energy at two different wavelengths, for example at 660 nm (red) and 940 nm (infrared, hereinafter IR) into the tissue and measure the attenuation of the energy as a function of time. The output signal of a pulse oximeter is sensitive to the pulsatile portion of the arterial blood flow and contains a component that is a waveform representative of the patient's arterial pulse. This type of signal, which contains a component related to the patient's pulse, is called a plethysmographic waveform or plethysmogram.

[0008] The period of rhythmic contraction of the heart by which blood is driven through the aorta and pulmonary

artery is known as systole. Maximum light absorbance occurs during the systole of a cardiac cycle and is indicated on a plethysmogram by a low point or systolic valley. Conversely, the period of rhythmic relaxation and dilation of the heart cavities occurs during diastole when blood is drawn into the heart cavities. Minimum light absorbance occurs during the diastole of a cardiac cycle and is indicated on a plethysmogram by a high point or diastolic peak.

[0009] Pulse oximetry measurements typically use a digit, such as a finger, or an ear lobe or other element of the body, where blood flows close to the skin as the medium through which light energy is transmitted. The finger, for example, is composed of various tissues and substances including skin, fat, bone, muscle, blood, etc. The extent to which each of these biological tissues and substances attenuate incident electromagnetic energy is generally known. However, the effect of motion can cause changes in the optical coupling of the sensor (or probe) to the finger, the underlying physiology, the local vasculature, optical properties of tissues due to changing optical path length as well as combinations and interactions of the all of the above. Thus, patient motion may cause erratic energy attenuation.

[0010] A typical pulse oximeter includes a sensor, cabling from the sensor to a computer for signal processing and visual display, the computer and visual display typically being included in a patient monitor. The sensor typically includes two light emitting diodes (LEDs) placed across a finger tip and a photodetector on the side opposite the LEDs. The detector measures both transmitted light signals once they have passed through the finger. The signals are routed to a computer for analysis and display of the various parameters measured.

[0011] The underlying physical basis of a pulse oximeter is Beer's law (also referred to as Beer-Lambert's or Bouguer's law) that describes attenuation of monochromatic light traveling through a uniform medium that absorbs light with the equation:

$$I_{transmitted} = I_{incident} \cdot e^{-dc\alpha(\lambda)}, \quad (1)$$

where $I_{transmitted}$ is the intensity of the light transmitted through the uniform medium, $I_{incident}$ is the intensity of incident light, d is the distance light is transmitted through the uniform medium, c is the concentration of the absorbing substance in the uniform medium, expressed in units of mmol L⁻¹, and $\alpha(\lambda)$ is the extinction or absorption coefficient of the absorbing substance at wavelength λ , expressed in units of L/(mmol cm). The properties of Beer's law are valid even if more than one substance absorbs light in the medium. Each light absorbing substance contributes its part to the total absorbance. However, Beer's law does not strictly apply since an LED's output is not monochromatic and scattering effects do have a significant influence. Thus, manufacturers often utilize an empirically determined lookup table to map from the ratio of absorbance (or transmittance) at the red and IR frequencies to a saturation value.

[0012] Two LEDs emit narrowband light (*i.e.*, half power bandwidth of typically 15 nm) at two different frequency bands, typically red (centered at about 660 nm) and IR (centered at about 940 nm). The intensity of light transmitted through tissue, $I_{transmitted}$, is different for each wavelength of light emitted by the LEDs. Oxyhemoglobin (oxygenated blood) tends to absorb IR light, whereas deoxyhemoglobin (deoxygenated blood) tends to absorb red light. Thus, the absorption of IR light relative to the red light increases with oxyhemoglobin. The ratio of the absorption coefficients can be used to determine the oxygen saturation of the blood.

[0013] To estimate blood oxygen saturation, SpO_2 , a two-solute concentration is assumed. A measure of functional blood oxygen saturation level, SpO_2 , can be defined as:

$$SpO_2 = 100 \cdot \frac{c_0}{c_r + c_0}, \quad (2)$$

where c_0 represents oxyhemoglobin solute concentration, and c_r represents reduced or deoxyhemoglobin solute concentration.

[0014] Noise signal components in a measured pulse oximetry light signal can originate from both AC and DC sources. DC noise signal components may be caused by transmission of electromagnetic energy through tissues of relatively constant thickness within the body, *e.g.*, bone, muscle, skin, blood, etc. Such DC noise signal components may be easily removed with conventional filtering techniques. AC noise signal components may occur when tissues being measured are perturbed and, thus, change in thickness while a measurement is being made. Such AC noise signal components are difficult to remove with conventional filtering techniques. Since most materials in and derived from the body are easily compressed, the thickness of such matter changes if the patient moves during a non-invasive physiological measurement. Thus, patient movement can cause the properties of energy attenuation to vary erratically. The erratic or unpredictable nature of motion artifacts induced by noise signal components is a major obstacle in removing them.

[0015] Various approaches to removing motion artifacts from measured physiological signals, and particularly for

use in pulse oximeters, have been proposed. U.S. Patent Nos. 5,482,036, 5,490,505, 5,632,272, 5,685,299, 5,769,785 and 6,036,642, all to Diab et al., and U.S. Patent No. 5,919,134 to Diab, disclose methods and apparatuses for removing motion artifacts using adaptive noise cancellation techniques. The basic proposition behind these Diab et al. patents is to first generate a noise reference signal from the two measured signals, and then use the noise reference signal as an input to an adaptive noise canceller along with either or both of the measured signals to remove the reference noise signal from the measured signals, thus approximating the actual parametric signals of interest. These Diab et al. patents appear to require the use of both measured input signals to generate a noise reference signal. Where the adaptive noise cancellation involves the use of a correlation canceller as disclosed in U.S. Patent No. 5,482,036, addition problems include significant computational overhead and under certain circumstances, the correlation canceller will drive the output signal to zero.

[0016] Another approach to noise artifact elimination is disclosed in U.S. Patent No. 5,588,427 to Tien. Tien uses fractal dimension analysis to determine the complexity of waveforms in order to determine the proper value of the ratio of true intensities based on signal complexity. The Tien approach employs a fractal analyzer to determine values for two ratios, α and β , based on the measured time varying intensity of the transmitted red and IR light signals including noise. α is defined as the ratio of the time varying true intensity of light transmitted from the red LED and the time varying true intensity of the light transmitted from the IR LED. β is a similar ratio relating the noise introduced during the measurement of the light transmitted by the red LED and the noise introduced during the measurement of the light transmitted by the IR LED. According to Tien, a fractal analyzer then determines values for α and β and provides (α , β) pairs to a statistical analyzer. The statistical analyzer performs analysis of one or more (α , β) pairs to determine the best value for α , which is then provided to a look-up table. The look-up table provides a value corresponding to the arterial oxygen saturation in the patient. While the Tien approach appears to be an innovative use of fractal analysis, it also appears to be computationally complex.

[0017] Yet another approach to noise artifact elimination is disclosed in U.S. Patent Nos. 5,885,213, 5,713,355, 5,555,882 and 5,368,224, all to Richardson et al. The basic proposition behind the Richardson et al. approach is to switch operative frequencies periodically based on evaluating the noise level associated with various possible frequencies of operation in order to select the frequency of operation that has the lowest associated noise level. It would appear that data measured at a noisy frequency, using the Richardson et al. approach could be invalid or useless for calculating arterial oxygen saturation. Furthermore, Richardson et al. requires a computational overhead to constantly monitor which frequency of operation provides the least noise.

[0018] Another approach to noise artifact elimination is disclosed in U.S. Patent No. 5,853,364 to Baker, Jr. et al. The Baker, Jr. et al. approach first calculates the heart rate of the patient using an adaptive comb filter, power spectrum and pattern matching. Once the heart rate is determined, the oximetry data is adaptively comb filtered so that only energy at integer multiples of the heart rate are processed. The comb filtered data and the raw oximetry data are filtered using a Kalman filter to adaptively modify averaging weights and averaging times to attenuate motion artifact noise. The adaptive filtering of the Baker, Jr. et al. approach appears to add significant computational complexity to solve the problem of motion artifact rejection.

[0019] Still another approach to noise artifact elimination is disclosed in U.S. Patent No. 5,431,170 to Mathews. Mathews couples a conventional pulse oximeter light transmitter and receiver with a transducer responsive to movement or vibration of the body. The transducer provides an electrical signal varying according to the body movements or vibrations, which is relatively independent of the blood or other fluid flow pulsations. Mathews then provides means for comparing the light signals measured with the transducer output and performing adaptive noise cancellation. An apparent disadvantage of the Mathews approach is the need for a secondary sensor to detect motion.

[0020] Still yet another approach to noise artifact elimination is disclosed in International Application WO 9846126 and its counterpart, U.S. Patent No. 6,002,952 to Diab et al (hereinafter the '952 patent). Diab et al. recognizes the limitations of adaptive noise cancellation and particularly the use of a correlation canceller. The '952 patent discloses the use of frequency domain analysis to extract a pulse rate from oximetry data. According to the '952 patent, coupling coefficients related to ratios of uncontaminated measurement data and contaminated (noisy) measurement data can be determined from taking the ratios at each of a series of spectral peaks identified in the frequency domain. The '952 patent further discloses using the coupling coefficients to identify the presence of noise by calculating the difference between the largest and smallest ratio lines for all spectral peaks, determining whether that difference is greater than a pre-selected threshold and whether the frequencies associated with the largest and smallest spectral peaks are arbitrarily close or not to each other. Where noise is detected, a scale factor is used to scrub the measurement data by controlling the gain control input of a gain controlled amplifier. The scale factor is zero in the presence of no noise, and can range up to the largest ratio line where there is noise and the frequencies are not close together. However, the signal scrubbing disclosed in the '952 patent appears to rely on a very limited measure of noise, i.e., whether the difference between the largest and smallest ratio lines is greater than a pre-selected threshold and how close the associated frequencies of largest spectral peak and the smallest spectral peak are relative to one another. It would be preferable to have multiple confidence measures in a method or system for determining physiological parameters in

the presence of motion artifacts, *e.g.*, a robust pulse oximeter.

[0021] Another approach to noise artifact elimination is disclosed in European Patent Application EP0870466A1 to Kastle (hereinafter the '466 patent). The '466 patent discloses the use of frequency domain analysis to extract a pulse rate from oximetry data. According to the '466 patent, the Red and IR signals captured in the time domain are converted to the frequency domain, and then combined to form complex combinatorial values representing peak spectral values of the combined Red-IR signal, referred to in the '466 patent as "needles." The '466 patent discloses signal-processing algorithms to identify these needles. Once identified, a selection process attempts to distinguish useful signals from disturbance signals in order to eliminate the disturbance signals.

[0022] Thus, a need in the art exists for a method, apparatus and system to eliminate motion-induced noise artifacts from light signals, that is relatively simple computationally, and that does not require more than one sensor, does not use correlation cancellers or adaptive noise cancellation and that uses multiple measures of confidence to determine physiological parameters accurately.

DISCLOSURE OF INVENTION

[0023] The present invention includes apparatuses for removing noise in physiological measurements caused by motion or other similar artifacts. The apparatuses of the present invention may eliminate noise from light signals using a single conventional sensor and are relatively simple computationally.

[0024] In accordance with the present invention, there is provided apparatus for removing motion artifacts from electrical signals representative of alternated light signals, as defined in the appendant independent claim, to which reference should now be made. Embodiments of the present invention are defined in the appendant dependent claims, to which reference should also now be made.

