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(54) **PHYSIOLOGICAL PARAMETER TRACKING SYSTEM**

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(57) **ABSTRACT**

A physiological parameter tracking system generates a reference parameter and a slowly varying parameter responsive to a physiological signal input. The slowly varying parameter is generated according to an update command. A physiological measurement output is provided that is responsive to a tracking function of the reference parameter and the slowly varying parameter.
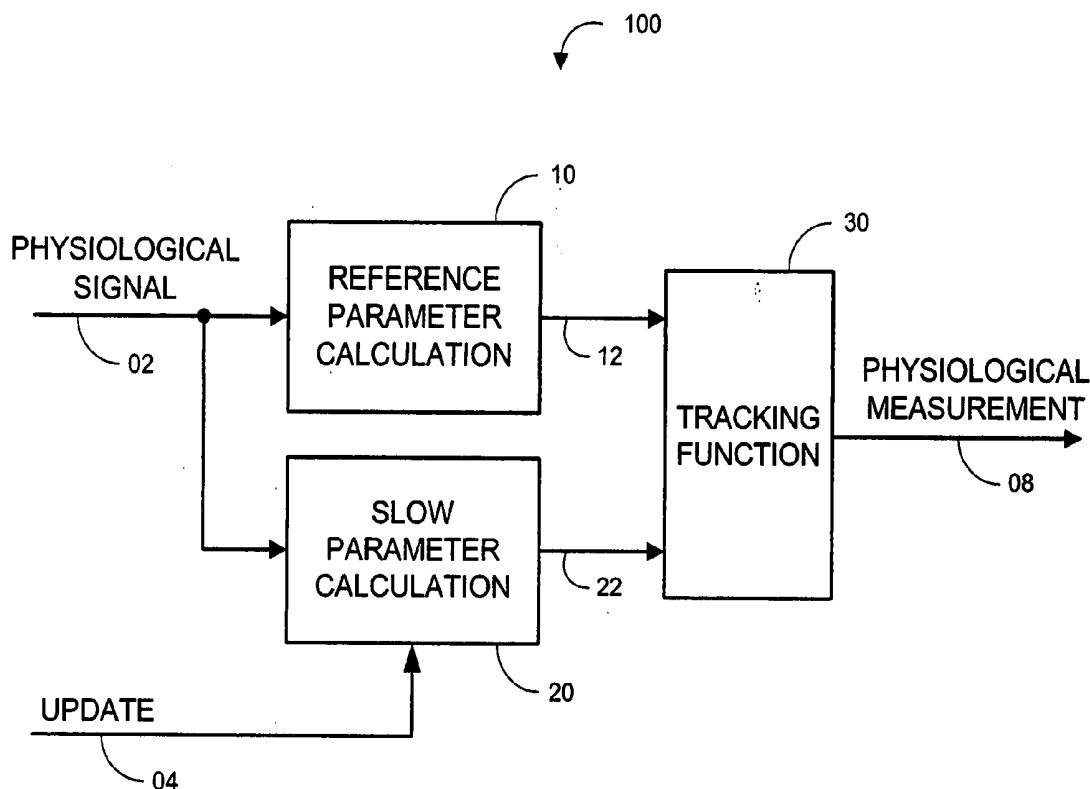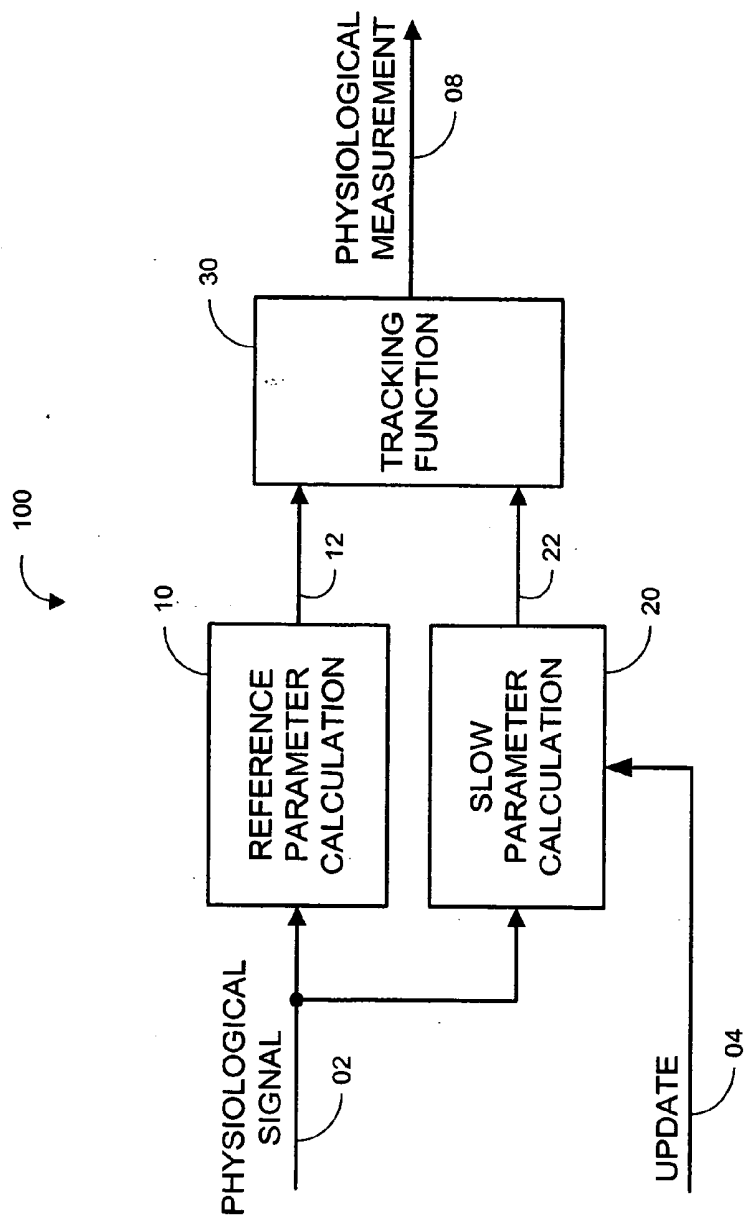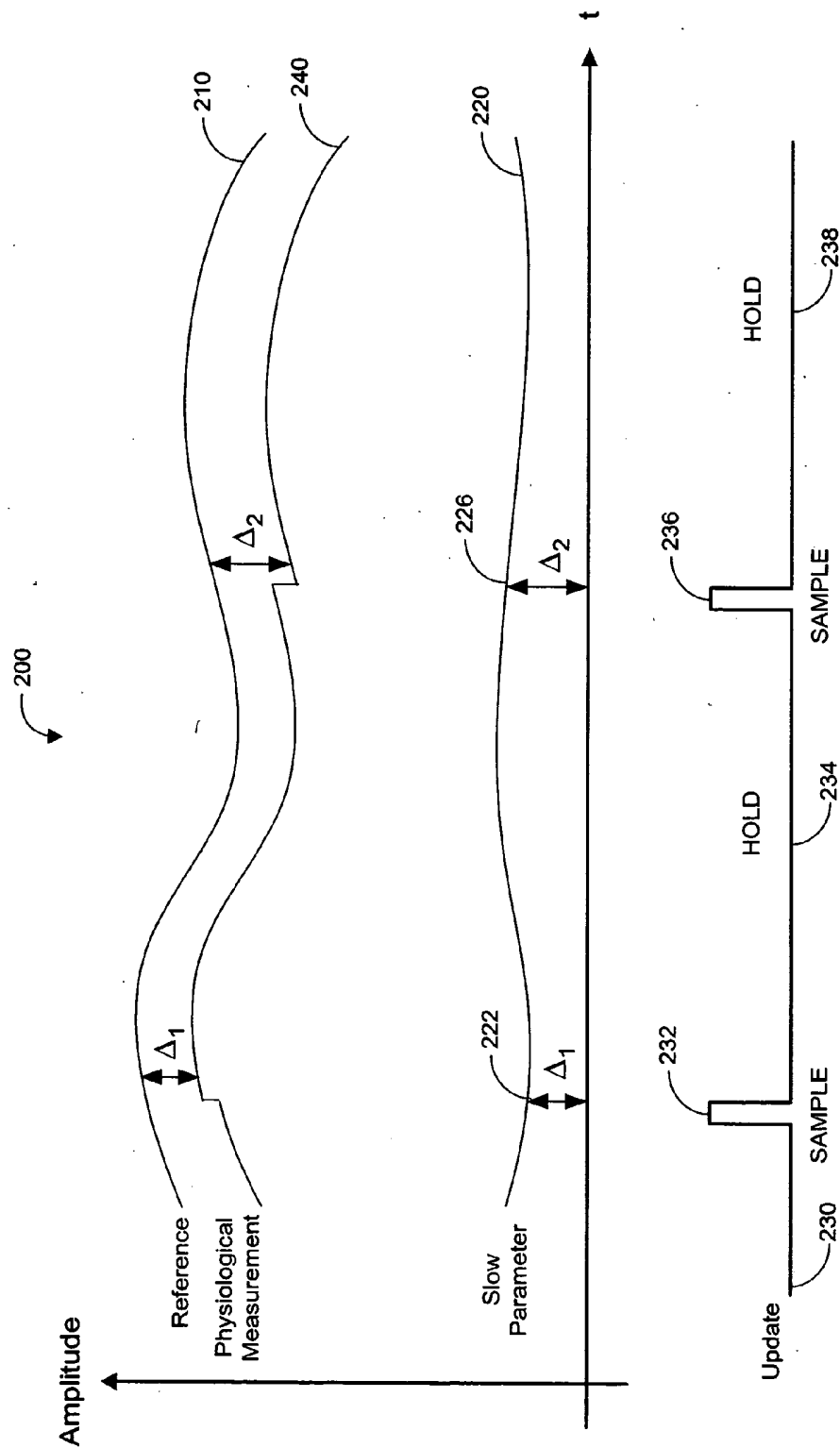