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(54) **SIGNAL COMPONENT PROCESSOR**

SIGNALKOMPONENTEN-PROZESSOR

PROCESSEUR DE COMPOSANTES DU SIGNAL

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(56) References cited:
WO-A-98/42250 **US-A- 5 995 858**
US-A- 6 002 952

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DescriptionBackground of the Invention

[0001] Early detection of low blood oxygen is critical in the medical field, for example in critical care and surgical applications, because an insufficient supply of oxygen can result in brain damage and death in a matter of minutes. Pulse oximetry is a widely accepted noninvasive procedure for measuring the oxygen saturation level of arterial blood, an indicator of oxygen supply. A pulse oximeter typically provides a numerical readout of the patient's oxygen saturation and pulse rate. A pulse oximetry system consists of a sensor attached to a patient, a monitor, and a cable connecting the sensor and monitor. Conventionally, a pulse oximetry sensor has both red (RD) and infrared (IR) light-emitting diode (LED) emitters and a photodiode detector. The pulse oximeter measurements are based upon the absorption by arterial blood of the two wavelengths emitted by the sensor. The pulse oximeter alternately activates the RD and IR sensor emitters and reads the resulting RD and IR sensor signals, i.e. the current generated by the photodiode in proportion to the detected RD and IR light intensity, in order to derive an arterial oxygen saturation value, as is well-known in the art. A pulse oximeter contains circuitry for controlling the sensor, processing the sensor signals and displaying the patient's oxygen saturation and pulse rate.

Summary of the Invention

[0002] The present invention is characterized by the features of the independent claims.

[0003] FIG. 1A illustrates a plethysmograph waveform **110**, which is a display of blood volume, shown along the ordinate **101**, over time, shown along the abscissa **102**. The shape of the plethysmograph waveform **110** is a function of heart stroke volume, pressure gradient, arterial elasticity and peripheral resistance. Ideally, the waveform **110** displays a short, steep inflow phase **111** during ventricular systole followed by a typically three to four times longer outflow phase **112** during diastole. A dicrotic notch **116** is generally attributed to closure of the aortic valve at the end of ventricular systole.

[0004] FIG. 1B illustrates a corresponding RD or IR sensor signal $s(t)$ **130**, such as described above. The typical plethysmograph waveform **110** (FIG. 1A), being a function of blood volume, also provides a light absorption profile. A pulse oximeter, however, does not directly detect light absorption and, hence, does not directly measure the plethysmograph waveform **110**. However, IR or RD sensor signals are 180° out-of-phase versions of the waveform **110**. That is, peak detected intensity **134** occurs at minimum absorption **114** and minimum detected intensity **138** occurs at maximum absorption **118**.

[0005] FIG. 1C illustrates the corresponding spectrum of $s(t)$, which is a display of signal spectral magnitude $|S(\omega)|$, shown along the ordinate **105**, versus frequency, shown along the abscissa **106**. The plethysmograph spectrum is depicted under both high signal quality **150** and low signal quality **160** conditions. Low signal quality can result when a pulse oximeter sensor signal is distorted by motion-artifact and noise. Signal processing technologies such as described in U.S. Patent 5,632,272, assigned to the assignee of the present invention allow pulse oximetry to function through patient motion and other low signal quality conditions.

[0006] Ideally, plethysmograph energy is concentrated at the pulse rate frequency **172** and associated harmonics **174**, **176**. Accordingly, motion-artifact and noise may be reduced and pulse oximetry measurements improved by filtering out sensor signal frequencies that are not related to the pulse rate. Under low signal quality conditions, however, the frequency spectrum is corrupted and the pulse rate fundamental **152** and harmonics **154**, **156** can be obscured or masked, resulting in errors in the computed pulse rate. In addition, a pulse rate, physiologically, is dynamic, potentially varying significantly between different measurement periods. Hence, maximum plethysmograph energy may not correspond to the computed pulse rate except under high signal quality conditions and stable pulse rates. Further, an oxygen saturation value calculated from an optical density ratio, such as a normalized red over infrared ratio, at the pulse rate frequency can be sensitive to computed pulse rate errors. In order to increase the robustness of oxygen saturation measurements, therefore, it is desirable to improve pulse rate based measurements by identifying sensor signal components that correspond to an optimization, such as maximum signal energy.

[0007] One aspect of a signal component processor comprises a physiological signal, a basis function index determined from the signal, a basis function waveform generated according to the index, a component derived from the sensor signal and the waveform, and a physiological measurement responsive to the component. In one embodiment, the component is responsive to the inner product of the sensor signal and the waveform. In another embodiment, the index is a frequency and the waveform is a sinusoid at the frequency. In that embodiment, the signal processor may further comprise a pulse rate estimate derived from the signal wherein the frequency is selected from a window including the pulse rate estimate. The physiological measurement may be an oxygen saturation value responsive to a magnitude of the component.

[0008] Another aspect of a signal component processor comprises a signal input, a basis function indicator derived

from the signal input, a plurality of basis functions generated according to the indicator, a plurality of characteristics of the signal input corresponding to the basis functions and an optimization of the characteristics so as to identify at least one of said basis functions. In one embodiment, the indicator is a pulse rate estimate and the processor further comprises a window configured to include the pulse rate estimate, and a plurality of frequencies selected from within the window. In another embodiment, the characteristic comprises a plurality of signal remainders corresponding to the basis functions and a plurality of magnitudes of the signal remainders. In that embodiment, the optimization comprises a minima of the magnitudes. In a further embodiment, the characteristic comprises a plurality of components corresponding to the basis functions and a plurality of magnitudes of the components. In this embodiment, the optimization comprises a maxima of the magnitudes.

[0009] An aspect of a signal component processing method comprises the steps of receiving a sensor signal, calculating an estimated pulse rate, determining an optimization of the sensor signal proximate the estimated pulse rate, defining a frequency corresponding to the optimization, and outputting a physiological measurement responsive to a component of the sensor signal at the frequency. In one embodiment the determining step comprises the substeps of transforming the sensor signal to a frequency spectrum encompassing the estimated pulse rate and detecting an extrema of the spectrum indicative of the frequency. The transforming step may comprise the substeps of defining a window including the estimated pulse rate, defining a plurality of selected frequencies within the window, canceling the selected frequencies, individually, from the sensor signal to generate a plurality of remainder signals and calculating a plurality of magnitudes of the remainder signals. The detecting step may comprise the substep of locating a minima of the magnitudes.

[0010] In another embodiment, the outputting step comprises the substeps of inputting a red (RD) portion and an infrared (IR) portion of the sensor signal, deriving a RD component of the RD portion and an IR component of the IR portion corresponding to the frequency and computing an oxygen saturation based upon a magnitude ratio of the RD component and the IR component. The deriving step may comprise the substeps of generating a sinusoidal waveform at the frequency and selecting the RD component and the IR component utilizing the waveform. The selecting step may comprise the substep of calculating the inner product between the waveform and the RD portion and the inner product between the waveform and the IR portion. The selecting step may comprise the substeps of canceling the waveform from the RD portion and the IR portion, leaving a RD remainder and an IR remainder, and subtracting the RD remainder from the RD portion and the IR remainder from the IR portion.

[0011] A further aspect of a signal component processor comprises a first calculator means for deriving an optimization frequency from a pulse rate estimate input and a sensor signal, and a second calculator means for deriving a physiological measurement responsive to a sensor signal component at the frequency. In one embodiment, the first calculator means comprises a signal component transform means for determining a plurality of signal values corresponding to a plurality of selected frequencies within a window including the pulse rate estimate, and a detection means for determining a particular one of the selected frequencies corresponding to an optimization of the sensor signal. The second calculator means may comprise a waveform means for generating a sinusoidal signal at the frequency, a frequency selection means for determining a component of the sensor signal from the sinusoidal signal and a calculator means for deriving a ratio responsive to the component.

Brief Description of the Drawings

[0012]

FIGS. **1A-C** are graphical representations of a pulse oximetry sensor signal;
 FIG. **1A** is a typical plethysmograph illustrating blood volume versus time;
 FIG. **1B** is a pulse oximetry sensor signal illustrating detected light intensity versus time;
 FIG. **1C** is a pulse oximetry sensor signal spectrum illustrating both high signal quality and low signal quality conditions;
 FIGS. **2-3** are magnitude versus frequency graphs for a pulse oximetry sensor signal illustrating an example of signal component processing;
 FIG. **2** illustrates a frequency window around an estimated pulse rate; and
 FIG. **3** illustrates an associated signal component transform;
 FIGS. **4-7** are functional block diagrams of one embodiment of a signal component processor;
 FIG. **4** is a top-level functional block diagram of a signal component processor;
 FIG. **5** is a functional block diagram of a frequency calculator;
 FIG. **6** is a functional block diagram of a saturation calculator; and
 FIG. **7** is a functional block diagram of one embodiment of a frequency selection;
 FIGS. **8A-B** are flowcharts of an iterative embodiment of a frequency calculator; and
 FIGS. **9-11** are functional block diagrams of another embodiment of a signal component processor;

FIG. 9 is a top-level functional block diagram of a signal component processor;

FIG. 10 is a functional block diagram of an index calculator; and

FIG. 11 is a functional block diagram of a measurement calculator.

Detailed Description of the Preferred Embodiments

[0013] FIGS. 2 and 3 provide graphical illustration examples of signal component processing. Advantageously, signal component processing provides a direct method for the calculation of saturation based on pulse rate. For example, it is not necessary to compute a frequency transform, such as an FFT, which derives an entire frequency spectrum. Rather, signal component processing singles out specific signal components, as described in more detail below. Further, signal component processing advantageously provides a method of refinement for the calculation of saturation based on pulse rate.

[0014] FIG. 2 illustrates high and low signal quality sensor signal spectrums 150, 160 as described with respect to FIG. 1C, above. A frequency window 220 is created, including a pulse rate estimate PR 210. A pulse rate estimate can be calculated as disclosed in US Patent No. 6,002,952, entitled "Signal Processing Apparatus and Method," assigned to the assignee of the present invention. A search is conducted within this window 220 for a component frequency f_o at an optimization. In particular, selected frequencies 230, which include PR, are defined within the window 220. The components of a signal $s(t)$ at each of these frequencies 230 are then examined for an optimization indicative of an extrema of energy, power or other signal characteristic. In an alternative embodiment, the components of the signal $s(t)$ are examined for an optimization over a continuous range of frequencies within the window 220.