BRIEF DESCRIPTION OF DRAWINGS

[0025] In the drawings, which illustrate what is currently regarded as the best mode for carrying out the invention and in which like reference numerals refer to like parts in different views or embodiments:

FIG. 1 is a high-level flowchart of a method embodiment of the invention.

FIG. 2 is two of graphs showing acquired IR and red data segments.

FIG. 3 is a graph of the power spectrum of the IR data segment in FIG. 2 in accordance with the invention.

FIG. 4 illustrates example graphs of measured IR and red data segments in accordance with the invention.

FIG. 5 is a graph of the frequency domain transformed IR signal from FIG. 4.

FIG. 6 illustrates three graphs of IR data after filtering with three different IR filters and segmented with vertical lines to show pulses and parameter calculations according to the invention.

FIG. 7 is a block diagram of a motion artifact rejection circuit card configured to remove noise artifacts from signals representing bodily parameters in accordance with the invention.

FIG. 8 is a block diagram of a pulse oximetry system including a motion artifact rejection circuit card capable of removing noise from pulse oximetry data in accordance with the invention.

FIG. 9 is a block diagram of a pulse oximetry system including a processor device programmed to remove noise from pulse oximetry data in accordance with the invention.

BEST MODES FOR CARRYING OUT THE INVENTION

[0026] The following detailed description discloses methods, apparatuses and systems for removing motion artifacts from measured plethysmographic waveforms, particularly, but without limitation, those used in pulse oximetry. A system described below includes pulse oximetry hardware and associated software to perform the motion artifact suppression. A method described below includes a series of steps that exploit certain characteristics of plethysmographic waveforms. The methods, apparatuses and systems described below are suitable for use with sensors employing light transmitted or reflected through bodily tissues and substances. For convenience, the following detailed description will assume measurement of light that has been transmitted through a finger of a human. The terms "signal" and "waveform" are used interchangeably herein.

[0027] FIG. 1 is a high-level flowchart of a method of removing motion artifacts from plethysmographic data and obtaining a measure of pulse rate and SpO₂ from that data. The method steps include acquiring segments of raw plethysmographic data 100, both a red data segment and an IR data segment, conditioning each segment of raw data for signal processing 110, transforming the conditioned data into the frequency domain 120, analyzing the frequency domain data for candidate spectral peaks 130, calculating selected parameters associated with the candidate spectral peaks 140, arbitrating between the candidate peaks based on the selected parameters to select a best frequency 150,

outputting pulse rate and median SpO₂ for the best frequency, if a best frequency was found 160, and repeating these steps for new raw data segments 170, as required. The method is applied to both red and IR data signals to eliminate or reduce noise from the data signals prior to outputting pulse rate and SpO₂. Both pulse rate and median SpO₂ may be output for valid best frequencies.

[0028] The method begins with acquiring a segment of data (e.g., five or more pulses or approximately ten seconds) measured from a single light source transmitted through a finger and detected with a sensor on the opposite side of the finger. Acquiring a data segment is depicted by block 100 of FIG. 1. FIG. 2 illustrates sample segments of IR and red data acquired according to block 100 of FIG. 1. The horizontal axis of FIG. 2 is measured in units of time, and specifically here in seconds. The vertical axis of FIG. 2 is measured in arbitrary units, and specifically here in analog-to-digital output units. For convenience, a 10.24 second segment of data will be used to illustrate the method. A 10.24 second segment of data corresponds to 1024 data points with a sampling rate of 100 data points per second. It should be readily apparent to one of ordinary skill in the art that the method of the invention is not limited to data segments of this size. The signal processing steps described herein may be performed on both red and IR data segments independently and simultaneously. Thus, while the steps of the method may be illustrated with data from an IR light signal, the same steps are applicable to data from a red light signal and vice versa. The terms "data segment", "input waveform", "data signal" and "signal" are used interchangeably herein.

[0029] A segment of data may be received from a sensor that converts transmitted or reflected light signals into electrical signals. U.S. Patent Nos. 5,190,038, 5,398,680, 5,448,991 and 5,820,550 to Polson et al., the disclosures of each of which are incorporated herein by reference, disclose and claim electronic systems for receiving red and IR data from a sensor, pre-conditioning the electrical signals and then converting the pre-conditioned electrical signals into digital data using an analog-to-digital converter for subsequent digital signal processing. The raw red and IR waveforms may be sampled at any convenient data rate. However, for simplicity of illustration, a sampling rate of 100 Hz will be assumed. Additionally, pulse rate and SpO₂ may be calculated on any convenient periodic or non-periodic basis. However, again for simplicity, we will assume that pulse rate and SpO₂ are calculated on a periodic basis every ½ second.

[0030] Once a segment of data from a single electrical signal (i.e., Red or IR) has been acquired and digitized, it may be conditioned for subsequent signal processing as depicted by block 110 of FIG. 1. Signal conditioning may include filtering to reduce spectral leakage resulting from subsequent frequency analysis. There are several window filters that may be suitable for such purposes. For example, and not by way of limitation, a Hanning window may be used to reduce spectral leakage. It will be readily apparent to one of ordinary skill in the art of digital signal processing that other window filters and methods of filtering data to reduce spectral leakage may be selected. As such methods of filtering and various filters are known to one of ordinary skill in the art of signal processing, they will not be further detailed herein. FIG. 3 illustrates the power spectrum of the IR data segment of FIG. 2 after filtering. The vertical axis of FIG. 3 may be measured in any arbitrary units of power. The horizontal axis is measured in any units of frequency, specifically here in units of bpm.

[0031] The conditioned data is then transformed into the frequency domain for further analysis and signal processing, see block 120 of FIG. 1. Signal processing as described herein is generally performed in the frequency domain. The segment of data is converted into the frequency domain by, for example, performing the conventional Fast Fourier Transform (FFT) on the data segment. FIG. 3 is a graph of the FFT of the IR data segment of FIG. 2. FIG. 3 illustrates a primary candidate peak at a frequency of approximately 70 bpm and a secondary candidate peak at a frequency of approximately 128 bpm. Other common techniques of converting time-domain data to the frequency domain may also be used, e.g., classical methods using the FFT such as the periodogram or correlogram, autoregressive methods, Prony's method, minimum variance methods, maximum likelihood methods. Additionally, time domain data may be converted to the frequency domain using transforms such as discrete cosine transform, wavelet transform, discrete Hartley transform, and Gabor transform. The preferred transform according to this method is the FFT with a window size of 1024 points. The 1024 data points are placed in a buffer, the FFT buffer. The FFT transforms the 1024 points of data from the time domain into the frequency domain. The output of the FFT is 512 points of real and 512 points of imaginary data in the frequency domain. From these 512 points of real and 512 points of imaginary data the power spectrum is calculated and placed in a power spectrum buffer.

[0032] Both transient and periodic noise artifacts can induce peaks in the frequency domain that may be larger than the peak associated with the patient's heart rate. The frequency peak that actually represents the patient's heart rate (best frequency) must then be determined. Analyzing the power spectrum peaks to determine candidate spectral peaks is depicted in block 130 of FIG. 1. One approach to determining the best frequency would be to order the frequencies by peak amplitude from largest to smallest, F_1 to F_n , where F_1 through F_n are not harmonics of each other, and analyze them one by one to find the correct frequency, i.e., the patient's heart rate. However, the preferred method selects up to three candidate spectral peaks for further analysis.

[0033] The function of block 130 is to locate candidate spectral peaks from the power spectrum computed in block 120. The power spectrum buffer is an array of 512 vector points (referred to herein as "bins") in the frequency domain.

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Each array element in the power spectrum buffer represents the power of the corresponding frequency in the original raw data waveform. Of the 512 bins, only bins 5 (29 bpm) through 43 (252 bpm) are of interest, since this range covers the physiological limits of the human heart rate. All other bins are unused by the method of the invention because they cannot physiologically represent a valid spectral frequency of a pulse rate. Table 1, below, shows the first 45 points of the power spectrum array.

Table 1

Power Spectrum Buffer	Frequency (Hz)	Pulse Rate (bpm)
bin number n	$f = n * 100/1024$	Pulse Rate = $f * 60$
0	0.00000	0.0
1	0.09766	5.9
2	0.19531	11.7
3	0.29297	17.6
4	0.39063	23.4
5	0.48828	29.3
6	0.58594	35.2
7	0.68359	41.0
8	0.78125	46.9
9	0.87891	52.7
10	0.97656	58.6
11	1.07422	64.5
12	1.17188	70.3
13	1.26953	76.2
14	1.36719	82.0
15	1.46484	87.9
16	1.56250	93.8
17	1.66016	99.6
18	1.75781	105.5
19	1.85547	111.3
20	1.95313	117.2
21	2.05078	123.0
22	2.14844	128.9
23	2.24609	134.8
24	2.34375	140.6
25	2.44141	146.5
26	2.53906	152.3
27	2.63672	158.2
28	2.73438	164.1
29	2.83203	169.9
30	2.92969	175.8
31	3.02734	181.6
32	3.12500	187.5

Table 1 (continued)

Power Spectrum Buffer	Frequency (Hz)	Pulse Rate (bpm)
bin number n	$f = n * 100/1024$	Pulse Rate = $f * 60$
33	3.22266	193.4
34	3.32031	199.2
35	3.41797	205.1
36	3.51563	210.9
37	3.61328	216.8
38	3.71094	222.7
39	3.80859	228.5
40	3.90625	234.4
41	4.00391	240.2
42	4.10156	246.1
43	4.19922	252.0
44	4.29688	257.8

[0034] In table 1, column 1 is the bin number, n ; column 2 is the center frequency, f , of the corresponding bin number, n , calculated as the product of the bin number and sampling rate (100 samples/sec) divided by the block size used by the FFT (*i.e.*, 1024); and column 3 is the pulse rate corresponding to the center frequency, f , of column 2, calculated by multiplying f (measured in units of beats per second) by 60 to convert to units of beats per minute.

[0035] In order to select candidate peaks (and corresponding frequencies), different amplitude analysis methods are applied to different frequency bands. The amplitude of adjacent and nearby frequency components of the candidate peak amplitude may be compared in terms of their absolute or relative values. For example, the frequencies represented by candidate bins 5 through 10 ("5-10" search method) may be stepped through in a sequential fashion. According to the "5-10" search method, a candidate bin is assumed to be a candidate power spectrum peak if the previous three bins and subsequent four bins relative to a candidate bin are all lower in power than the candidate bin. For example, in order for bin 6 to be a candidate spectral peak, bins 3, 4, 5, 7, 8, 9 and 10 must all be lower in power than bin 6. The terms "spectral peak", "power peak", or simply "peak" are used synonymously herein. Various amplitude, shape, syntactic or other pattern analysis methods may be applied to identify a candidate peak. Also, multiple curve fit methods, as known to one of ordinary skill in the spectroscopic analysis, may also be applied.