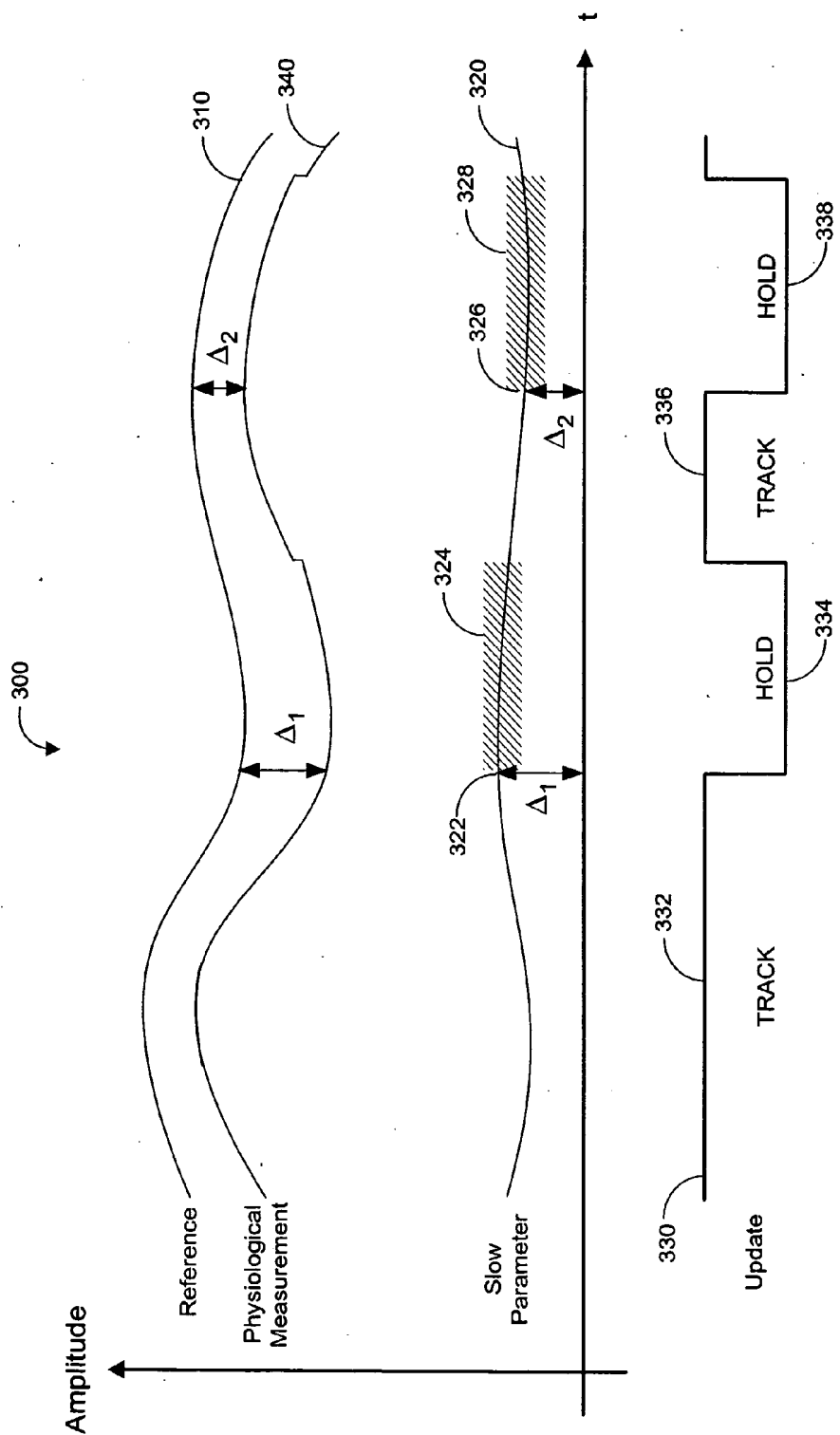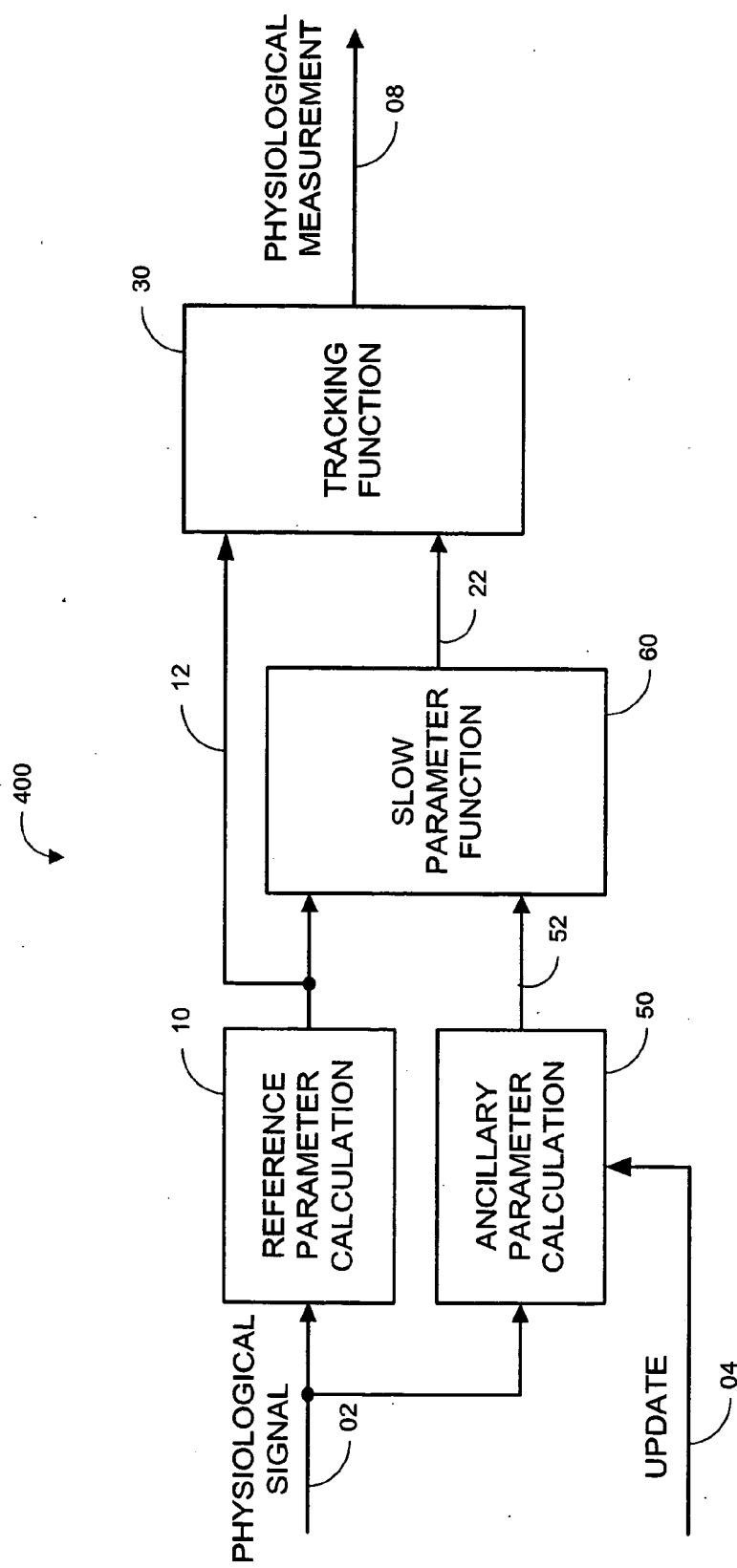
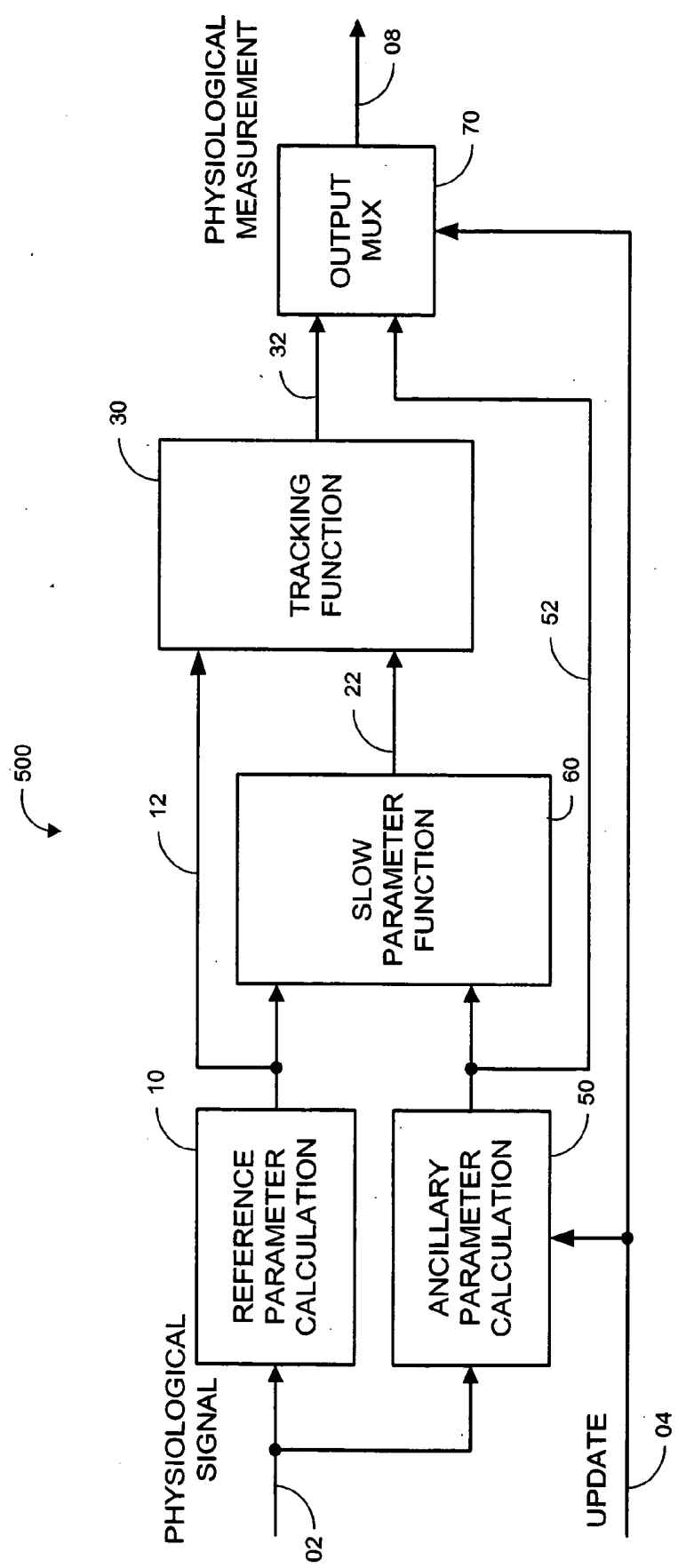FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