[0015] FIG. 3 illustrates an expanded portion of the graph described with respect to FIG. 2, above. Superimposed on the high signal quality 150 and low signal quality 160 spectrums is a signal component transform 310. In one embodiment, a signal component transform 310 is indicative of sensor signal energy and is calculated at selected signal frequencies 230 within the window 220. A signal component transform 310 has an extrema 320 that indicates, in this embodiment, energy optimization at a particular one 330 of the selected frequencies 230. The extrema 320 can be, for example, a maxima, minima or inflection point. In the embodiment illustrated, each point of the transform 310 is the magnitude of the signal remaining after canceling a sensor signal component at one of the selected frequencies. The extrema 320 is a minima, which indicates that canceling the corresponding frequency 330 removes the most signal energy. In an alternative embodiment, not illustrated, the transform 310 is calculated as the magnitude of signal components at each of the selected frequencies 230. In that embodiment, the extrema is a maxima, which indicates the largest energy signal at the corresponding frequency. The result of a signal component transform 310 is identification of a frequency f_o 330 determined from the frequency of a signal component transform extrema 320. Frequency f_o 330 is then used to calculate an oxygen saturation. A signal component transform and corresponding oxygen saturation calculations are described in additional detail with respect to FIGS. 4-8, below. Although signal component processing is described above with respect to identifying a particular frequency within a window including a pulse rate estimate PR, a similar procedure could be performed on 2PR, 3PR etc. resulting in the identification of multiple frequencies f_{O1} , f_{O2} , etc., which could be used for the calculation of oxygen saturation as well.

[0016] Advantageously, a signal component transform 310 is calculated over any set of selected frequencies, unrestricted by the number or spacing of these frequencies. In this manner, a signal component transform 310 differs from a FFT or other standard frequency transforms. For example, a FFT is limited to N evenly-distributed frequencies spaced at a resolution of f_s/N_t where N is the number of signal samples and f_s is the sampling frequency. That is, for a FFT, a relatively high sampling rate or a relatively large record length or both are needed to achieve a relatively high resolution in frequency. Signal component processing, as described herein, is not so limited. Further, a signal component transform 310 is advantageously calculated only over a range of frequencies of interest. A FFT or similar frequency transformation may be computationally more burdensome than signal component processing, in part because such a transform is computed over all frequencies within a range determined by the sampling frequency, f_s .

[0017] FIGS. 4-7 illustrate one embodiment of a signal component processor. FIG. 4 is a top-level functional block diagram of a signal component processor 400. The signal component processor 400 has a frequency calculator 410 and a saturation calculator 460. The frequency calculator 410 has an IR signal input 402, a pulse rate estimate signal PR input 408 and a component frequency f_o output 412. The frequency calculator 410 performs a signal component transform based upon the PR input 408 and determines the f_o output 412, as described with respect to FIGS. 2-3, above. The frequency calculator 410 is described in further detail with respect to FIG. 5, below.

[0018] In an alternative embodiment, the frequency calculator 410 determines f_o 412 based upon a RD signal input substituted for, or in addition to, the IR signal input 402. Similarly, one of ordinary skill in the art will recognize that f_o can be determined by the frequency calculator 410 based upon one or more inputs responsive to a variety of sensor wavelengths.

[0019] The saturation calculator 460 has an IR signal input 402, a RD signal input 404, a component frequency f_o input 412 and an oxygen saturation output, SAT_{f_o} 462. The saturation calculator 460 determines values of the IR signal

input **402** and the RD signal input **404** at the component frequency f_o **412** and computes a ratio of those values to determine SAT_{f_o} **462**, as described with respect to FIG. 6, below. The IR signal input **402** and RD signal input **404** can be expressed as:

$$IR = \begin{bmatrix} IR_0 \\ \vdots \\ IR_{N-1} \end{bmatrix}; \quad RD = \begin{bmatrix} RD_0 \\ \vdots \\ RD_{N-1} \end{bmatrix} \quad (1)$$

where N is the number of samples of each signal input.

[0020] FIG. 5 shows one embodiment of the frequency calculator **410**. In this particular embodiment, the frequency calculator functions are window generation **520**, frequency cancellation **540**, magnitude calculation **560** and minima determination **580**. Window generation **520**, frequency cancellation **540** and magnitude calculation **560** combine to create a signal component transform **310** (FIG. 3), as described with respect to FIG. 3, above. Minima determination **580** locates the signal component transform extrema **320** (FIG. 3), which identifies f_o **412**, also described with respect to FIG. 3, above.

[0021] As shown in FIG. 5, window generation **520** has a PR input **408** and defines a window **220** (FIG. 3) about PR **210** (FIG. 3) including a set of selected frequencies **230** (FIG. 3)

$$\{f_m; m = 0, \dots, M - 1\}; \quad f = \begin{bmatrix} f_0 \\ \vdots \\ f_{M-1} \end{bmatrix} \quad (2)$$

where M is the number of selected frequencies **230** (FIG. 3) within the window **220** (FIG. 3). Window generation **520** has a sinusoidal output X_f, Y_f **522**, which is a set of sinusoidal waveforms $x_{n,f}, y_{n,f}$ each corresponding to one of the set of selected frequencies **230** (FIG. 3). Specifically

$$X_f = \begin{bmatrix} x_{0,f} \\ \vdots \\ x_{N-1,f} \end{bmatrix}; \quad Y_f = \begin{bmatrix} y_{0,f} \\ \vdots \\ y_{N-1,f} \end{bmatrix} \quad (3a)$$

$$x_{n,f} = \sin(2\pi fn); \quad y_{n,f} = \cos(2\pi fn) \quad (3b)$$

[0022] Also shown in FIG. 5, the frequency cancellation **540** has IR **402** and X_f, Y_f **522** inputs and a remainder output R_f **542**, which is a set of remainder signals $r_{n,f}$ each corresponding to one of the sinusoidal waveforms $x_{n,f}, y_{n,f}$. For each selected frequency f **230** (FIG. 3), frequency cancellation **540** cancels that frequency component from the input signal IR **402** to generate a remainder signal $r_{n,f}$. In particular, frequency cancellation **540** generates a remainder R_f **542**

$$R_f = \begin{bmatrix} r_{0,f} \\ \vdots \\ r_{N-1,f} \end{bmatrix} \quad (4a)$$

$$R_f = IR - \frac{IR \cdot X_f}{|X_f|^2} X_f - \frac{IR \cdot Y_f}{|Y_f|^2} Y_f \quad (4b)$$

[0023] Additionally, as shown in FIG. 5, the magnitude calculation **560** has a remainder input R_f **542** and generates a magnitude output W_f **562**, where

$$W_f = |R_f| = \sqrt{\sum_{n=0}^{N-1} r_{n,f}^2} \quad (5)$$

[0024] Further shown in FIG. 5, the minima determination 580 has the magnitude values W_f 562 as inputs and generates a component frequency f_o output. Frequency f_o is the particular frequency associated with the minimum magnitude value

$$W_{f_o} = \min \{W_f\} \quad (6)$$

[0025] FIG. 6 shows that the saturation calculator 460 functions are sinusoid generation 610, frequency selection 620, 640 and ratio calculation 670. Sinusoid generation has a component frequency f_o input 208 and a sinusoidal waveform X_{f_o} , Y_{f_o} output 612, which has a frequency of f_o . Frequency selection 620, 640 has a sensor signal input, which is either an IR signal 202 or a RD signal 204 and a sinusoid waveform X_{f_o} , Y_{f_o} input 612. Frequency selection 620, 640 provides magnitude outputs z_{IR,f_o} 622 and z_{RD,f_o} 642 which are the frequency components of the IR 202 and RD 204 sensor signals at the f_o frequency. Specifically, from equation 3(a)

$$X_{f_o} = \begin{bmatrix} x_{0,f_o} \\ \vdots \\ x_{N-1,f_o} \end{bmatrix}; \quad Y_{f_o} = \begin{bmatrix} y_{0,f_o} \\ \vdots \\ y_{N-1,f_o} \end{bmatrix} \quad (7)$$

[0026] Then, referring to equation 1

$$z_{IR,f_o} = \left| \frac{IR \cdot X_{f_o}}{|X_{f_o}|^2} X_{f_o} + \frac{IR \cdot Y_{f_o}}{|Y_{f_o}|^2} Y_{f_o} \right| = \sqrt{\frac{(IR \cdot X_{f_o})^2}{|X_{f_o}|^2} + \frac{(IR \cdot Y_{f_o})^2}{|Y_{f_o}|^2}} \quad (8a)$$

$$z_{RD,f_o} = \left| \frac{RD \cdot X_{f_o}}{|X_{f_o}|^2} X_{f_o} + \frac{RD \cdot Y_{f_o}}{|Y_{f_o}|^2} Y_{f_o} \right| = \sqrt{\frac{(RD \cdot X_{f_o})^2}{|X_{f_o}|^2} + \frac{(RD \cdot Y_{f_o})^2}{|Y_{f_o}|^2}} \quad (8b)$$

[0027] For simplicity of illustration, EQS. 8a-b assume that the cross-product of X_{f_o} and Y_{f_o} is zero, although generally this is not the case. The ratio calculation and mapping 670 has z_{IR,f_o} 622 and z_{RD,f_o} 642 as inputs and provides SAT_{f_o} 262 as an output. That is

$$SAT_{f_o} = g \left\{ \frac{z_{RD,f_o}}{z_{IR,f_o}} \right\} \quad (9)$$

where g is a mapping of the red-over-IR ratio to oxygen saturation, which may be an empirically derived lookup table, for example.

[0028] FIG. 7 illustrates an alternative embodiment of frequency selection 620 (FIG. 6), as described above. In this embodiment, frequency cancellation 540 and magnitude calculation 560, as described with respect to FIG. 5, can also be used, advantageously, to perform frequency selection. Specifically, frequency cancellation 540 has IR 202 and X_{f_o} , Y_{f_o} 612 as inputs and generates a remainder signal R_{f_o} 712 as an output, where

$$R_{f_o} = IR - \frac{IR \cdot X_{f_o}}{|X_{f_o}|^2} X_{f_o} - \frac{IR \cdot Y_{f_o}}{|Y_{f_o}|^2} Y_{f_o} \quad (10)$$

5 [0029] The remainder R_{f_o} 712 is subtracted 720 from IR 202 to yield

$$10 \quad Z_{f_o} = IR - \left[IR - \frac{IR \cdot X_{f_o}}{|X_{f_o}|^2} X_{f_o} - \frac{IR \cdot Y_{f_o}}{|Y_{f_o}|^2} Y_{f_o} \right] = \frac{IR \cdot X_{f_o}}{|X_{f_o}|^2} X_{f_o} + \frac{IR \cdot Y_{f_o}}{|Y_{f_o}|^2} Y_{f_o} \quad (11)$$

where z_{f_o} 722 is the component of IR 202 at the f_o frequency. The magnitude calculation 560 has z_{f_o} 722 as an input and calculates

$$20 \quad |Z_{f_o}| = \left| \frac{IR \cdot X_{f_o}}{|X_{f_o}|^2} X_{f_o} + \frac{IR \cdot Y_{f_o}}{|Y_{f_o}|^2} Y_{f_o} \right| = \sqrt{\frac{(IR \cdot X_{f_o})^2}{|X_{f_o}|^2} + \frac{(IR \cdot Y_{f_o})^2}{|Y_{f_o}|^2}} \quad (12)$$

which is equivalent to equation 8a, above.