[0036] Once all possible power spectrum peak candidates are found, predetermined criteria are applied to select, at most, three candidate spectral peaks. First, the power peak associated with the largest power amplitude is selected to be the primary candidate peak. Then, any power peaks that are determined to be harmonics of the primary candidate power peak are eliminated. According to the method, a harmonic is defined as any power peak the frequency of which is a multiple of the primary peak, ± 1 bin, and the amplitude of which is less than half the maximum allowed power of the previous harmonic, or in the case of the first harmonic, less than half the power of the primary peak. For example, assume a primary candidate peak is found at bin 10. Possible harmonic bins of 10 are bins 19-21, 29-31 and 39-41. Continuing with the example, if the primary power peak amplitude (bin 10) is 100 arbitrary power spectrum units, then bins 19-21 must be less than 50 units to be deemed a harmonic, bins 29-31 must be less than 25 units and bins 39-41 must be less than about 12 units, where units are the measure of the amplitude of the power spectrum. Other weights may be applied to the analysis of the sequence for detection of harmonics of the candidate spectral peak without departing from the scope of the invention.

[0037] After harmonics of the primary candidate peak are eliminated, the next largest remaining power peak found (if any) is selected to be the secondary candidate peak. Finally, if the previous pulse rate is non-zero, the power spectrum corresponding to the previous pulse rate is determined. If the bin corresponding to the previous pulse rate is not equal to the primary or secondary candidate power peak, then the bin corresponding to the previous pulse rate is selected to be the tertiary candidate peak. Thus, up to three candidate peaks (primary, secondary and tertiary) and corresponding frequencies of each candidate peak are identified in block 130 of FIG. 1.

[0038] Block 140 of FIG. 1 depicts calculating selected parameters associated with the candidate peaks identified in block 130. Block 140 may include pulse window filtering, and calculating such parameters as peak detection, pulse rejection criteria and descriptive parameters associated with each of the up to three candidate power peaks found from

block 130. These parameters are used to determine a pulse confidence for each candidate peak. The parameters calculated according to the invention for each filtered candidate peak include measures of central tendency and variability of pulse width, pulse rate and SpO₂, as well as measures of the history and confidence of these parameters. The preferred embodiment includes parameters such as: (1) *Window Pulse Rate*, (2) *Pulse Width Variability*, (3) *SpO₂ Variability*, (4) *Pulse Window SpO₂*, (5) *Pulse Peak Amplitude Variability*, (6) *Pulse Rate History Percentage*, and (7) *Pulse Window Confidence*. It should be noted that other parameters including, but not limited to, other measures of central tendency, variability (*i.e.*, skewness, kurtosis), history/trend and confidence, could be calculated from the candidate power peaks without departing from the scope of the invention. Each of the parameters listed is discussed in greater detail below, beginning with pulse window filtering.

[0039] Prior to calculating the aforementioned parameters, each candidate peak is filtered with a narrow band filter, such as a bandpass, finite impulse response (FIR) filter. In one aspect of the present invention, one of several predefined FIR filters is applied to a given bin or candidate peak. The peak frequencies of the filters may be separated by a fixed difference in frequency (measured in Hz or bpm), such as 25 bpm, or may be variable and a function of either frequency or a characteristic of the spectrum, for example variability or noise, or both. For example, if a candidate peak was found at bin 12, a filter with center or peak frequency of 76.2 bpm might be chosen. A fixed difference in frequency may be in a range from about 15 bpm to about 40 bpm. Likewise, a variable difference in frequency may be in a range from about 15 bpm to about 40 bpm.

[0040] Preferably, to improve discrimination, especially with closely spaced peaks, the bandpass filter coefficients may be stored or generated and adjusted as needed so that the center frequency is nearly identical to the candidate frequency. Additionally, other filtering methods such as (a) other types of bandpass filters, *i.e.*, infinite impulse response (IIR) filters, and (b) frequency domain methods such as transforming the data into the frequency domain (for example, FFT), filtering or eliminating unwanted components in the frequency domain and transforming back into the time domain (for example, inverse FFT) for further signal processing, may be applied.

[0041] Once the up to three peak candidates are selected and filtered, a peak detector algorithm is applied to each of the up to three candidate peaks in the time domain. The function of the peak detector algorithm is to identify power spectrum peaks in each of the filtered time domain data segments and their associated center frequencies. The terms "window" and "pulse window" are used interchangeably with "time domain data segment" herein. For each peak found in the time domain, the pulse width is calculated as the time between each peak. The *Window Pulse Rate* is calculated by dividing the sum of the pulse width time of all peaks by the number of peaks detected.

[0042] *Pulse Width Variability*, a measure of how consistent the pulse width is for all the peaks in a given pulse window, is calculated according to the present invention. With the exception of subjects presenting cardiac arrhythmias, particularly ventricular arrhythmias, the variability of the pulse width of all the peaks should be low within a short time interval such as a 10.24 second window. Higher pulse width variability often is an indication of either (a) cardiac arrhythmias or (b) physiological artifacts such as motion. *Pulse Width Variability* is calculated as the sum of absolute differences between individual pulse widths and the average pulse width normalized by the average pulse width:

$$\text{Pulse Width Variability} = \frac{\sum_i |\text{Average Pulse Width} - \text{Pulse Width}_i|}{\text{Average Pulse Width}}, \quad (3)$$

where, i is the number of peaks detected in the window, Pulse Width_i is the pulse width for the i th peak, and *Average Pulse Width* is the sum of the individual pulse widths divided by the number of pulses. For example, a pulse rate of 180 bpm has a pulse width of 330 ms; and a pulse rate of 60 bpm has a pulse width of 1000 ms. If an average pulse width difference was found to be 100 ms, this would have a much greater effect at 180 bpm than 60 bpm. Thus, dividing by the pulse rate normalizes the pulse width variability. Returning to the 180 bpm versus 60 bpm example, dividing by the *Average Pulse Width* causes the *Pulse Width Variability* to be 3 times greater at 180 bpm than at 60 bpm.

[0043] SpO₂ is calculated for each peak in the pulse window using the ratio, R , which is 'mapped' to SpO₂ via a lookup table. This ratio, R , is defined as:

$$R = \frac{\left(\frac{\text{Red AC Component}}{\text{Red DC Component}} \right)}{\left(\frac{\text{IR AC Component}}{\text{IR DC Component}} \right)}, \quad (4)$$

The ratio, R , in equation 4 is used to index into an empirically derived table to determine SpO_2 . The *IR AC Component* is chosen at the point of maximum negative slope between the peak and valley for each peak of the filtered IR waveform. The *Red AC Component* is the slope of the filtered Red waveform at the time coincident with the above selected *IR AC Component*. The peak and valley points from the IR filtered waveforms are transposed onto the raw Red and IR waveform. The average between the peak and the valley is considered the DC component (analogous to a DC offset for a positively biased AC waveform). This DC component is calculated for both the Red and IR waveforms (*i.e.*, *Red DC Component* and *IR DC Component*). This process is repeated for each of the up to three bandpass filtered pulse windows corresponding to the candidate peaks identified in block 130 of FIG. 1. The term "pulse window" is used herein to represent time domain data corresponding to a particular candidate peak that has been bandpass filtered.

[0044] *SpO₂ Variability*, a measure of how consistent the SpO_2 is for all the peaks in a pulse window, may be calculated. Under typical conditions, *SpO₂ Variability* is low, often within ± 2 percent saturation over a short time interval such as the 10.24 second pulse window. When the pulse window is filtered by a frequency that is not related to the pulse rate (*e.g.*, random noise), the *SpO₂ Variability* tends to be high. Therefore, *SpO₂ Variability* is a good measure for determining confidence in a pulse window. *SpO₂ Variability* is calculated as the sum of the absolute difference between the individual SpO_2 values and the average SpO_2 for the pulse window.

$$\text{SpO}_2 \text{ Variability} = \sum_i | \text{Average SpO}_2 - \text{SpO}_{2,i} |, \quad (5)$$

where i is the number of peaks detected in the window, and $\text{SpO}_{2,i}$ is the saturation calculated for the i th peak detected and *Average SpO₂* is sum of the individual SpO_2 values divided by the number of individual SpO_2 values.

[0045] The *Pulse Window SpO₂* is calculated as the median value of all of the SpO_2 values within the current pulse window. Other methods of determining central tendency may be used including by not limited to a weighted mean or average.

[0046] The *Pulse Peak Amplitude Variability*, a measure of the consistency of the amplitude of the pulse peaks in a pulse window, may be calculated. *Pulse Peak Amplitude Variability* is calculated as the sum of the differences between the individual pulse peak amplitudes and the average pulse peak amplitude for the pulse window.

[0047] Motion artifacts are usually not purely rhythmic in nature. Therefore, the portion of the power spectrum comprising motion artifacts changes dynamically as the spectrum of the motion artifacts changes. In contrast, the spectrum of the underlying pulse rate varies much less over longer periods of time relative to motion artifact spectrum.

[0048] *Pulse Rate History Percentage*, another parameter useful for detecting motion artifacts, may also be calculated. According to the method, a pulse rate is calculated for the primary and secondary candidate peaks and these pulse rate calculations are saved in memory. This memory may be any capacity but preferably is capable of storing at least between 10-60 seconds of pulse rates (for the primary and secondary candidate peaks) and is updated periodically with the newest values overwriting the oldest values. For illustration purposes, assume the memory stores 30 seconds of pulse rates for the primary and secondary peaks. *Pulse Rate History Percentage* is calculated as the percentage that the pulse rate corresponding to the candidate peak occurred in a given period of time, *e.g.*, the most recent 30 seconds. Of course, one of ordinary skill in the art may recognize that a *Pulse Rate History Percentage* may be calculated in other analogous ways. For example, there could be a longer history of pulse rates (*i.e.*, more or less than 30 seconds) and it could be weighted or filtered in various manners without departing from the scope of the invention.

[0049] A pulse window under evaluation may be rejected from further processing and flagged as an invalid pulse window if certain criteria are met. A pulse window under evaluation may be checked against the following criterion:

1. The number of peaks in the pulse window, i , is two or less ($i \leq 2$)
2. The *Window Pulse Rate* is zero (*i.e.*, no frequency found).

Additional criteria related to variability and history may include the following:

1. The *Pulse Rate History Percentage* is less than a percentage of a significant portion of the pulse. According to the preferred embodiment of the invention, a percentage of a significant portion of the pulse would be in the range from about 25% to about 30%.

2. The *SpO₂ Variability* is greater than "normal" variation in SpO₂ in either absolute or relative terms. According to the preferred embodiment of the invention, *SpO₂ Variability* greater than a threshold ranging from about 3% to about 5% is greater than "normal" variation in SpO₂.

3. The *Pulse Width Variability* is greater than a threshold representing excessive variations. According to the preferred embodiment of the invention, a threshold representing excessive variations may fall within the range of about 200 to about 400 points for a pulse window of 1024 points.

4. The *Window Pulse Rate* differs by more than an excessive amount either in absolute or relative terms from the center frequency of the candidate power spectrum peak. According to the preferred embodiment of the invention, an excessive amount is a threshold greater than about 20 bpm to about 30 bpm, or about 20% to about 35% of the center frequency, whichever maximum threshold is smaller.

[0050] If the pulse window under evaluation meets any of these criteria, then the pulse window under evaluation is rejected as invalid and flagged as such. Also, the optimal thresholds and values for each of the above criteria may be optionally adjusted by methods known to one of ordinary skill in the art, including but not limited to, learning or search methods.