[0030] FIGS. 8A-B illustrate an iterative embodiment of the frequency calculator 410 (FIG. 4) described above. An iterative frequency calculator 410 has an initialization 810, a signal component transform 820, an extrema detection 850, a resolution decision 860 and a resolution refinement 880 and provides a component frequency f_o 870. Initialization 810 defines a window around the pulse rate estimate PR and a frequency resolution within that window.

[0031] As shown in FIG. 8A, a signal component transform 820 has an initial frequency selection 822, a frequency cancellation 824 and an magnitude calculation 828. A decision block 830 determines if the magnitude calculation 828 has been performed at each frequency within the window. If not, the loop of frequency cancellation 824 and magnitude calculation 828 is repeated for another selected frequency in the window. The frequency cancellation 824 removes a frequency component from the IR sensor signal, as described with respect to FIG. 5, above. The magnitude calculation 828 determines the magnitude of the remainder signal, also described with respect to FIG. 5, above. If the decision block 830 determines that the remainder signal magnitudes have been calculated at each of the selected frequencies, then the signal component transform loop 820 is exited to the steps described with respect to FIG. 8B.

[0032] As shown in FIG. 8B, the extrema detector 850 finds a minima of a signal component transform 820 and a resolution decision block 860 determines if the final frequency resolution of a signal component transform is achieved. If not, resolution refinement 880 is performed. If the final resolution is achieved, the component frequency output f_o is equated to the frequency of the minima 870, i.e. a signal component transform minima determined by the extrema detector 850.

[0033] Further shown in FIG. 8B, the resolution refinement 880 has a set frequency estimate 882, a window decrease 884 and a frequency resolution increase 888. Specifically, the frequency estimate 882 is set to a signal component transform minima, as determined by the extrema detector 850. The window decrease 884 defines a new and narrower window around the frequency estimate, and the frequency resolution increase 888 reduces the spacing of the selected frequencies within that window prior to the next iteration of a signal component transform 820. In this manner, a signal component transform 820 and the resulting frequency estimate are refined to a higher resolution with each iteration of signal component transform 820, extrema detection 850, and resolution refinement 880.

[0034] In a particular embodiment, the component calculation requires three iterations. A frequency resolution of 4 beats per minute or 4 BPM is used initially and a window of five or seven selected frequencies, including that of the initial pulse rate estimate PR, is defined. That is, a window of either 16 BPM or 24 BPM centered on PR is defined, and a signal component transform is computed for a set of 5 or 7 selected frequencies evenly spaced at 4 BPM. The result is a frequency estimate f_1 . Next, the frequency resolution is reduced from 4 BPM to 2 BPM and a 4 BPM window centered on f_1 is defined with three selected frequencies, i.e. f_1-2 BPM, f_1 , and f_1+2 BPM. The result is a higher resolution frequency estimate f_2 . On the final iteration, the frequency resolution is reduced to 1 BPM and a 2 BPM window centered on f_2 is defined with three selected frequencies, i.e. f_2-1 BPM, f_2 , and f_2+1 BPM. The final result is the component frequency f_o determined by a signal component transform to within a 1BPM resolution. This component frequency f_o is then used to calculate the oxygen saturation, SAT_{f_o} , as described above.

[0035] The signal component processor has been described above with respect to pulse oximetry and oxygen saturation measurements based upon a frequency component that optimizes signal energy. The signal component proc-

essor, however, is applicable to other physiological measurements, such as blood glucose, carboxy-hemoglobin, respiration rate and blood pressure to name a few. Further, the signal component processor is generally applicable to identifying, selecting and processing any basis function signal components, of which single frequency components are one embodiment, as described in further detail with respect to FIG. 9, below.

[0036] FIGS. 9-11 illustrate another embodiment of a signal component processor 900. As shown in FIG. 9, the processor 900 has an index calculator 910 and a measurement calculator 960. The index calculator has a sensor signal input S 902 and outputs a basis function index κ_o 912, as described with respect to FIG. 10, below. The measurement calculator 960 inputs the basis function index κ_o 912 and outputs a physiological measurement U_{κ_o} 962, as described with respect to FIG. 11, below. The processor 900 also has a basis function indicator 980, which is responsive to the sensor signal input S 902 and provides a parameter ε 982 that indicates a set of basis functions to be utilized by the index calculator 910, as described with respect to FIG. 10, below.

[0037] As shown in FIG. 10, the functions of the index calculator 910 are basis subset generation 1020, component cancellation 1040 and optimization calculation 1060. The basis subset generation 1020 outputs a subset Φ_{κ} 1022 of basis function waveforms corresponding to a set of selected basis function indices κ . The basis functions can be any complete set of functions such that

$$S = \sum_{\kappa} a_{\kappa} \Phi_{\kappa} \quad (13)$$

[0038] For simplicity of illustration purposes, these basis functions are assumed to be orthogonal

$$\langle \vec{\Phi}_{\gamma}, \vec{\Phi}_{\eta} \rangle = 0; \gamma \neq \eta \quad (14)$$

where $\langle \rangle$ denotes an inner product. As such

$$a_{\kappa} = \langle S, \Phi_{\kappa} \rangle / \langle \Phi_{\kappa}, \Phi_{\kappa} \rangle \quad (15)$$

$$S_{\kappa} = a_{\kappa} \Phi_{\kappa} \quad (16)$$

[0039] In general, the basis functions may be non-orthogonal. The subset of basis functions generated is determined by an input parameter ε 982. In the embodiment described with respect to FIG. 5, above, the basis functions are sinusoids, the indices are the sinusoid frequencies and the input parameter ε 982 is a pulse rate estimate that determines a frequency window.

[0040] As shown in FIG. 10, the component cancellation 1040 generates a remainder output R_{κ} 1042, which is a set of remainder signals corresponding to the subset of basis function waveforms Φ_{κ} 1022. For each basis function waveform generated, component cancellation removes the corresponding basis function component from the sensor signal S 902 to generate a remainder signal. In an alternative embodiment, component cancellation 1040 is replaced with a component selection that generates a corresponding basis function component of the sensor signal S 902 for each basis function generated. The optimization calculation 1060 generates a particular index κ_o 912 associated with an optimization of the remainders R_{κ} 1042 or, alternatively, an optimization of the selected basis function signal components.

[0041] As shown in FIG. 11, the functions of the measurement calculator 960 are basis function generation 1120, component selection 1140, and physiological measurement calculation 1170. The component selection 1140 inputs the sensor signal S 902 and a particular basis function waveform Φ_{κ_o} 1122 and outputs a sensor signal component S_{κ_o} 1142. The physiological measurement 1170 inputs the sensor signal component S_{κ_o} 1142 and outputs the physiological measurement U_{κ_o} 962, which is responsive to the sensor signal component S_{κ_o} 1142. In the embodiment described with respect to FIG. 6, above, the basis functions Φ_{κ} are sinusoids and the index κ_o is a particular sinusoid frequency. The basis function generation 1120 creates sine and cosine waveforms at this frequency. The component selection 1140 selects corresponding frequency components of the sensor signal portions, RD and IR. Also, the physiological measurement 1170 computes an oxygen saturation based upon a magnitude ratio of these RD and IR frequency components.

[0042] The signal component processor has been disclosed in detail in connection with various embodiments. These embodiments are disclosed by way of examples only and are not to limit the scope of the claims that follow. One of

ordinary skill in the art will appreciate many variations and modifications.

Claims

1. A signal processing method comprising the steps of:

receiving a sensor signal;
calculating an estimated pulse rate;
determining an optimization of said sensor signal proximate said estimated pulse rate; defining a frequency
corresponding to said optimization; and
outputting a physiological measurement responsive to a component of said sensor signal at said frequency.

2. The signal processing method according to claim 1 wherein said determining step comprises the substeps of:

transforming said sensor signal to a frequency spectrum encompassing said estimated pulse rate; and
detecting an extrema of said spectrum indicative of said frequency.

3. The signal processing method according to claim 2 wherein said transforming step comprises the substeps of:

defining a window including said estimated pulse rate;
defining a plurality of selected frequencies within said window,
canceling said selected frequencies, individually, from said sensor signal to generate a plurality of remainder
signals; and
calculating a plurality of magnitudes of said remainder signals.

4. The signal processing method according to claim 3 wherein said detecting step comprises the substep of locating
a minima of said magnitudes.

5. The signal processing method according to claim 1 wherein said outputting step comprises the substeps of:

inputting a red (RD) portion and an infrared (IR) portion of said sensor signal;
deriving a RD component of said RD portion and an IR component of said IR portion corresponding to said
frequency; and
computing an oxygen saturation based upon a magnitude ratio of said RD component and said IR component.

6. The signal processing method according to claim 5 wherein said deriving step comprises the substeps of:

generating a sinusoidal waveform at said frequency; and
selecting said RD component and said IR component utilizing said waveform.

7. The signal processing method according to claim 6 wherein said selecting step comprises the substep of calculating
the Inner product between said waveform and said RD portion and the inner product between said waveform and
said IR portion.

8. The signal processing method according to claim 7 wherein said selecting step comprises the substeps of:

canceling said waveform from said RD portion and said IR portion, leaving a RD remainder and an IR remain-
der, and
subtracting said RD remainder from said RD portion and said IR remainder from said IR portion.

9. A signal processor comprising:

a first calculator means for deriving an optimization frequency from a pulse rate estimate and a sensor signal;
and
a second calculator means for deriving a physiological measurement responsive to a sensor signal component
at said frequency.

10. The signal processor according to claim 9 wherein said first calculator means comprises:

a signal component transform means for determining a plurality of signal values corresponding to a plurality of selected frequencies within a window including said pulse rate estimate; and
a detection means for determining a particular one of said selected frequencies corresponding to an optimization of said sensor signal.

11. The signal processor according to claim 10 wherein said second calculator means comprises:

a waveform means for generating a sinusoidal signal at said frequency;
a frequency selection means for determining a component of said sensor signal from said sinusoidal signal; and
a calculator means for deriving a ratio responsive to said component.

Patentansprüche

1. Signalverarbeitungsverfahren, das die folgenden Schritte aufweist:

Empfangen eines Sensorsignals;
Berechnen einer geschätzten Pulsrate;
Bestimmen einer Optimierung des Sensorsignals in der Nähe der geschätzten Pulsrate;
Definieren einer der Optimierung entsprechenden Frequenz; und
Ausgeben einer physiologischen Messung als Antwort auf eine Komponente des Sensorsignals bei der Frequenz.

2. Signalverarbeitungsverfahren nach Anspruch 1, wobei der Bestimmungsschritt die folgenden Teilschritte aufweist:

Transformieren des Sensorsignals in ein Frequenzspektrum, das die geschätzte Pulsrate umfaßt; und
Detektieren eines Extremwerts des Spektrums, welches die Frequenz anzeigt.