[0051] A confidence measure, *Pulse Window Confidence*, is also calculated according to block 140 of FIG. 1. According to the preferred method of the invention, *Pulse Window Confidence* is calculated as a weighted sum of the *Pulse Width Variability*, *SpO₂ Variability*, *Pulse Amplitude Variability* and the *Pulse Rate History Percentage* parameters. The lower the value of *Pulse Window Confidence* measure, the higher the confidence that the candidate peak under evaluation is a valid pulse rate. The *Pulse Window Confidence*, which is a point value without units, is only computed for each of the up to three remaining candidate peaks and then passed to the arbitrating step, see block 150 of FIG. 1.

[0052] The function of the arbitrating step, block 150 of FIG. 1, is to determine which, if any, of the up to three candidate peaks should be accepted. The arbitrating step 150, is accomplished by evaluating the calculated parameters, including the confidence or quality measures, (i.e., *Pulse Window Confidence*), of the candidate peaks relative to one another. Some of the candidate peaks may already have been flagged as an invalid pulse window, and thus, are not evaluated further. If none of the up to three candidate peaks is valid, no new pulse rate or new saturation will be displayed according to the method of the invention. Alternatively, if none of the up to three candidate peaks are valid, another algorithm (other than the method of the invention) may be employed to determine the pulse rate and saturation, see for example U.S. Patent Nos. 5,190,038, 5,398,680, 5,448,991 and 5,820,550 to Polson et al. Arbitration is then conducted among the up to three remaining candidate peaks in order to determine which, if any candidate peak, should be selected as the best frequency. The arbitration is preferably executed in the sequence presented below.

1. If the primary candidate peak frequency, f_1 , is zero, then there is no valid candidate peak (i.e., no best frequency).

2. If the tertiary candidate peak *Pulse Window Confidence* is less than the *Pulse Window Confidence* for either the primary candidate peak or the secondary candidate peak, then the tertiary candidate peak is the best frequency. Recall that the lower the *Pulse Window Confidence* value, the higher the confidence that the candidate peak is the true pulse rate.

3. If the primary candidate peak and the secondary candidate peak have both been rejected, then there is no valid candidate peak (i.e., no best frequency).

4. If the primary candidate peak has not been rejected and the secondary candidate peak has been rejected, then the primary candidate peak is the best frequency.

5. If the primary candidate peak has been rejected and the secondary candidate peak has not been rejected, then the secondary candidate peak is the best frequency.

6. If the primary candidate peak *Pulse Window Confidence* is greater than the secondary candidate peak *Pulse Window Confidence* by a specified threshold, t_1 , and the primary candidate peak *Pulse Rate History Percentage* is greater than another specified threshold, t_2 , then the primary candidate peak is the best frequency. Similar criteria apply if the secondary candidate peak *Pulse Window Confidence* is greater than the primary candidate peak.

7. If the secondary candidate peak frequency, f_2 , is a rough harmonic of the primary candidate peak frequency, f_1 , and the *Pulse Window Confidence* of the primary candidate peak is not more than a specified number of points greater than the *Pulse Window Confidence* of the secondary candidate peak, then accept the primary candidate peak. Secondary candidate peak frequency, f_2 , is a rough harmonic of the primary candidate peak frequency, f_1 , if the candidate frequency is within a frequency tolerance of approximately ± 10 bpm. Again, similar criteria apply if the secondary candidate peak is a rough harmonic of the primary candidate peak.

8. If the *Pulse Window Confidence* of the primary candidate peak is no more than a specified number of points greater than the *Pulse Window Confidence* of the secondary candidate peak, then accept the primary candidate

peak. Otherwise, accept the secondary candidate peak.

[0053] Once a candidate peak has been accepted (as the best frequency) according to the arbitrating step 150, the pulse rate and SpO_2 are calculated for the best frequency and output, for example, to a display or monitor, as depicted in block 160 of FIG. 1. The steps 100-160 may then be repeated for any new segments of data as depicted in decision block 170 of FIG. 1. The above sequence is exemplary only, and not intended to be limiting. Furthermore, one of ordinary skill in the art will recognize that the various criteria selected to evaluate pulse shape may be assigned weights to emphasize relative importance.

[0054] FIGS. 4-6 illustrate exemplary graphical results from application of the described method. FIG. 4 shows graphs of measured IR and red data segments. FIG. 5 is a graph of the frequency domain transformed IR signal from FIG. 4, showing a primary candidate peak at approximately 82 bpm, a secondary candidate peak at approximately 105 bpm.

[0055] FIG. 6 illustrates three graphs of IR data after filtering with three different FIR filters and segmented with vertical lines to delineate pulses and parameter calculations according to the invention. The parameter calculations displayed to the right in the graphs shown in FIG. 6 are exemplary only, and are not necessary for practicing the invention. With respect to those parameter calculations displayed, "PRHist" corresponds to *Pulse Rate History Percentage*; "PR" corresponds to *Window Pulse Rate*; "PWVar" corresponds to *Pulse Width Variability*; "MSat" corresponds to *Pulse Window SpO_2* ; "SVar" corresponds to *SpO_2 Variability*; "PConf" corresponds to *Pulse Window Confidence*; "Conf OK" corresponds to an accepted candidate peak or the best frequency, and "R:xxxx" corresponds to a notation that the candidate peak under evaluation has been rejected for the reason "xxxx", i.e., a parameter calculation has concluded with a rejection of the candidate peak all as disclosed herein.

[0056] The top graph in FIG. 6 represents the pulse window corresponding to the primary candidate peak at approximately 82 bpm as shown in FIG. 5. The middle graph in FIG. 6 represents the pulse window corresponding to the secondary candidate peak at approximately 105 bpm as shown in FIG. 5. The bottom graph in FIG. 6 represents the pulse window corresponding to the tertiary candidate peak at approximately 158 bpm as shown in FIG. 5. Note that in this instance, the tertiary candidate at frequency of 158 bpm has the lowest *Pulse Window Confidence* and no rejections based on calculated parameters. Note that FIGS. 4-6 are merely exemplary graphs illustrating sample calculations based on actual data obtained from typical pulse oximetry measurements.

[0057] The methods described above may be integrated into apparatuses and/or systems for calculating blood oxygen saturation. Referring to FIG. 7, one apparatus embodiment of this invention comprises a motion artifact rejection circuit card 10 with an I/O device 11, a processor 12 and memory 14 for storing a computer programmed algorithm for motion artifact rejection as described in the above methods. Processor 12 may be a digital signal processor. I/O device 11 may be any circuitry that allows communication to and from external circuitry, for example, and not by way of limitation, bus interface circuitry. I/O device 11 may include a circuit card edge connector for plugging into a pulse oximetry monitor system. Memory 14 may be any solid-state electronic memory suitable for storing digital data including, for example, computer code and measurement data.

[0058] Referring to FIG. 8, the motion artifact rejection circuit card 10 of FIG. 7 may be incorporated in a complete pulse oximetry system 16 for eliminating motion-induced noise artifacts in electrical signals (as described in the method embodiments above) and calculating and displaying physiological parameters, either as a discrete circuit card or as part of a larger circuit card, such as a motherboard, controlling other functions of the pulse oximetry system 16. The pulse oximetry system 16 also includes an input device 18 and an output device 20. Input device 18 may be a pulse oximeter sensor with red and IR LED light sources and a photodetector to convert transmitted or reflected light into an electrical signal. Output device 20 may be a display device such as a cathode ray tube device, liquid crystal display, active matrix display or any other suitable display device known to one of skill in the art. Alternatively, output device 20 may be a printer for producing a permanent or written record such as a laser printer, ink jet printer, thermal printer, dot matrix printer or any other suitable printer known to one of skill in the art. The pulse oximetry system 16 may be any pulse oximeter that uses the principles of operation as described above. A particular pulse oximeter for which the circuit card embodiment as described above is suitable for use is the Novamatrix Medical Systems, Inc., Model 520A, Pulse Oximeter.

[0059] Referring to FIG. 9, a block diagram of a pulse oximetry system 22 including a processor device 12, an input device 18, an output device 20 and a storage device 24, is shown. Input device 18 may be a pulse oximeter sensor with red and IR LED light sources and a photodetector to convert transmitted or reflected light into an electrical signal. Output device 20 may be a display device such as a cathode ray tube device, liquid crystal display, active matrix display or any other suitable display device known to one of skill in the art. Alternatively, output device 20 may be a printer for producing a permanent or written record such as a laser printer, ink jet printer, thermal printer, dot matrix printer or any other suitable printer known to one of skill in the art. Storage device 24 may be a disk drive, or any kind of solid-state electronic memory device suitable for storing digital data including, for example, computer code and measurement data.

[0060] Although this invention has been described with reference to particular embodiments, the invention is not limited to these described embodiments. Rather, it should be understood that the embodiments described herein are

merely exemplary and that a person skilled in the art may make many variations and modifications without departing from the scope of the invention, as defined in the appended claims.

Claims

1. An apparatus (22) for removing motion artifacts from electrical signals representative of attenuated light signals, said apparatus comprising:

a processor (12) configured for processing computer instructions to implement a method for removing motion artifacts from said electrical signals, said method comprising:

transforming said electrical signals into frequency domain data;
 identifying a plurality of peaks from said frequency domain data, including
 identifying a primary peak corresponding to a largest amplitude peak;

characterised by selecting a plurality of candidate peaks from the plurality of identified peaks by eliminating harmonic frequencies of the primary peak having a maximum amplitude which is less than half that of a previous harmonic or, in the case of a first harmonic, a maximum amplitude which is less than half that of the primary peak;
 determining parameters associated with each of said plurality of selected candidate peaks;
 analyzing each of said plurality of candidate peaks with respect to at least some of said determined parameters; and
 arbitrating between at least some of said plurality of candidate peaks employing at least some of said determined parameters to select a best frequency.

2. The apparatus (22) of claim 1, wherein said method further comprises conditioning said electrical signals to reduce spectral leakage prior to said transforming step.

3. The apparatus (22) of claim 2, further including a filter for use in said conditioning said electrical signals.

4. The apparatus (22) of claim 3, wherein said filter comprises a Hanning window.

5. The apparatus (22) of claim 1, wherein said transforming said electrical signals into frequency domain data is performed with a fast Fourier transform.

6. The apparatus (22) of claim 1, wherein said transforming said electrical signals into frequency domain data is performed with a technique selected from the group comprising a periodogram, a correlogram, autoregressive methods, Prony's method, minimum variance methods, maximum likelihood methods, a discrete cosine transform, a wavelet transform, a discrete Hartley transform and a Gabor transform.

7. The apparatus (22) of claim 1, wherein said identifying said plurality of candidate peaks comprises:

assigning a largest power amplitude from said frequency domain data as a primary candidate peak;
 assigning a next largest power amplitude as a secondary candidate peak; and
 assigning a previous non-zero pulse rate as a tertiary candidate peak if said previous non-zero pulse rate is neither said primary candidate peak nor said secondary candidate peak.

8. The apparatus (22) of claim 1, wherein said identifying said plurality of candidate peaks comprises identifying n peaks, by frequency, F_1 to F_n , in descending order of peak amplitude.

9. The apparatus (22) of claim 1, further comprising a narrow band filter for filtering each of said plurality of candidate peaks before said determining parameters step.

10. The apparatus (22) of claim 9, wherein said narrow band filter comprises a finite impulse response filter.

11. The apparatus (22) of claim 9, wherein said narrow band filter comprises an infinite impulse response filter.

12. The apparatus (22) of claim 1, further comprising n narrow band filters, one of said n narrow band filters being

selectable for filtering each of said plurality of candidate peaks before said determining parameters step to mask influence of candidate frequencies not under evaluation.

13. The apparatus (22) of claim 12, wherein $n = 8$ and wherein each of said 8 narrow band filters is separated by a fixed difference in frequency in a range of approximately 25 bpm to approximately 30 bpm.
14. The apparatus (22) of claim 12, wherein each of said n narrow band filters is separated by a variable difference in frequency in a range of approximately 25 bpm to approximately 30 bpm.
15. The apparatus (22) of claim 1, further comprising a narrow band filter of variable center frequency for filtering each of said plurality of candidate peaks.
16. The apparatus (22) of claim 1, further comprising a narrow band filter having filter coefficients generated and adjusted so that the center frequency of said narrow band filter may be shifted to approximate a frequency associated with each of said candidate peaks.
17. The apparatus (22) of claim 1, further comprising a fast Fourier transform (FFT), narrow band filter and inverse FFT for filtering each of said plurality of candidate peaks.
18. The apparatus (22) of claim 1, wherein said analyzing each of said plurality of candidate peaks with respect to said developed parameters includes calculating a window pulse rate.
19. The apparatus (22) of claim 1, wherein said analyzing each of said plurality of candidate peaks with respect to said developed parameters includes calculating pulse width variability.
20. The apparatus (22) of claim 1, wherein said analyzing each of said plurality of candidate peaks with respect to said developed parameters includes calculating SpO₂ variability.
21. The apparatus (22) of claim 1, wherein said analyzing each of said plurality of candidate peaks with respect to said developed parameters includes calculating pulse window SpO₂.
22. The apparatus (22) of claim 1, wherein said analyzing each of said plurality of candidate peaks with respect to said developed parameters includes calculating pulse rate history percentage.
23. The apparatus (22) of claim 1, wherein said analyzing each of said plurality of candidate peaks with respect to said developed parameters includes calculating pulse window confidence.
24. The apparatus (22) of claim 23, wherein said calculating pulse window confidence includes a weighted sum of pulse width variability, SpO₂ variability and pulse rate history percentage.
25. The apparatus (22) of claim 1, wherein said analyzing each of said plurality of candidate peaks with respect to at least some of said developed parameters includes calculating a window pulse rate, pulse width variability, SpO₂ variability, pulse window SpO₂, pulse rate history percentage and pulse window confidence.
26. The apparatus (22) of claim 1, wherein said arbitrating between at least some of said plurality of candidate peaks based on said developed parameters includes applying a predetermined criterion to select said best frequency.
27. The apparatus (22) of claim 1, wherein said plurality of candidate peaks comprises up to three candidate peaks, including a primary candidate peak, a secondary candidate peak and a tertiary candidate peak.
28. The apparatus (22) of claim 27, wherein said arbitrating between each of said up to three candidate peaks includes applying the following criteria using at least some of said developed parameters to select said best frequency:
 - (a) if the primary candidate peak frequency is zero, then there is no valid candidate peak;
 - (b) if the tertiary candidate peak pulse window confidence is less than the pulse window confidence for either the primary candidate peak or the secondary candidate peak, then the tertiary candidate peak is said best frequency;
 - (c) if the primary candidate peak and the secondary candidate peak have both been rejected, then there is no

valid candidate peak;

(d) if the primary candidate peak has not been rejected and the secondary candidate peak has been rejected, then the primary candidate peak is said best frequency;

(e) if the primary candidate peak has been rejected and the secondary candidate peak has not been rejected, then the secondary candidate peak is said best frequency;

(f) if the primary candidate peak pulse window confidence is greater than the secondary candidate peak pulse window confidence by a first threshold, t_1 , and the primary candidate peak pulse rate history percentage is greater than a second threshold, t_2 , then the primary candidate peak is said best frequency;

(g) if the secondary candidate peak frequency is a rough harmonic of the primary candidate peak frequency and the pulse window confidence of the primary candidate peak is not more than a specified number of points greater than the pulse window confidence of the secondary candidate peak, then accept the primary candidate peak; and

(h) if the pulse window confidence of the primary candidate peak is no more than a specified number of points greater than the pulse window confidence of the secondary candidate peak, then said primary candidate peak is said best frequency, otherwise, said secondary candidate peak is said best frequency.

29. The apparatus (22) of claim 1, further comprising a sensor (18) in communication with said processor for receiving said attenuated light signals.

30. The apparatus (22) of claim 1, further comprising:

a circuit card (10) configured for mounting said processor (12) thereto and configured for insertion into and communication with a pulse oximeter; and

a memory device (14) mounted to said circuit card and configured for storing said computer instructions.

Patentansprüche

1. Vorrichtung (22) zur Entfernung von Bewegungsartefakten aus elektrischen Signalen, die repräsentativ für gedämpfte Lichtsignale sind, wobei die Vorrichtung aufweist:

einen Prozessor (12) zur Verarbeitung von Maschinenbefehlen zur Implementierung eines Verfahrens zur Entfernung von Bewegungsartefakten aus den elektrischen Signalen, wobei das Verfahren umfasst:

Transformation der elektrischen Signale in Frequenzbereichsdaten, Kennzeichnung mehrerer Spitzenwerte unter den Frequenzbereichsdaten, einschließlich Kennzeichnung eines primären Spitzenwertes, der einem Spitzenwert mit der größten Amplitude entspricht,

gekennzeichnet durch die Auswahl mehrerer Kandidatenspitzenwerte aus den mehreren gekennzeichneten Spitzenwerten **durch** die Eliminierung von Oberschwingungsfrequenzen des primären Spitzenwertes mit einer maximalen Amplitude, die weniger als die Hälfte der Amplitude einer vorhergehenden Harmonischen beträgt, oder, im Falle einer ersten Harmonischen, mit einer maximalen Amplitude, die weniger als die Hälfte der Amplitude des primären Spitzenwertes beträgt,

Bestimmung von Parametern, die mit jedem der mehreren ausgewählten Kandidatenspitzenwerte verknüpft sind,

Analyse jedes der mehreren Kandidatenspitzenwerte hinsichtlich mindestens einiger der bestimmten Parameter, und

Entscheidung zwischen mindestens einigen der mehreren Kandidatenspitzenwerte unter Verwendung mindestens einiger der bestimmten Parameter, um eine beste Frequenz auszuwählen.

2. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** das Verfahren weiterhin die Konditionierung der elektrischen Signale zur Reduzierung der spektralen Streuverluste vor dem Schritt der Transformation umfasst.

3. Vorrichtung (22) nach Anspruch 2, weiterhin einschließend einen Filter zur Verwendung bei der Konditionierung der elektrischen Signale.

4. Vorrichtung (22) nach Anspruch 3, **dadurch gekennzeichnet, dass** der Filter ein Hanning-Fenster aufweist.
5. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Transformation der elektrischen Signale in Frequenzbereichsdaten mit einer schnellen Fourier-Transformierten ausgeführt wird.
6. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Transformation der elektrischen Signale in Frequenzbereichsdaten mit Hilfe eines Verfahrens ausgeführt wird, das aus der Verfahrensgruppe ausgewählt wird, die ein Wellenschaubild, ein Beziehungsschaubild, autoregressive Verfahren, das Prony-Verfahren, Minimalvarianzverfahren, Maximum-Likelihood-Verfahren, eine diskrete Kosinus-Transformation, eine Wavelet-Transformation, eine diskrete Hartley-Transformation und eine Gabor-Transformation umfasst.
7. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** der Schritt der Kennzeichnung der mehreren Kandidatenspitzenwerte umfasst:
 - Bestimmung einer in den Frequenzbereichsdaten vorhandenen Amplitude mit der höchsten Leistung zu einem primären Kandidatenspitzenwert,
 - Bestimmung einer Amplitude mit der nächsthöchsten Leistung zu einem sekundären Kandidatenspitzenwert, und
 - Bestimmung einer vorhergehenden von Null verschiedenen Pulsfrequenz zu einem tertiären Kandidatenspitzenwert, wenn die vorhergehende von Null verschiedene Pulsfrequenz weder der primäre Kandidatenspitzenwert noch der sekundäre Kandidatenspitzenwert ist.
8. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** der Schritt der Kennzeichnung der mehreren Kandidatenspitzenwerte die Kennzeichnung von n Spitzenwerten, F_1 bis F_n der Frequenz nach, in absteigender Ordnung der Spitzenwertamplitude umfasst.
9. Vorrichtung (22) nach Anspruch 1, weiterhin aufweisend einen Schmalbandfilter zum Filtern jedes der mehreren Kandidatenspitzenwerte vor dem Schritt der Parameterbestimmung.
10. Vorrichtung (22) nach Anspruch 9, **dadurch gekennzeichnet, dass** der Schmalbandfilter einen Filter mit endlicher Impulsantwort aufweist.
11. Vorrichtung (22) nach Anspruch 9, **dadurch gekennzeichnet, dass** der Schmalbandfilter einen Filter mit unendlicher Impulsantwort aufweist.
12. Vorrichtung (22) nach Anspruch 1, weiterhin aufweisend n Schmalbandfilter, wobei einer der n Schmalbandfilter zum Filtern jedes der mehreren Kandidatenspitzenwerte vor dem Schritt der Parameterbestimmung zur Ausblendung des Einflusses der gerade nicht der Auswertung unterzogenen Kandidatenfrequenzen auswählbar ist.
13. Vorrichtung (22) nach Anspruch 12, **dadurch gekennzeichnet, dass** n den Wert 8 hat und jeder der 8 Schmalbandfilter durch einen festen Frequenzabstand, der zwischen ca. 25 bpm und ca. 30 bpm liegt, abgetrennt ist.
14. Vorrichtung (22) nach Anspruch 12, **dadurch gekennzeichnet, dass** jeder der n Schmalbandfilter durch einen variablen Frequenzabstand, der zwischen ca. 25 bpm und ca. 30 bpm liegt, abgetrennt ist.
15. Vorrichtung (22) nach Anspruch 1, weiterhin aufweisend einen Schmalbandfilter mit variabler Mittenfrequenz zum Filtern jedes der mehreren Kandidatenspitzenwerte.
16. Vorrichtung (22) nach Anspruch 1, weiterhin aufweisend einen Schmalbandfilter mit Filterkoeffizienten, die so generiert und eingestellt sind, dass die Mittenfrequenz des Schmalbandfilters zur Annäherung an eine mit jedem der Kandidatenspitzenwerte verknüpfte Frequenz verschiebbar ist.
17. Vorrichtung (22) nach Anspruch 1, weiterhin aufweisend eine schnelle Fourier-Transformierte (FFT), einen Schmalbandfilter und eine inverse FFT zum Filtern jedes der mehreren Kandidatenspitzenwerte.
18. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Analyse jedes der mehreren Kandidatenspitzenwerte hinsichtlich der entwickelten Parameter die Berechnung einer Fensterpulsfrequenz einschließt.

19. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Analyse jedes der mehreren Kandidatenspitzenwerte hinsichtlich der entwickelten Parameter die Berechnung der Impulsbreitenveränderlichkeit einschließt.

20. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Analyse jedes der mehreren Kandidatenspitzenwerte hinsichtlich der entwickelten Parameter die Berechnung der SpO₂-Veränderlichkeit einschließt:

21. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Analyse jedes der mehreren Kandidatenspitzenwerte hinsichtlich der entwickelten Parameter die Berechnung des Impulsfenster-SpO₂-Wertes einschließt.

22. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Analyse jedes der mehreren Kandidatenspitzenwerte hinsichtlich der entwickelten Parameter die Berechnung des prozentualen Pulsfrequenzverlaufs einschließt.

23. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Analyse jedes der mehreren Kandidatenspitzenwerte hinsichtlich der entwickelten Parameter die Berechnung des Impulsfenstervertrauens einschließt.

24. Vorrichtung (22) nach Anspruch 23, **dadurch gekennzeichnet, dass** die Berechnung des Impulsfenstervertrauens eine gewichtete Summe aus Impulsbreitenveränderlichkeit, SpO₂-Veränderlichkeit und prozentualem Pulsfrequenzverlauf einschließt.

25. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Analyse jedes der mehreren Kandidatenspitzenwerte hinsichtlich mindestens einiger der entwickelten Parameter die Berechnung einer Fensterpulsfrequenz, einer Impulsbreitenveränderlichkeit, einer SpO₂-Veränderlichkeit, eines Impulsfenster-SpO₂-Wertes, eines prozentualen Pulsfrequenzverlaufs und eines Impulsfenstervertrauens einschließt.

26. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die Entscheidung zwischen mindestens einigen der mehreren Kandidatenspitzenwerte auf der Grundlage der entwickelten Parameter die Anwendung eines vorbestimmten Kriteriums zur Auswahl der besten Frequenz einschließt.

27. Vorrichtung (22) nach Anspruch 1, **dadurch gekennzeichnet, dass** die mehreren Kandidatenspitzenwerte bis zu drei Kandidatenspitzenwerte umfassen, einschließend einen primären Kandidatenspitzenwert, einen sekundären Kandidatenspitzenwert und einen tertiären Kandidatenspitzenwert.

28. Vorrichtung (22) nach Anspruch 27, **dadurch gekennzeichnet, dass** die Entscheidung zwischen jedem der bis zu drei Kandidatenspitzenwerte die Anwendung der folgenden Kriterien unter Verwendung mindestens einiger der entwickelten Parameter zur Auswahl der besten Frequenz einschließt:

a) wenn die Frequenz des primären Kandidatenspitzenwertes Null ist, dann gibt es keinen gültigen Kandidatenspitzenwert;

b) wenn das Impulsfenstervertrauen des tertiären Kandidatenspitzenwertes geringer als das Impulsfenstervertrauen entweder des primären Kandidatenspitzenwertes oder des sekundären Kandidatenspitzenwertes ist, dann ist der tertiäre Kandidatenspitzenwert die beste Frequenz;

c) wenn sowohl der primäre Kandidatenspitzenwert als auch der sekundäre Kandidatenspitzenwert zurückgewiesen worden ist, dann gibt es keinen gültigen Kandidatenspitzenwert;

d) wenn der primäre Kandidatenspitzenwert nicht zurückgewiesen worden ist und der sekundäre Kandidatenspitzenwert zurückgewiesen worden ist, dann ist der primäre Kandidatenspitzenwert die beste Frequenz;

e) wenn der primäre Kandidatenspitzenwert zurückgewiesen worden ist und der sekundäre Kandidatenspitzenwert nicht zurückgewiesen worden ist, dann ist der sekundäre Kandidatenspitzenwert die beste Frequenz;

f) wenn das Impulsfenstervertrauen des primären Kandidatenspitzenwertes um einen ersten Schwellenwert t_1 größer als das Impulsfenstervertrauen des sekundären Kandidatenspitzenwertes ist und der prozentuale Pulsfrequenzverlauf des primären Kandidatenspitzenwertes größer als ein zweiter Schwellenwert t_2 ist, dann ist der primäre Kandidatenspitzenwert die beste Frequenz;

g) wenn die Frequenz des sekundären Kandidatenspitzenwertes eine grobe Harmonische der Frequenz des primären Kandidatenspitzenwertes ist und das Impulsfenstervertrauen des primären Kandidatenspitzenwertes nicht mehr als um eine spezifizierte Anzahl von Punkten größer als das Impulsfenstervertrauen des sekundären Kandidatenspitzenwertes ist, dann wird der primäre Kandidatenspitzenwert angenommen; und

h) wenn das Impulsfenstervertrauen des primären Kandidatenspitzenwertes nicht mehr als um eine spezifi-

zierte Anzahl von Punkten größer als das Impulsfenstervertrauen des sekundären Kandidatenspitzenwertes ist, dann ist der primäre Kandidatenspitzenwert die beste Frequenz, während anderenfalls der sekundäre Kandidatenspitzenwert die beste Frequenz ist.

5 29. Vorrichtung (22) nach Anspruch 1, weiterhin aufweisend einen Sensor (18), der mit dem Prozessor in Verbindung steht, zum Empfang der gedämpften Lichtsignale.

30. Vorrichtung (22) nach Anspruch 1, weiterhin aufweisend:

10 eine Leiterplatte (10), auf der der Prozessor (12) befestigt wird und die in ein Pulsoxymeter gesteckt wird und mit diesem in Verbindung steht; und
ein Speicherelement (14), das auf der Leiterplatte befestigt ist und die Maschinenbefehle speichert.

15 Revendications

1. Appareil (22) d'élimination d'artefacts dus au mouvement à partir de signaux électriques représentatifs de signaux lumineux atténués, ledit appareil comprenant :

20 un processeur (12) configuré pour traiter des instructions informatiques pour mettre en oeuvre une méthode pour éliminer des artefacts dus au mouvement à partir desdits signaux électriques, ladite méthode comprenant :

la transformation desdits signaux électriques en données de domaines de fréquence ;
25 l'identification d'une pluralité de pics à partir desdites données de domaines de fréquence, comprenant l'identification d'un pic primaire correspondant à un pic d'amplitude maximale ; **caractérisé par** la sélection d'une pluralité de pics candidats à partir de la pluralité de pics identifiés en éliminant les fréquences harmoniques du pic primaire ayant une amplitude maximale qui est inférieure à la moitié de celle d'une harmonique précédente ou, dans le cas d'une première harmonique, une amplitude maximale qui est inférieure à la moitié de celle du pic primaire ;
30 la détermination de paramètres associés à chaque pic de ladite pluralité de pics candidats sélectionnés ; l'analyse de chaque pic de ladite pluralité de pics candidats par rapport à au moins certains desdits paramètres déterminés ; et
l'arbitrage entre au moins certains pics de ladite pluralité de pics candidats employant au moins certains
35 desdits paramètres déterminés pour choisir une fréquence optimale.

2. Appareil (22) selon la revendication 1, dans lequel ladite méthode comprend en outre le conditionnement desdits signaux électriques pour réduire la fuite spectrale avant ladite étape de transformation.

40 3. Appareil (22) selon la revendication 2, comprenant en outre un filtre destiné à être utilisé dans ledit conditionnement desdits signaux électriques.

4. Appareil (22) selon la revendication 3, dans lequel ledit filtre comprend un créneau de Hanning.

45 5. Appareil (22) selon la revendication 1, dans lequel ladite transformation desdits signaux électriques en données de domaines de fréquence est réalisée avec une transformée de Fourier rapide.

6. Appareil (22) selon la revendication 1, dans lequel ladite transformation desdits signaux électriques en données de domaines de fréquence est réalisée avec une technique sélectionnée dans le groupe comprenant un périodogramme, un corrélogramme, des méthodes autorégressives, la méthode de Prony, des méthodes de variance
50 minimale, des méthodes de probabilité maximale, une transformée en cosinus discrète, une transformée en vaguelette, une transformée de Hartley discrète et une transformée de Gabor.

7. Appareil (22) selon la revendication 1, dans lequel ladite identification de ladite pluralité de pics candidats
55 comprend :

l'attribution d'une amplitude de puissance maximale à partir desdites données de domaines de fréquence en tant que pic candidat primaire ;

l'attribution d'une amplitude de puissance maximale suivante en tant que pic candidat secondaire ; et
l'attribution d'un rythme de pulsations non nul précédent en tant que pic candidat tertiaire si ledit rythme de
pulsations non nul précédent n'est ni ledit pic candidat primaire, ni ledit pic candidat secondaire.

- 5 8. Appareil (22) selon la revendication 1, dans lequel ladite identification de ladite pluralité de pics candidats comprend l'identification de n pics, par fréquence, F_1 à F_n , dans l'ordre décroissant de l'amplitude du pic.
9. Appareil (22) selon la revendication 1, comprenant en outre un filtre à bande étroite pour filtrer chaque pic de ladite pluralité de pics candidats avec avant ladite étape de paramètres de détermination.
- 10 10. Appareil (22) selon la revendication 9, dans lequel ledit filtre à bande étroite comprend un filtre à réponse impulsionnelle finie.
11. Appareil (22) selon la revendication 9, dans lequel ledit filtre à bande étroite comprend un filtre à réponse impulsionnelle infinie.
- 15 12. Appareil (22) selon la revendication 1, comprenant en outre n filtres à bande étroite, l'un desdits n filtres à bande étroite pouvant être sélectionné pour filtrer chaque pic de ladite pluralité de pics candidats avant ladite étape de paramètres de détermination pour masquer l'influence des fréquences candidates qui ne sont pas en cours d'évaluation.
- 20 13. Appareil (22) selon la revendication 12, dans lequel $n = 8$ et dans lequel chacun desdits 8 filtres à bande étroite est séparé par une différence de fréquence déterminée dans une plage allant approximativement de 25 bpm à approximativement 30 bpm.
- 25 14. Appareil (22) selon la revendication 12, dans lequel chacun desdits n filtres à bande étroite est séparé par une différence de fréquence variable dans une plage allant approximativement de 25 bpm à approximativement 30 bpm.
- 30 15. Appareil (22) selon la revendication 1, comprenant en outre un filtre à bande étroite de fréquence centrale variable pour filtrer chaque pic de ladite pluralité de pics candidats.
- 35 16. Appareil (22) selon la revendication 1, comprenant en outre un filtre à bande étroite ayant des coefficients de filtrage générés et réglés de sorte que la fréquence centrale dudit filtre à bande étroite peut être décalée pour atteindre approximativement une fréquence associée à chacun desdits pics candidats.
17. Appareil (22) selon la revendication 1, comprenant en outre une transformée de Fourier rapide (FFT), un filtre à bande étroite et une FFT inverse pour filtrer chaque pic de ladite pluralité de pics candidats.
- 40 18. Appareil (22) selon la revendication 1, dans lequel ladite analyse de chaque pic de ladite pluralité de pics candidats par rapport auxdits paramètres développés inclut le calcul d'un rythme de pulsations dans un créneau.
19. Appareil (22) selon la revendication 1, dans lequel ladite analyse de chaque pic de ladite pluralité de pics candidats par rapport auxdits paramètres développés inclut le calcul d'une variabilité de la largeur de pulsation.
- 45 20. Appareil (22) selon la revendication 1, dans lequel ladite analyse de chaque pic de ladite pluralité de pics candidats par rapport auxdits paramètres développés inclut le calcul d'une variabilité de la SpO_2 .
21. Appareil (22) selon la revendication 1, dans lequel ladite analyse de chaque pic de ladite pluralité de pics candidats par rapport auxdits paramètres développés inclut le calcul de la SpO_2 dans le créneau de pulsations.
- 50 22. Appareil (22) selon la revendication 1, dans lequel ladite analyse de chaque pic de ladite pluralité de pics candidats par rapport auxdits paramètres développés inclut le calcul du pourcentage d'une histoire du rythme de pulsations.
- 55 23. Appareil (22) selon la revendication 1, dans lequel ladite analyse de chaque pic de ladite pluralité de pics candidats par rapport auxdits paramètres développés inclut le calcul d'une mesure fiable du créneau de pulsations.
24. Appareil (22) selon la revendication 23, dans lequel ladite mesure fiable du créneau de pulsations inclut une somme

pondérée de la variabilité de largeur de pulsation, de la variabilité de la SpO_2 et du pourcentage d'une histoire du rythme de pulsations.