3. Signalverarbeitungsverfahren nach Anspruch 2, wobei der Transformationsschritt die folgenden Teilschritte aufweist:

Definieren eines Fensters, das die geschätzte Pulsrate enthält;
Definieren mehrerer ausgewählter Frequenzen innerhalb des Fensters;
einzelnes Löschen der ausgewählten Frequenzen aus dem Sensorsignal, um mehrere Restsignale zu erzeugen; und
Berechnen von mehreren Beträgen der Restsignale.

4. Signalverarbeitungsverfahren nach Anspruch 3, wobei der Detektionsschritt den Teilschritt des Auffindens eines Minimums der Beträge aufweist.

5. Signalverarbeitungsverfahren nach Anspruch 1, wobei der Ausgabeschritt die folgenden Teilschritte aufweist:

Eingeben eines roten (RD) Anteils und eines infraroten (IR) Anteils des Sensorsignals;
Ableiten einer RD-Komponente des RD-Anteils und einer IR-Komponente des IR-Anteils, die der genannten Frequenz entsprechen; und
Berechnen einer Sauerstoffsättigung auf der Basis eines Betragsverhältnisses der RD-Komponente und der IR-Komponente.

6. Signalverarbeitungsverfahren nach Anspruch 5, wobei der Ableitungsschritt die folgenden Teilschritte aufweist:

Erzeugen einer sinusförmigen Wellenform bei der genannten Frequenz; und
Auswählen der RD-Komponente und der IR-Komponente unter Verwendung der Wellenform.

7. Signalverarbeitungsverfahren nach Anspruch 6, wobei der Auswahlsschritt den Teilschritt des Berechnens des inneren Produkts aus der Wellenform und dem RD-Anteil und des inneren Produkts aus der Wellenform und dem IR-Anteil aufweist.

8. Signalverarbeitungsverfahren nach Anspruch 7, wobei der Auswahlschritt die folgenden Teilschritte aufweist:

Löschen der Wellenform aus dem RD-Anteil und dem IR-Anteil, wobei ein RD-Rest und ein IR-Rest übrig bleiben; und

Subtrahieren des RD-Rests von dem RD-Anteil und des IR-Rests von dem IR-Anteil.

9. Signalprozessor, der aufweist:

eine erste Berechnungseinrichtung zum Ableiten einer Optimierungsfrequenz aus einer Pulsratenschätzung und einem Sensorsignal; und

eine zweite Berechnungseinrichtung zum Ableiten einer physiologischen Messung als Antwort auf eine Sensorsignalkomponente bei der Frequenz.

10. Signalprozessor nach Anspruch 9, wobei die erste Berechnungseinrichtung aufweist:

eine Signalkomponenten-Transformationseinrichtung zum Bestimmen mehrerer Signalwerte, die mehreren ausgewählten Frequenzen innerhalb eines Fensters entsprechen, das die Pulsratenschätzung enthält; und eine Detektionseinrichtung zum Bestimmen einer bestimmten der ausgewählten Frequenzen, die einer Optimierung des Sensorsignals entspricht.

11. Signalprozessor nach Anspruch 10, wobei die zweite Berechnungseinrichtung aufweist:

eine Wellenformeinrichtung zum Erzeugen eines sinusförmigen Signals bei der genannten Frequenz; eine Frequenzauswahleinrichtung zum Bestimmen einer Komponente des Sensorsignals aus dem sinusförmigen Signal; und eine Berechnungseinrichtung zum Ableiten eines Verhältnisses als Antwort auf die Komponente.

Revendications

1. Procédé de traitement de signal comprenant les étapes consistant à :

recevoir un signal de capteur ;
calculer une vitesse d'impulsion estimée ;
déterminer une optimisation dudit signal de capteur proche de ladite vitesse d'impulsion estimée ;
définir une fréquence qui correspond à ladite optimisation ; et
sortir une mesure physiologique sensible à une composante dudit signal de capteur à ladite fréquence.

2. Procédé de traitement de signal selon la revendication 1, dans lequel ladite étape de détermination comprend les sous-étapes consistant à :

transformer ledit signal de capteur en un spectre de fréquence englobant ladite vitesse d'impulsion estimée ; et
détecter un extrema dudit spectre indiquant ladite fréquence.

3. Procédé de traitement de signal selon la revendication 2, dans lequel ladite étape de transformation comprend les sous-étapes consistant à :

définir une fenêtre comprenant ladite vitesse d'impulsion estimée ;
définir une pluralité de fréquences sélectionnées à l'intérieur de ladite fenêtre ;
éliminer lesdites fréquences sélectionnées, individuellement, dudit signal de capteur pour générer une pluralité de signaux résiduels ; et
calculer une pluralité d'amplitudes desdits signaux résiduels.

4. Procédé de traitement de signal selon la revendication 3, dans lequel ladite étape de détection comprend la sous-étape consistant à localiser un minima desdites amplitudes.

5. Procédé de traitement de signal selon la revendication 1, dans lequel ladite étape de sortie comprend les sous-étapes consistant à :

entrer une partie rouge (RD) et une partie infrarouge (IR) dudit signal de capteur ;
dériver une composante RD de ladite partie RD et une composante IR de ladite partie IR qui correspondent
à ladite fréquence ; et
calculer une saturation en oxygène sur la base d'un rapport d'amplitude entre ladite composante RD et ladite
composante IR.

6. Procédé de traitement de signal selon la revendication 5, dans lequel ladite étape consistant à dériver comprend
les sous-étapes consistant à :

générer une forme d'onde sinusoïdale à ladite fréquence ; et
sélectionner ladite composante RD et ladite composante IR en utilisant ladite forme d'onde.

7. Procédé de traitement de signal selon la revendication 6, dans lequel ladite étape de sélection comprend la sous-
étape consistant à calculer le produit interne entre ladite forme d'onde et ladite partie RD et le produit interne entre
ladite forme d'onde et ladite partie IR.

8. Procédé de traitement de signal selon la revendication 7, dans lequel ladite étape de sélection comprend les sous-
étapes consistant à :

éliminer ladite forme d'onde de ladite partie RD et de ladite partie IR, en laissant un signal résiduel RD et un
signal résiduel IR ; et
soustraire ledit signal résiduel RD de ladite partie RD et ledit signal résiduel IR de ladite partie IR.

9. Processeur de signal comprenant :

un premier moyen de calcul destiné à dériver une fréquence d'optimisation à partir d'une estimation de vitesse
d'impulsion et d'un signal de capteur ; et
un second moyen de calcul destiné à dériver une mesure physiologique sensible à une composante de signal
de capteur à ladite fréquence.

10. Processeur de signal selon la revendication 9, dans lequel ledit premier moyen de calcul comprend :

un moyen de transformation de composante de signal destiné à déterminer une pluralité de valeurs de signaux
correspondant à une pluralité de fréquences sélectionnées à l'intérieur d'une fenêtre comprenant ladite esti-
mation de vitesse d'impulsion ; et
un moyen de détection destiné à déterminer une particulière parmi lesdites fréquences sélectionnées corres-
pondant à une optimisation dudit signal de capteur.

11. Processeur de signal selon la revendication 10, dans lequel ledit second moyen de calcul comprend :

un moyen de génération de forme d'onde destiné à générer un signal sinusoïdal à ladite fréquence ;
un moyen de sélection de fréquence destiné à déterminer une composante dudit signal de capteur à partir
dudit signal sinusoïdal ; et
un moyen de calcul destiné à dériver un rapport sensible à ladite composante.