25. Appareil (22) selon la revendication 1, dans lequel ladite analyse de chaque pic de ladite pluralité de pics candidats par rapport à au moins certains desdits paramètres développés inclut le calcul d'un rythme de pulsations dans un créneau, de la variabilité de la largeur de pulsation, de la variabilité de la SpO_2 , de la SpO_2 dans le créneau de pulsations, du pourcentage d'une histoire du rythme de pulsations et de la mesure fiable du créneau de pulsations.

26. Appareil (22) selon la revendication 1, dans lequel ledit arbitrage entre au moins certains pics de ladite pluralité de pics candidats basé sur lesdits paramètres développés inclut l'application d'un critère prédéterminé pour sélectionner ladite fréquence optimale.

27. Appareil (22) selon la revendication 1, dans lequel ladite pluralité de pics candidats comprend jusqu'à trois pics candidats, incluant un pic candidat primaire, un pic candidat secondaire et un pic candidat tertiaire.

28. Appareil (22) selon la revendication 27, dans lequel ledit arbitrage entre chaque pic desdits jusqu'à trois pics candidats inclut l'application des critères suivants en utilisant au moins certains desdits paramètres développés pour choisir ladite fréquence optimale ;

- (a) si la fréquence de pic candidat primaire est nulle, alors il n'existe pas de pic candidat valide ;
- (b) si la mesure fiable du créneau de pulsations du pic candidat tertiaire est inférieure à la mesure fiable du créneau de pulsations soit du pic candidat primaire, soit du pic candidat secondaire, alors le pic candidat tertiaire est ladite fréquence optimale ;
- (c) si le pic candidat primaire et le pic candidat secondaire sont tous deux rejetés, alors il n'existe pas de pic candidat valide ;
- (d) si le pic candidat primaire n'est pas rejeté et que le pic candidat secondaire est rejeté, alors le pic candidat primaire est ladite fréquence optimale ;
- (e) si le pic candidat primaire est rejeté et que le pic candidat secondaire n'est pas rejeté, alors le pic candidat secondaire est ladite fréquence optimale ;
- (f) si la mesure fiable du créneau de pulsations du pic candidat primaire est supérieure à la mesure fiable du créneau de pulsations du pic candidat secondaire par un premier seuil, t_1 , et que le pourcentage d'une histoire du rythme de pulsations du pic candidat primaire est supérieur à un second seuil, t_2 , alors le pic candidat primaire est ladite fréquence optimale ;
- (g) si la fréquence du pic candidat secondaire est une harmonique prononcée de la fréquence du pic candidat primaire et si la mesure fiable du créneau de pulsations du pic candidat primaire n'est pas plus grande qu'un nombre spécifié de points supérieur à la mesure fiable du créneau de pulsations du pic candidat secondaire, on accepte alors le pic candidat primaire ; et
- (h) si la mesure fiable du créneau de pulsations du pic candidat primaire n'est pas plus grande qu'un nombre spécifié de points supérieur à la mesure fiable du créneau de pulsations du pic candidat secondaire, alors ledit pic candidat primaire est ladite fréquence optimale, sinon, ledit pic candidat secondaire est ladite fréquence optimale.

29. Appareil (22) selon la revendication 1, comprenant en outre un capteur (18) en communication avec ledit processeur pour recevoir lesdits signaux lumineux atténués.

30. Appareil (22) selon la revendication 1, comprenant en outre :

- une plaquette de circuit imprimé (10) configurée pour monter ledit processeur (12) sur celle-ci et configurée pour être insérée dans et en communication avec un oxymètre de pouls ; et
- un dispositif à mémoire (14) monté sur ladite plaquette de circuit imprimé et configuré pour mémoriser lesdites instructions informatiques.