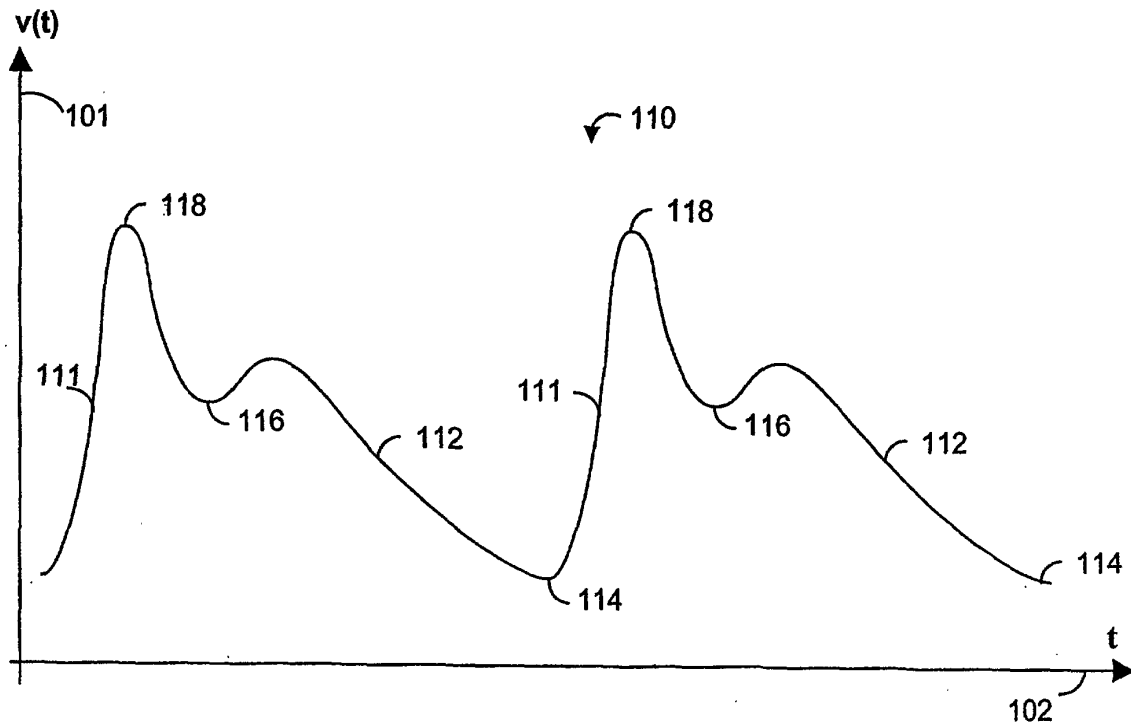


FIG. 1A

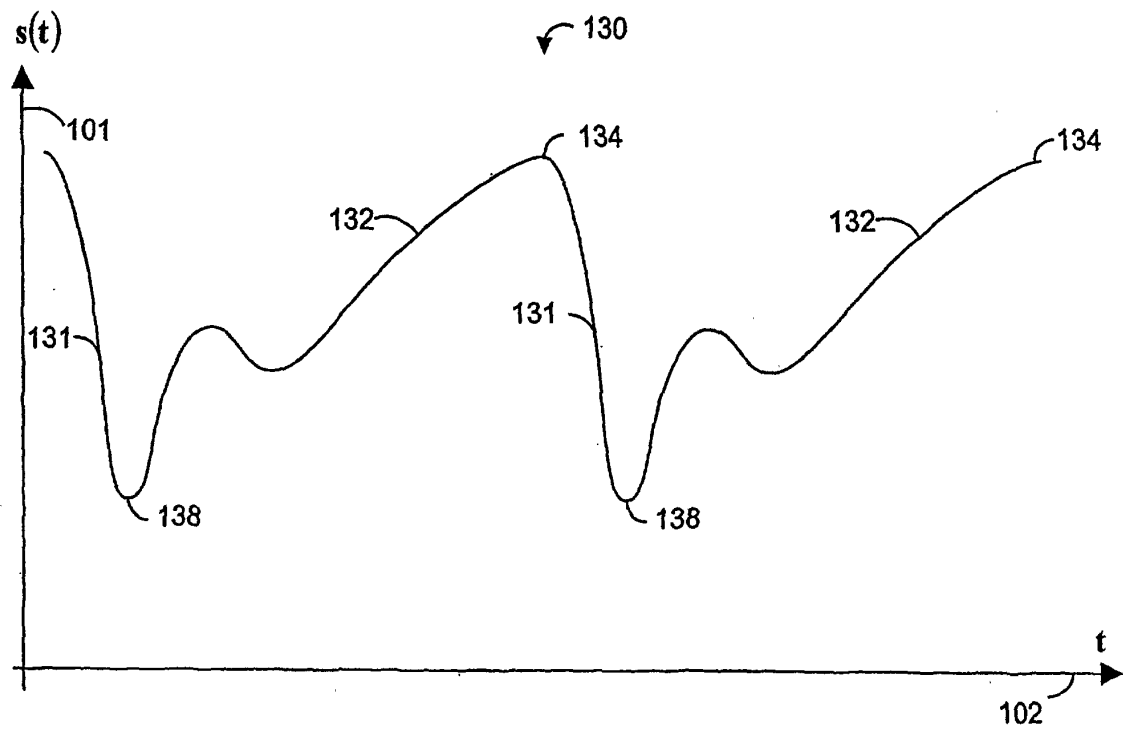


FIG. 1B

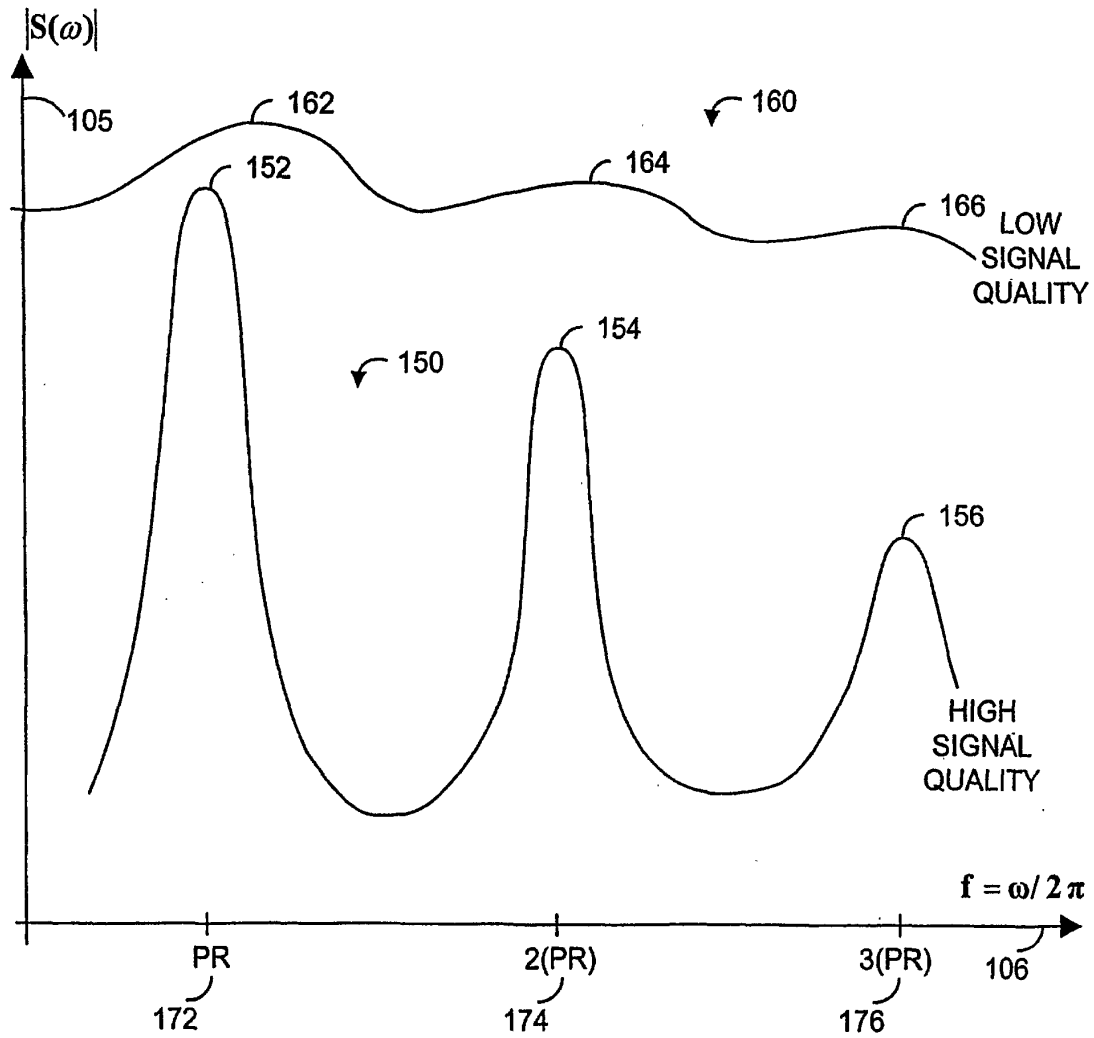


FIG. 1C

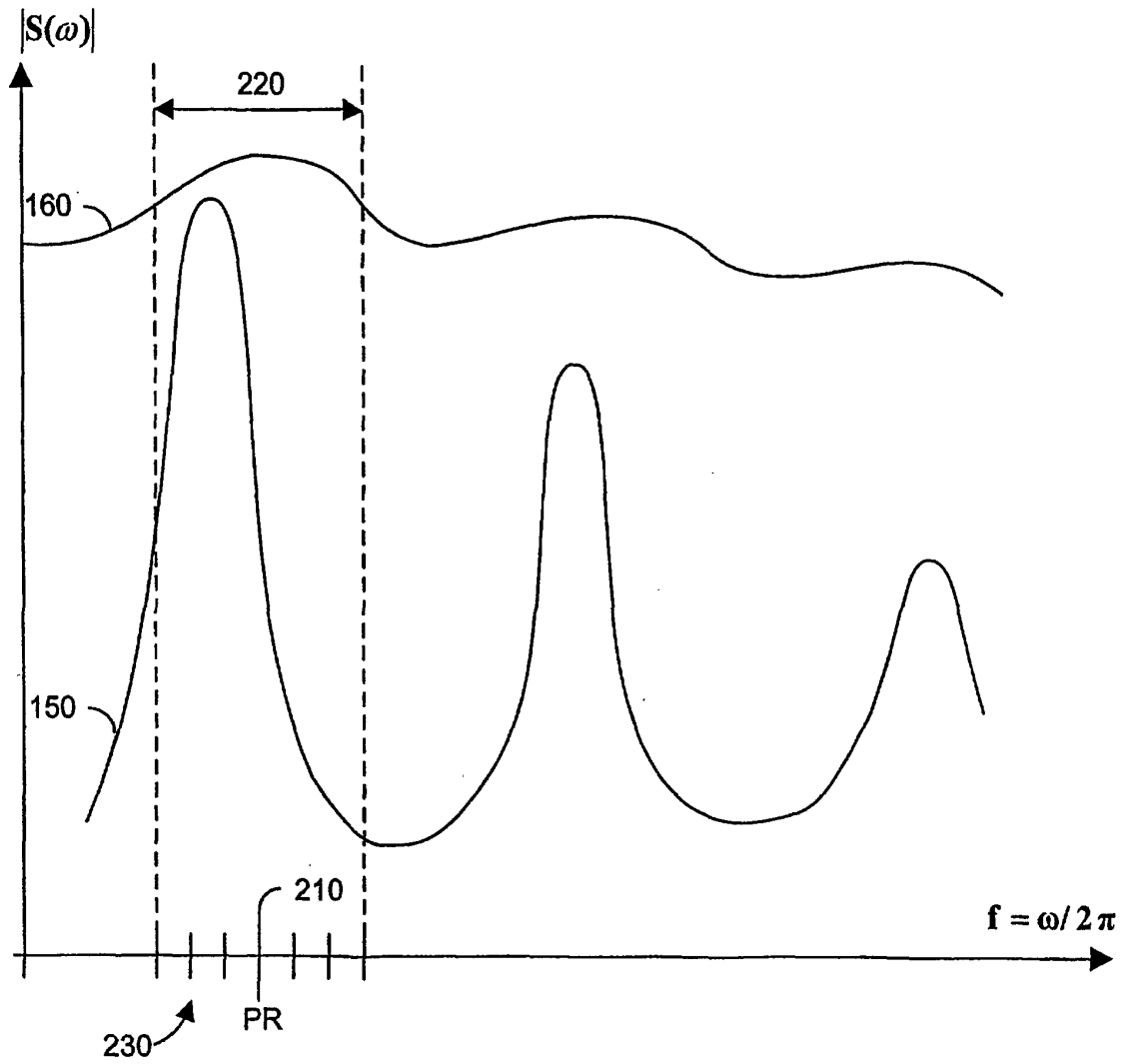


FIG. 2

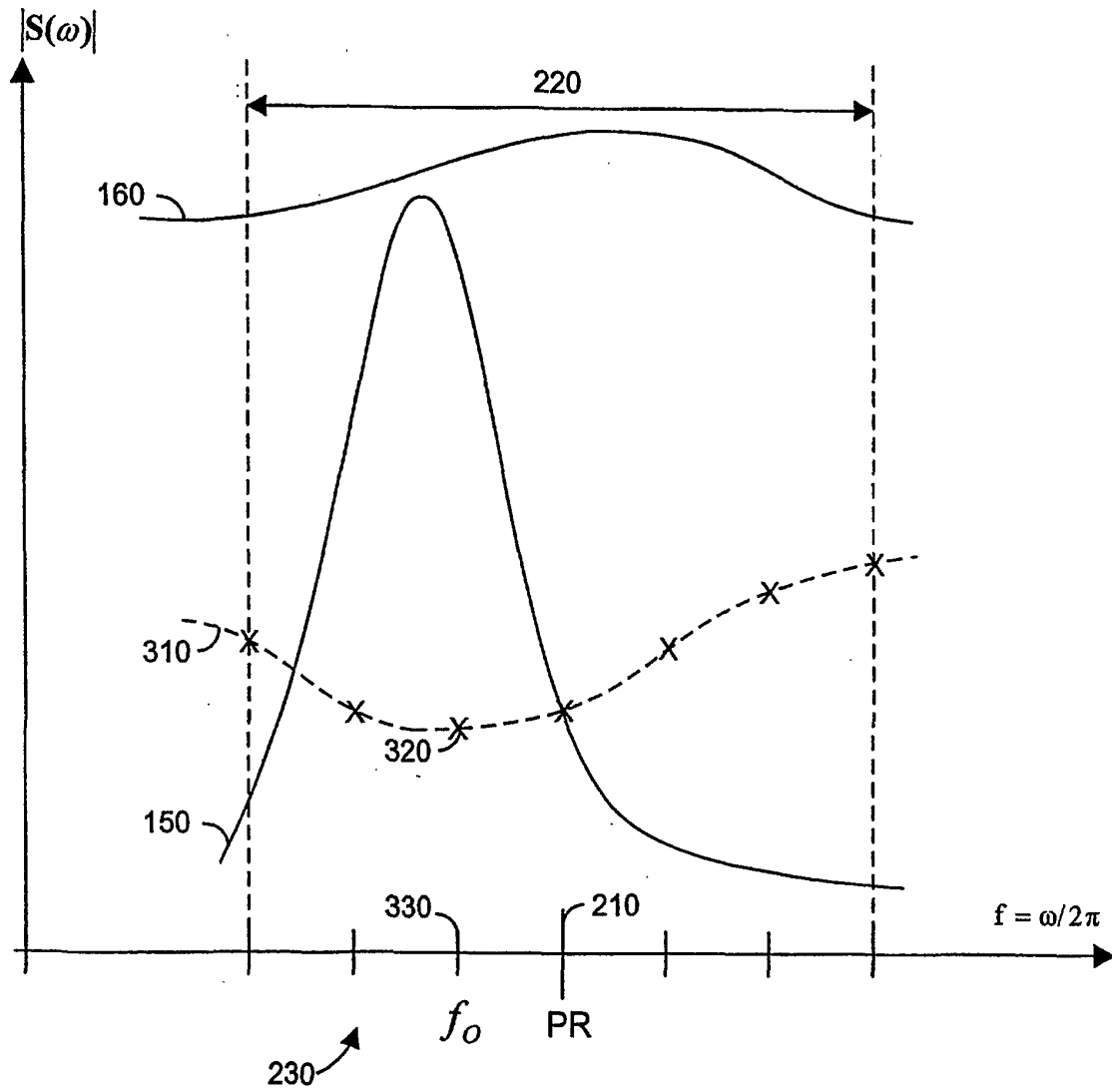


FIG. 3

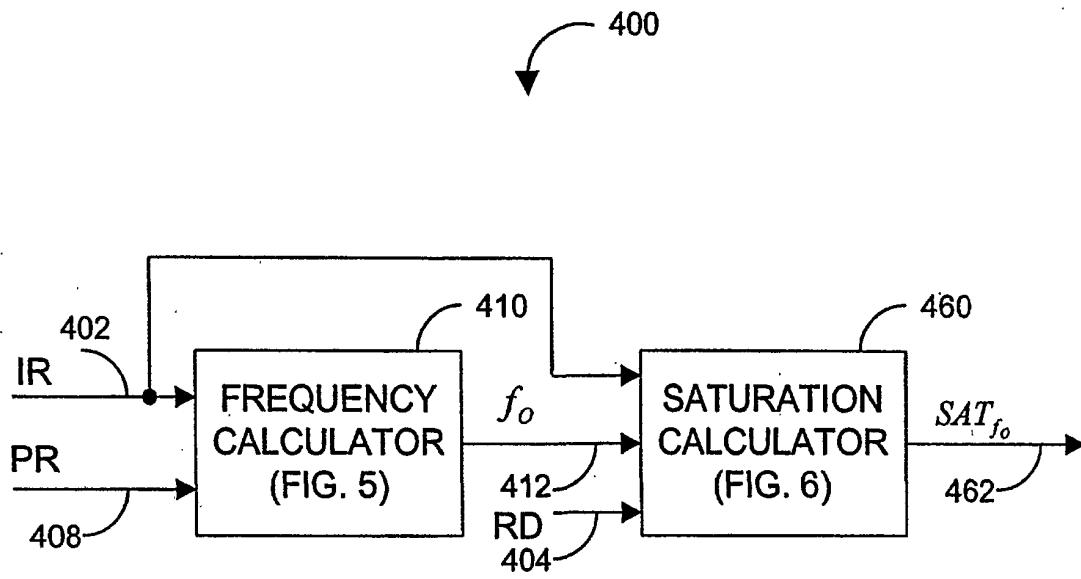


FIG. 4

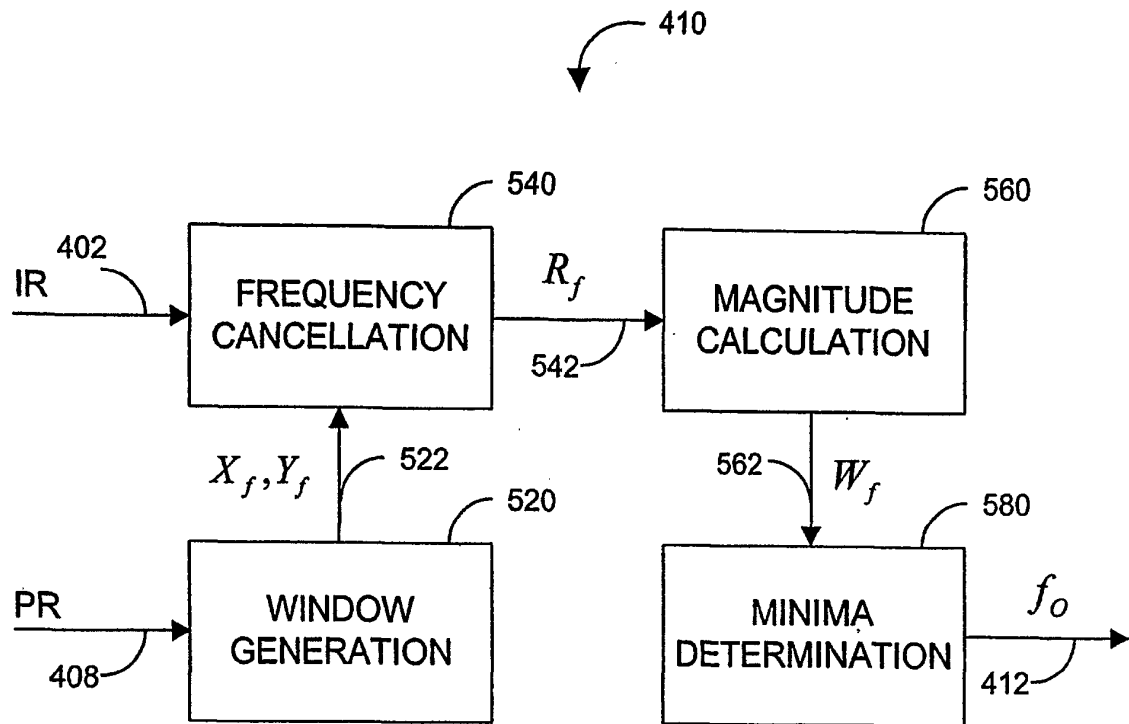


FIG. 5

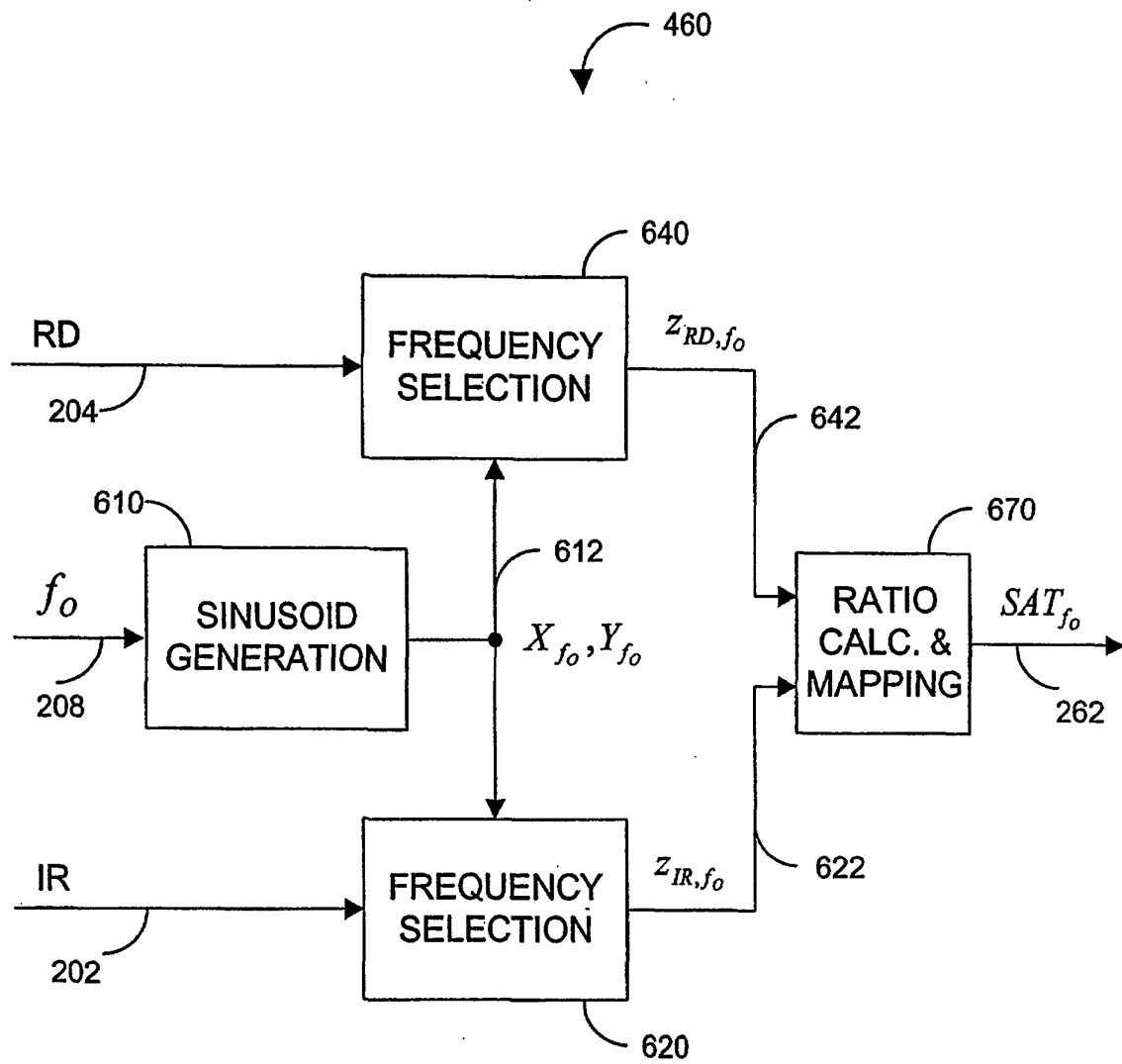


FIG. 6

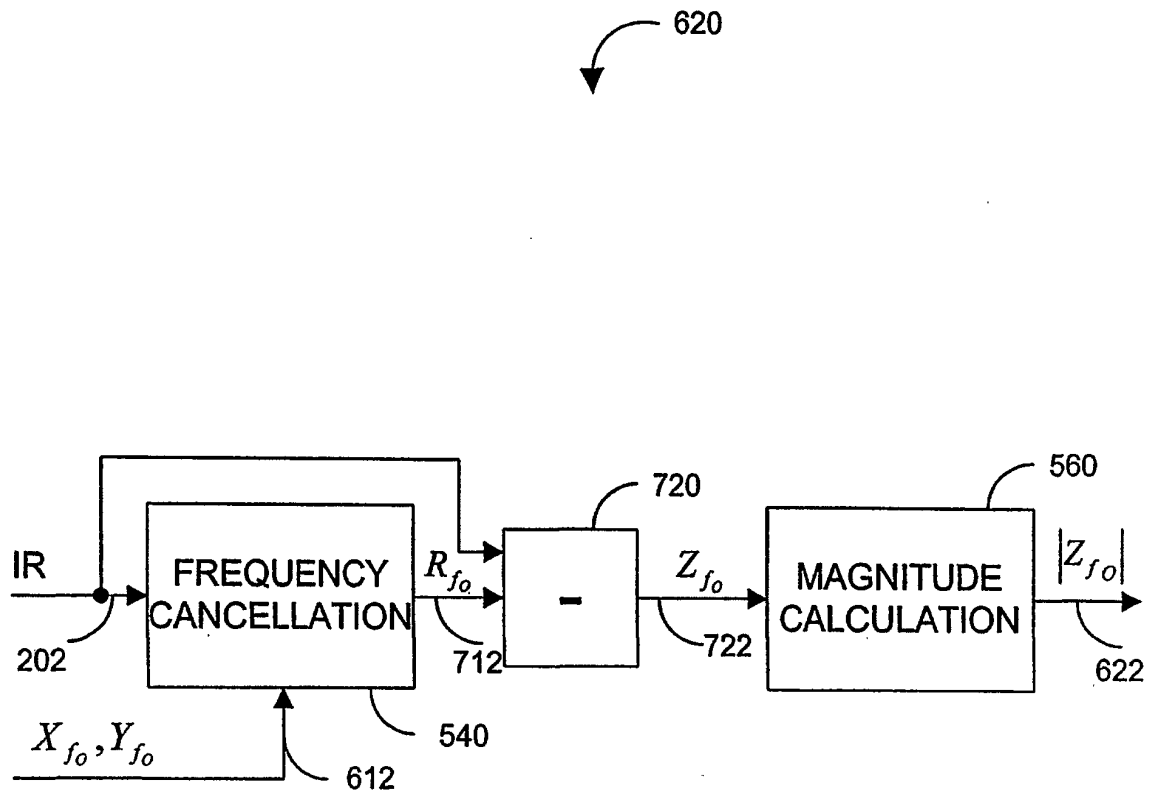


FIG. 7

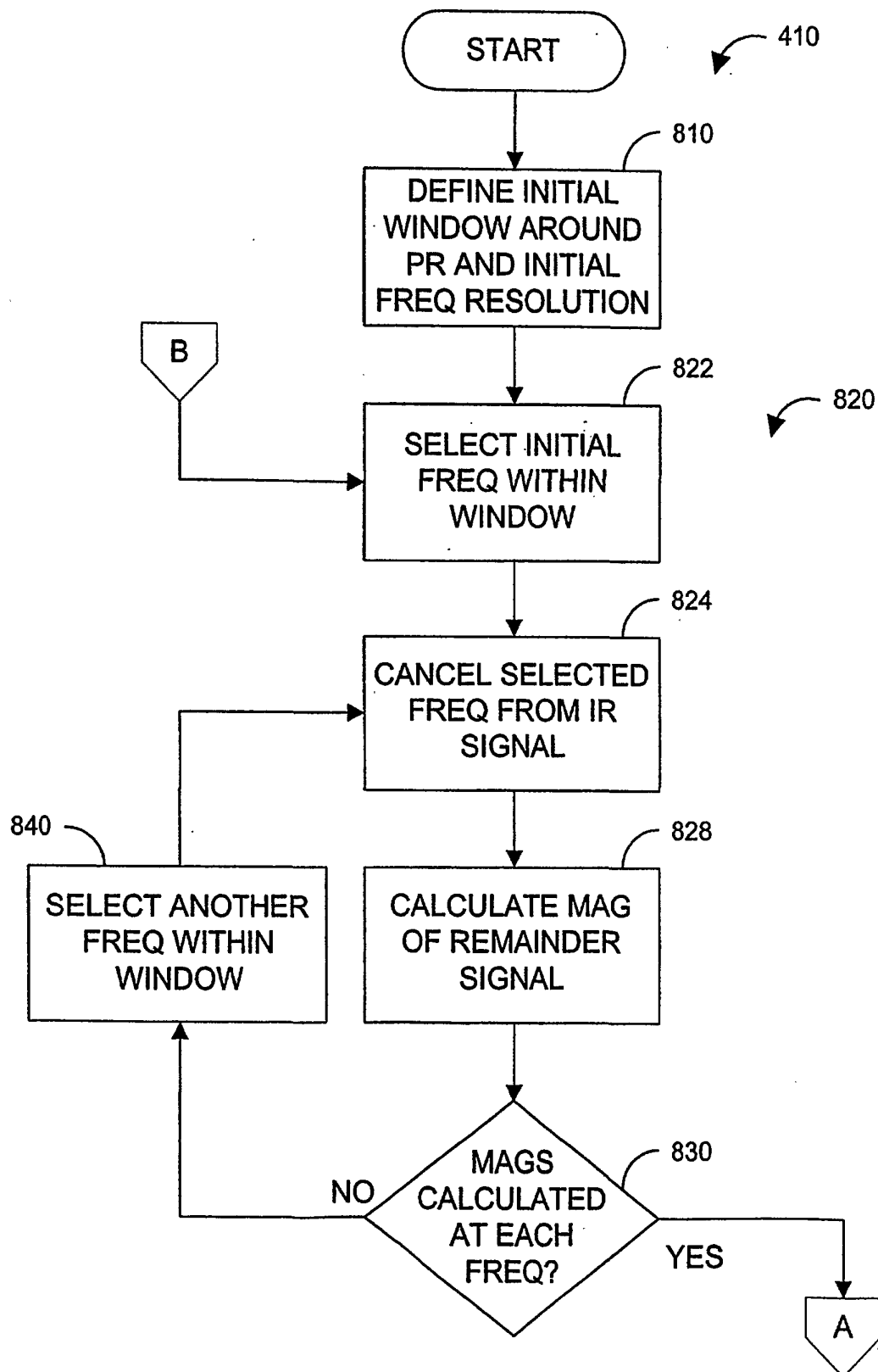


FIG. 8A

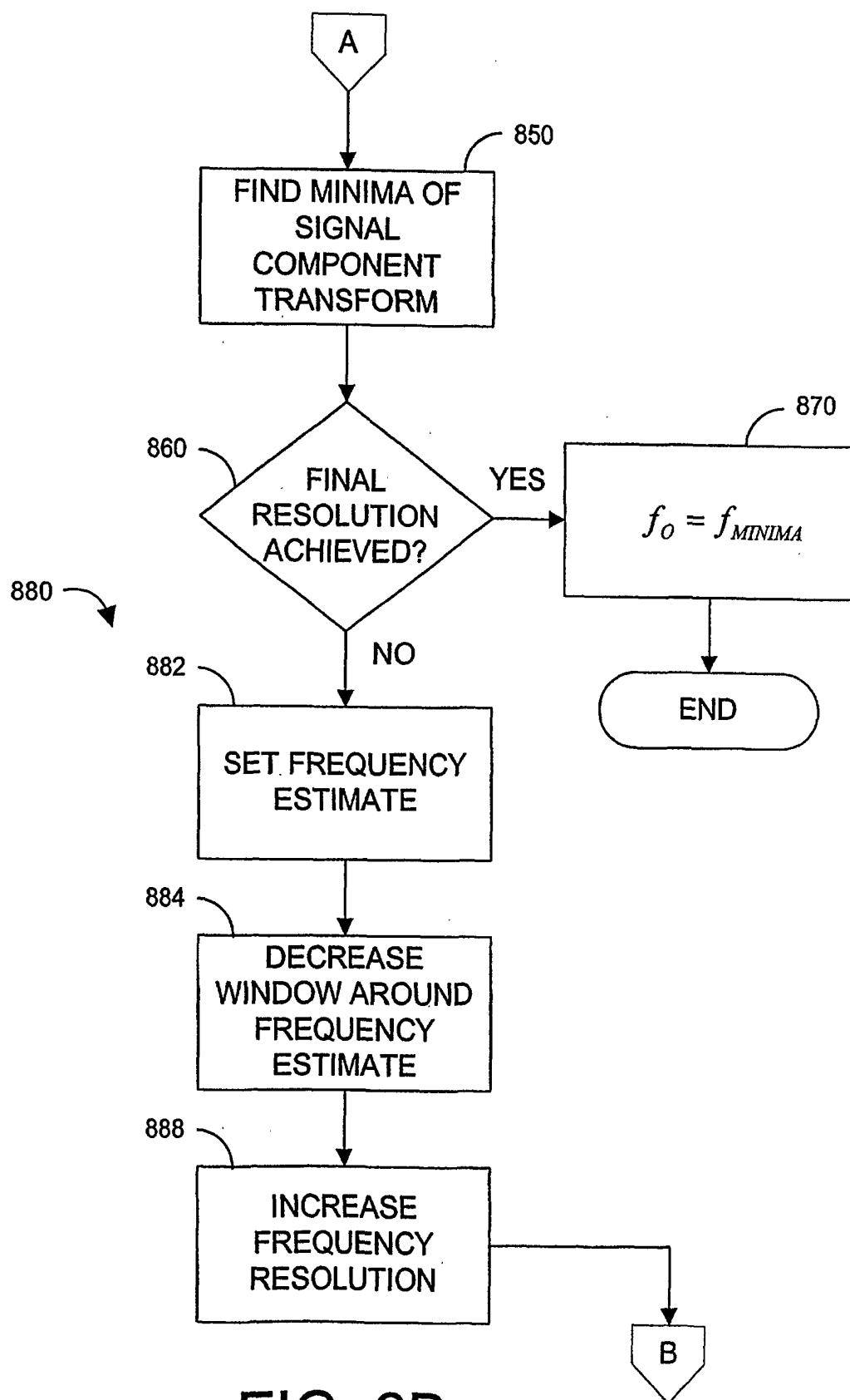


FIG. 8B

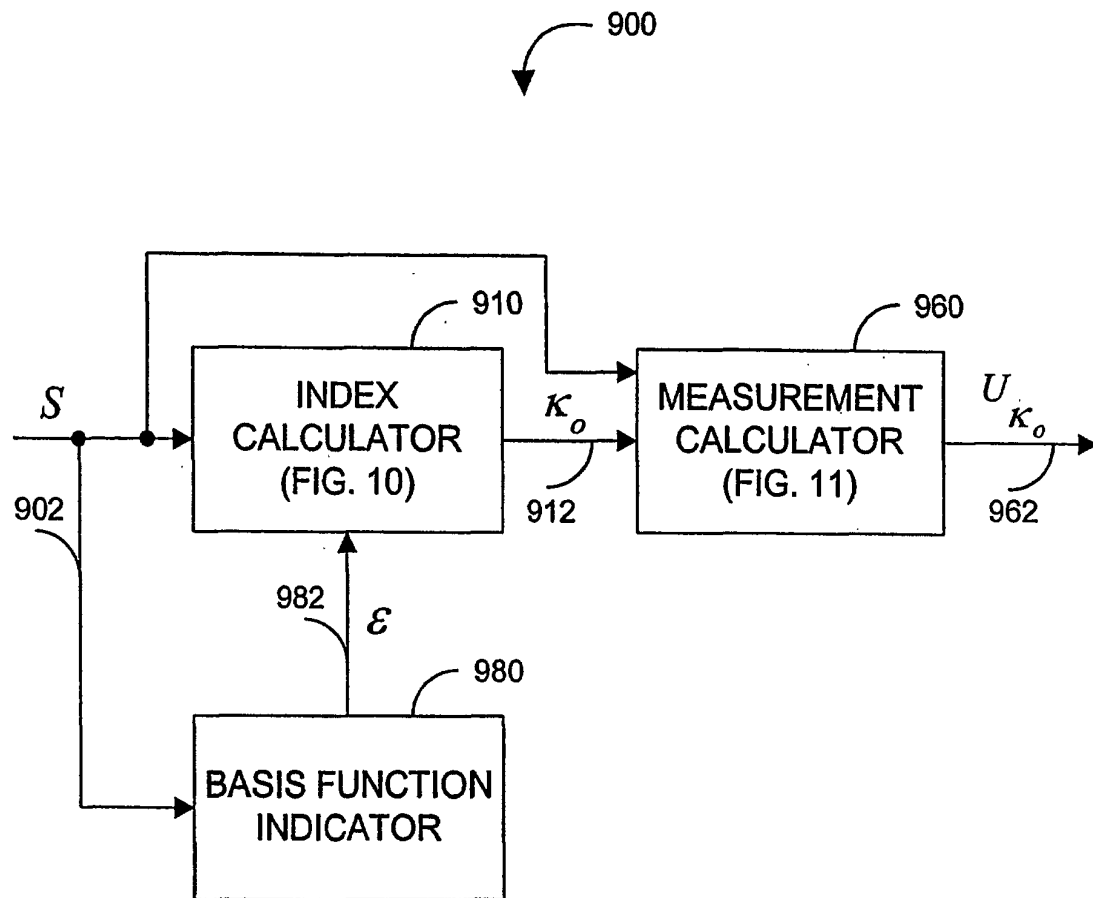


FIG. 9

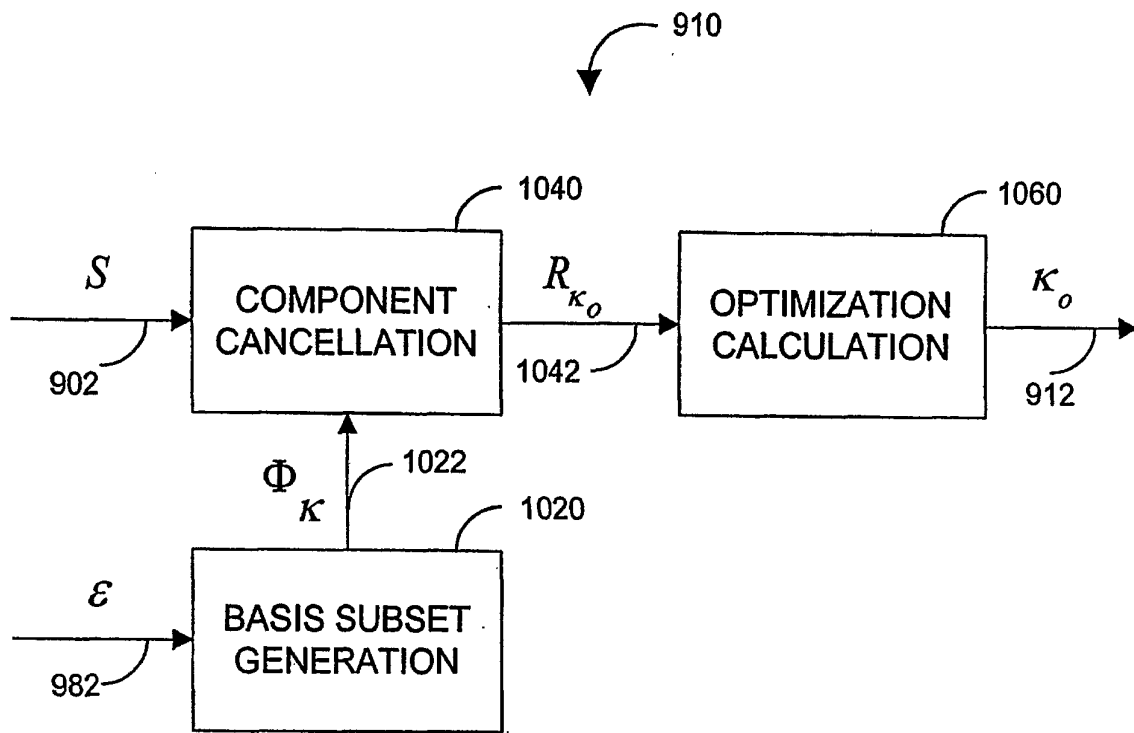


FIG. 10

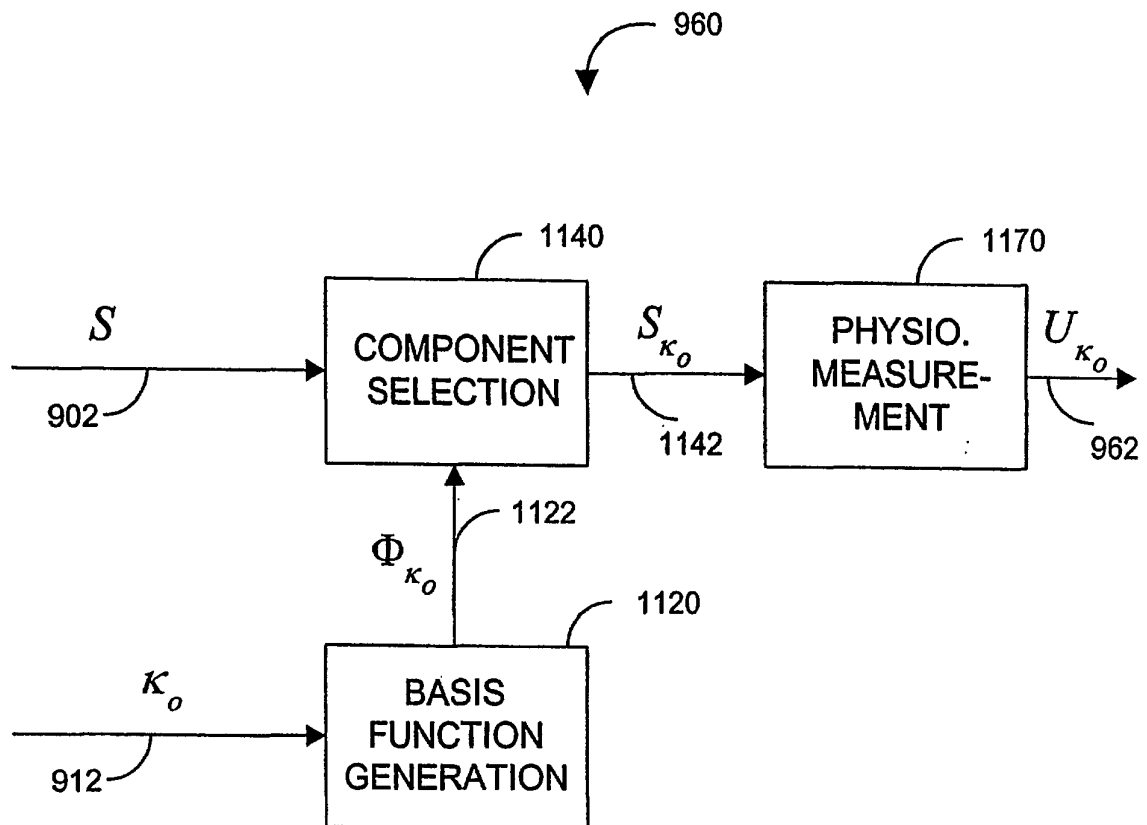


FIG. 11

专利名称(译)	信号分量处理器		
公开(公告)号	EP1399058B1	公开(公告)日	2005-11-30