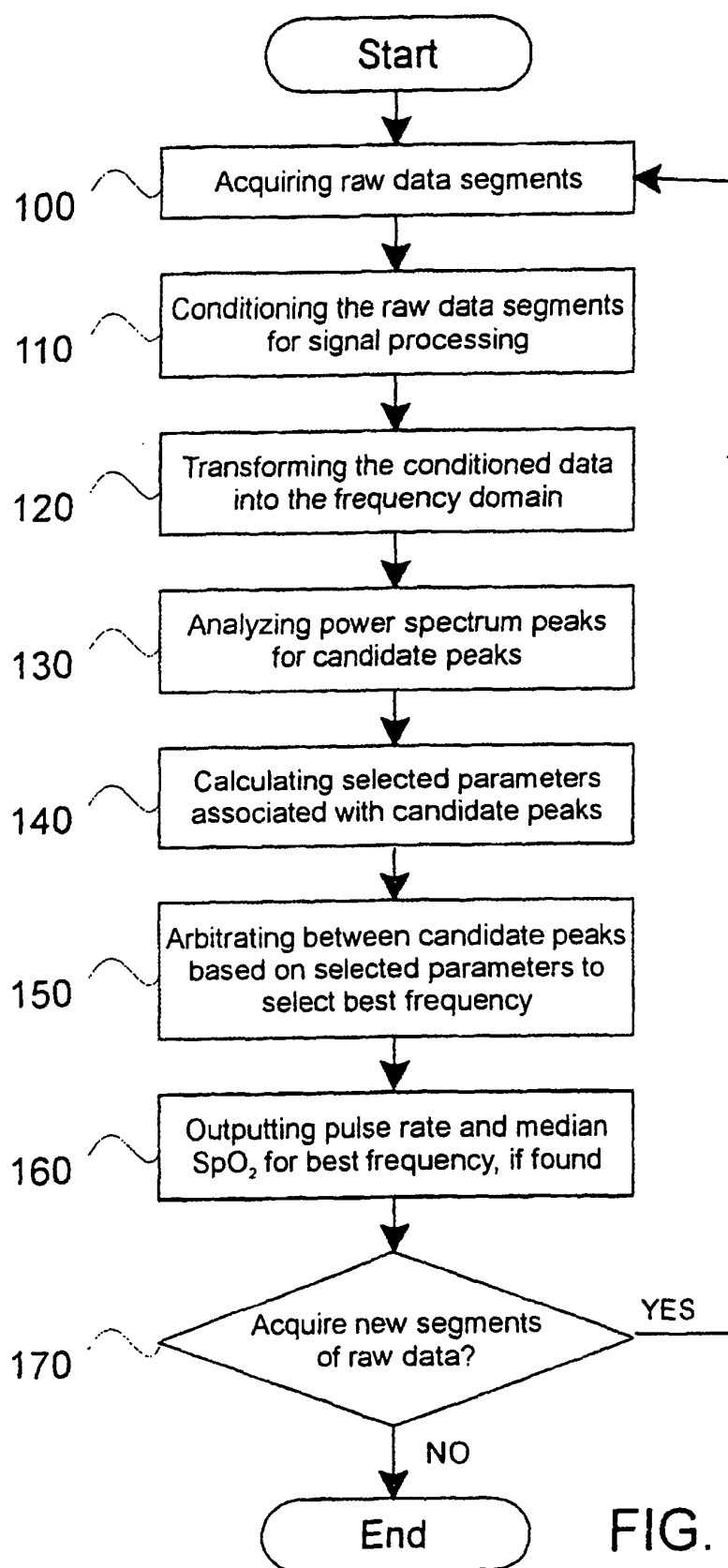


FIG. 1

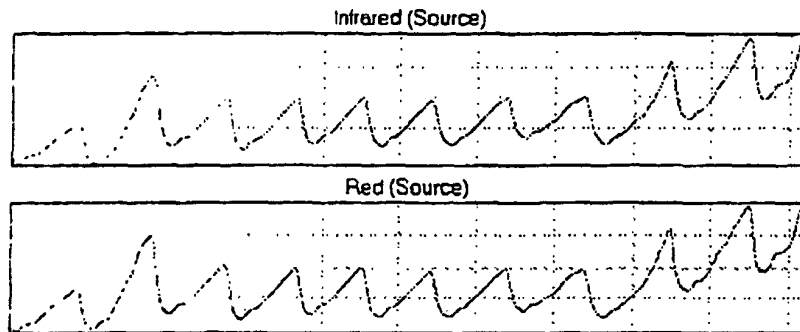


FIG. 2

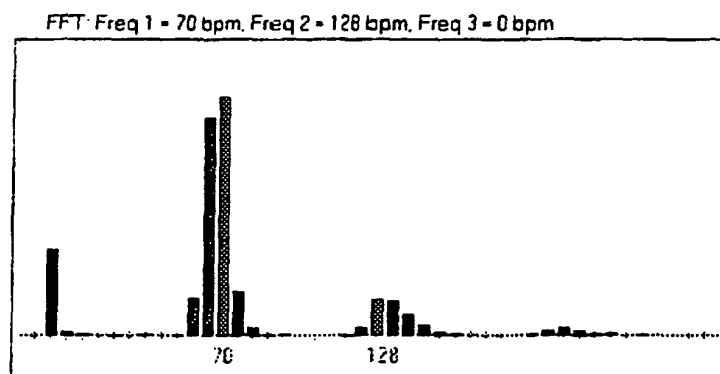


FIG. 3

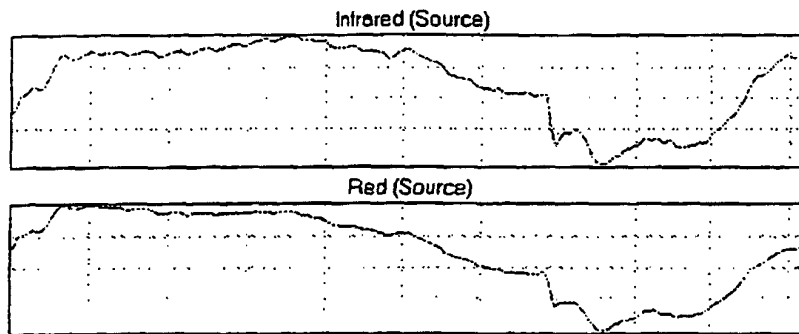


FIG. 4

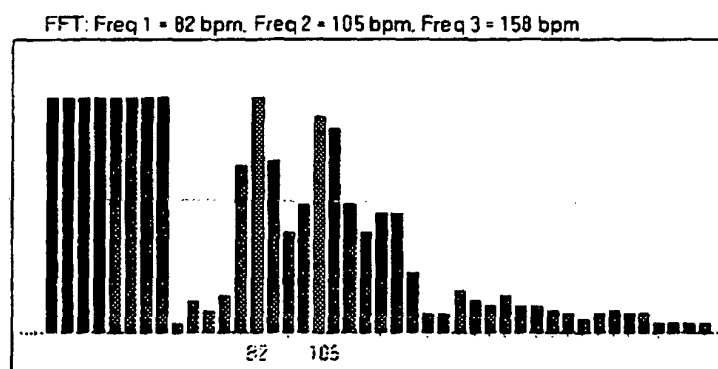


FIG. 5

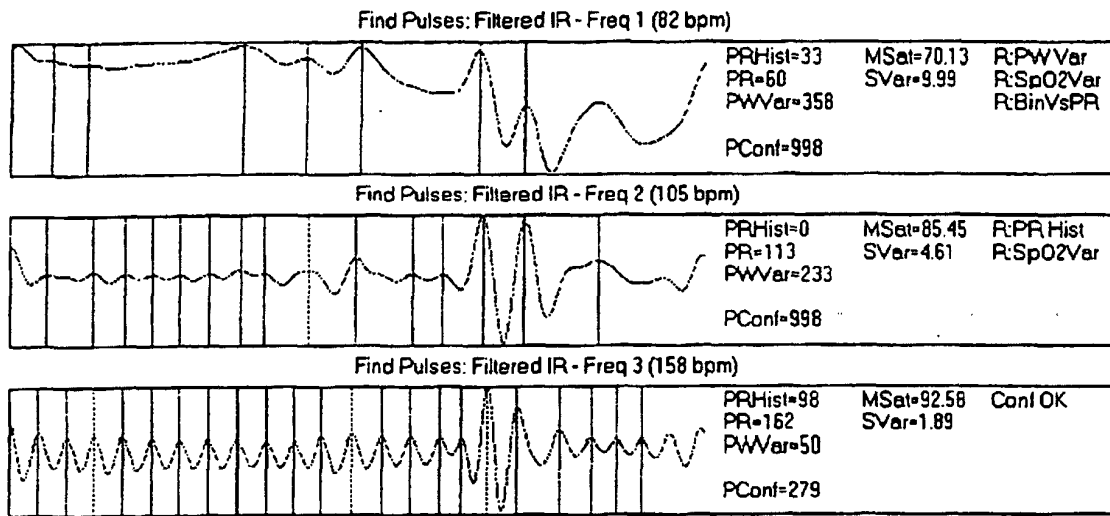


FIG. 6

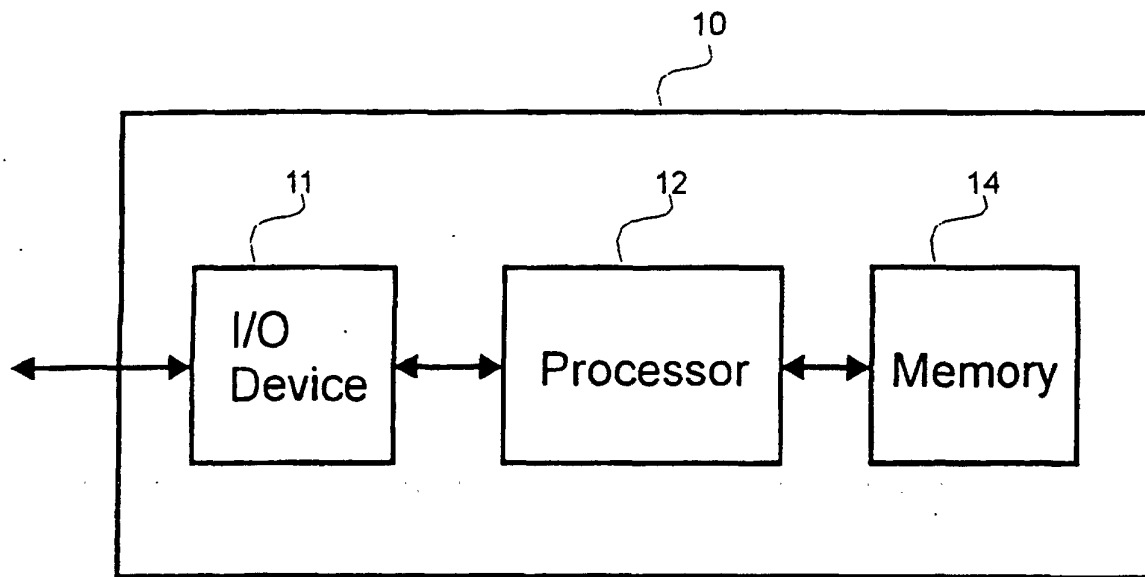


FIG. 7

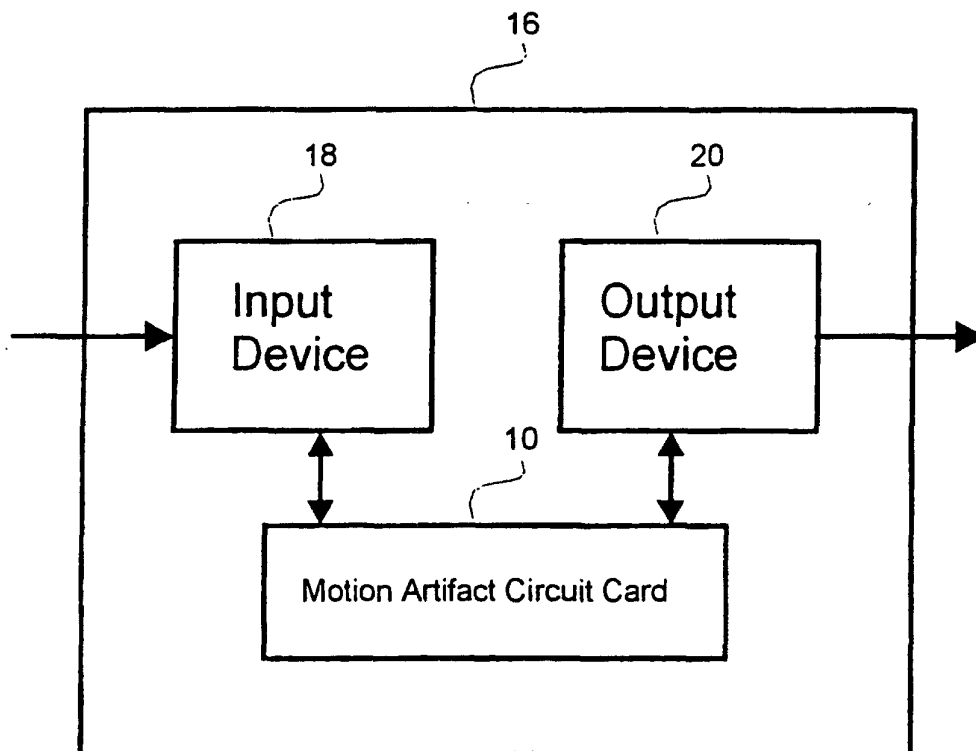


FIG. 8

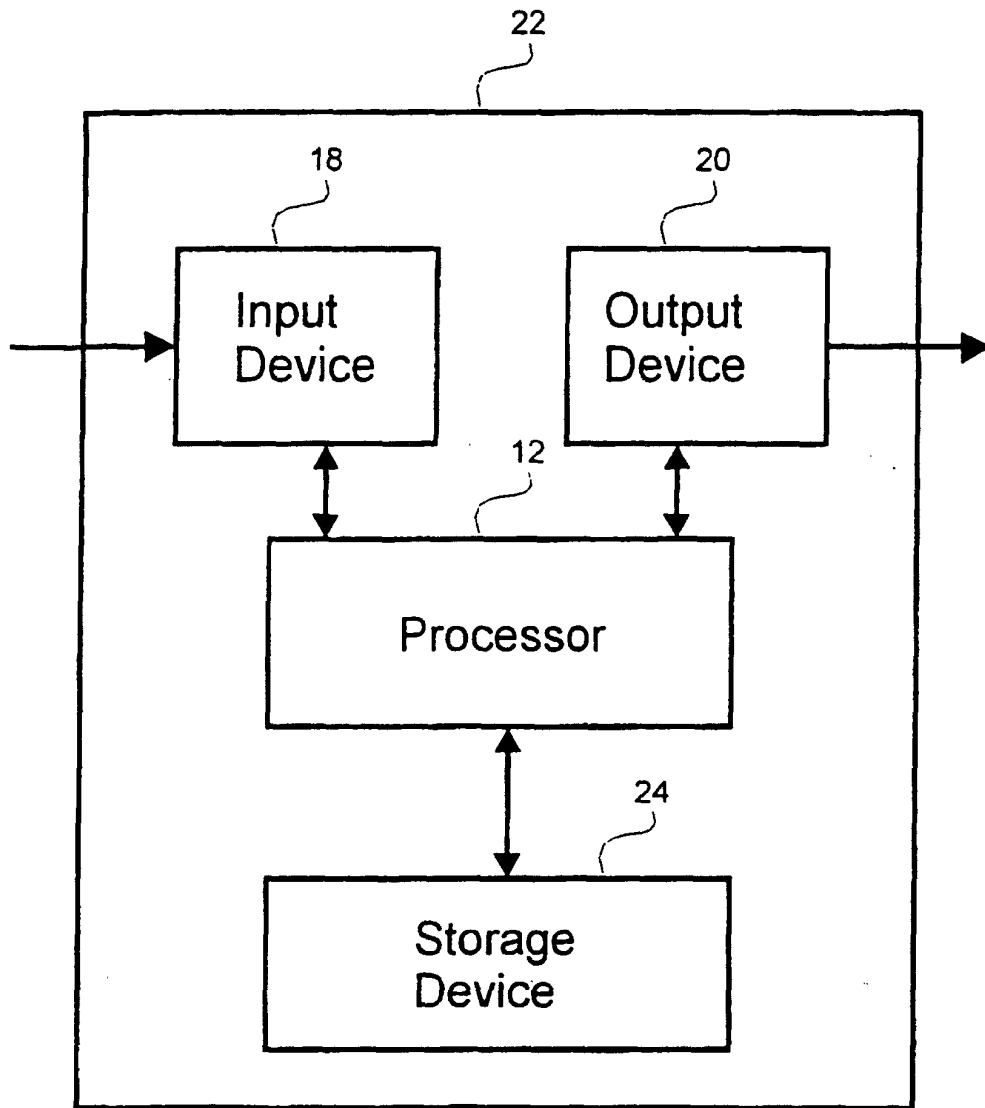


FIG. 9

专利名称(译)	用于从身体参数的测量中去除运动伪影的装置		
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申请(专利权)人(译)	NTC科技股份有限公司.		
当前申请(专利权)人(译)	NTC科技股份有限公司.		
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摘要(译)

一种用于从用于感测身体参数的装置移除运动伪影的方法以及用于实现其的装置和系统。该方法包括分析表示身体参数和可能来自运动伪影的噪声的测量数据的片段。每个测量数据段可以对应于在通过身体组织传输或反射之后传输和检测的单个光信号。对每个数据段进行频率分析，以确定最多三个候选峰值以供进一步分析。可以对多达三个候选频率中的每一个进行滤波，并且计算与多达三个候选频率中的每一个相关联的各种参数。如果存在最佳频率，则通过根据预定标准使用计算出的参数仲裁候选频率来确定最佳频率。如果找到最佳频率，则可输出脉冲率和 SpO_2 。如果未找到最佳频率，则可以使用用于计算脉冲率和 SpO_2 的其他常规技术。在计算脉搏率和/或脉动血氧浓度之前，上述方法可以应用于红色和红外脉搏血氧饱和度信号。所公开的装置和系统被配置为执行根据本发明公开的方法。

$$I_{transmitted} = I_{incident} e^{-\mu_{eff}(\lambda) d}$$