申请号	EP2002742353	申请日	2002-06-28
[标]申请(专利权)人(译)	梅西莫股份有限公司		
申请(专利权)人(译)	Masimo公司		
当前申请(专利权)人(译)	Masimo公司		
[标]发明人	WEBER WALTER M AL ALI AMMAR CAZZOLI LORENZO		
发明人	WEBER, WALTER, M. AL-ALI, AMMAR CAZZOLI, LORENZO		
IPC分类号	A61B5/02 A61B5/00 A61B5/145 A61B5/1455		
CPC分类号	A61B5/14552 A61B5/024 A61B5/02433 A61B5/14532 A61B5/1455 A61B5/14551 A61B5/7282		
代理机构(译)	法思博事务所		
优先权	60/302438 2001-06-29 US		
其他公开文献	EP1399058A1		
外部链接	Espacenet		

摘要(译)

信号处理器生成基函数并识别传感器信号的至少一个基函数分量，以便计算生理测量。信号处理器有利地应用于脉搏血氧测定法，以便直接计算氧饱和度并且以便计算稳健的氧饱和度测量值。特别地，可以在导出的脉搏率估计周围的窗口内计算信号分量变换。信号分量变换还可以利用正弦基函数，并且信号分量变换的优化可以在特定频率或一组频率处发生。产生该频率或频率组的正弦波形或波形以选择传感器信号的相关红色和红外分量，并根据这些分量的幅度比计算氧饱和度。

$$R = \begin{bmatrix} R_0 \\ \vdots \\ R_{N-1} \end{bmatrix} \quad RD = \begin{bmatrix} RD_0 \\ \vdots \\ RD_{N-1} \end{bmatrix} \quad (1)$$