PHYSIOLOGICAL PARAMETER TRACKING SYSTEM

[0001] The present application claims benefit of U.S. Provisional Application No. 60/498,749 filed on Aug. 28, 2003, entitled "Physiological Parameter Tracking System." The present application incorporates the disclosure of the foregoing application herein by reference.

BACKGROUND OF THE INVENTION

[0002] Oxygen transport from the lungs to body tissue can be monitored by measuring various physiological parameters. For example, oxygen saturation of arterial blood (S_aO_2) is a measure of the ratio of oxyhemoglobin (HbO_2) concentration to the sum of HbO_2 and deoxyhemoglobin (Hb) concentrations in the arterial blood. Because HbO_2 is the major oxygen carrying component of blood, S_aO_2 is indicative of oxygen delivery to body tissues. As another example, oxygen saturation of venous blood (S_vO_2) is a similar measure of HbO_2 and Hb concentrations in venous blood and is indicative of oxygen consumption by body tissues. Measurements of the concentrations of carboxyhemoglobin (HbCO) and methemoglobin (MetHb) are indicative of abnormal hemoglobin constituents that interfere with oxygen transport.

[0003] Pulse oximetry is a noninvasive, easy to use, inexpensive procedure for measuring the oxygen saturation level of arterial blood. Pulse oximeters perform a spectral analysis of the pulsatile component of arterial blood in order to determine oxygen saturation ($S_{pa}O_2$), which is an estimate of S_aO_2. A pulse oximetry system has a sensor and a monitor. The sensor has emitters that typically consist of a red light emitting diode (LED) and an infrared LED that project light through blood vessels and capillaries underneath a tissue site, such as a fingernail bed. A sensor also has a detector that typically is a photodiode positioned opposite the LEDs so as to detect the emitted light as it emerges from the tissue site. A pulse oximetry sensor is described in U.S. Pat. No. 6,088,607 entitled "Low Noise Optical Probe," which is assigned to Masimo Corporation, Irvine, Calif. and incorporated by reference herein.

SUMMARY OF THE INVENTION

[0004] One aspect of a physiological parameter tracking system comprises a physiological signal input having first and second intensity signal components received from a light-sensitive detector that detects light of at least first and second wavelengths transmitted through body tissue carrying pulsing blood. The first and second intensity signal components are at least partially based on a pulse of the pulsing blood. A reference parameter is calculated in response to the physiological signal. Also, a slow parameter is generated in response to the physiological signal according to an update command. A physiological measurement output is generated in response to a tracking function of the reference parameter and the slowly varying parameter.

[0005] Another aspect of a physiological parameter tracking system is a method comprising the steps of inputting a physiological signal and calculating a reference parameter from the signal. Further steps include defining an update command, tracking the reference parameter according to the update command, and outputting a physiological measurement responsive to the tracking step.

[0006] A further aspect of a physiological parameter tracking system is a method comprising the steps of providing a physiological signal, calculating arterial oxygen saturation from the signal, and calculating a slowly varying parameter during a first period. Additional steps include holding the slowly varying parameter during a second period and outputting a physiological measurement responsive to the arterial oxygen saturation and the slowly varying parameter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a block diagram of a slow parameter calculation embodiment of a physiological parameter tracking system;

[0008] FIG. 2 is a graph illustrating operation of a physiological parameter tracking system in a sample and hold (S/H) mode;

[0009] FIG. 3 is a graph illustrating operation of a physiological parameter tracking system in a track and hold (T/H) mode;

[0010] FIG. 4 is a block diagram of an ancillary calculation embodiment of a physiological parameter tracking system for operation in a S/H mode; and

[0011] FIG. 5 is a block diagram of an ancillary calculation embodiment of a physiological parameter tracking system for operation in a T/H mode.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0012] Overview

[0013] FIGS. 1, 4 and 5 illustrate embodiments of a physiological parameter tracking system that advantageously provide a clinically accurate physiological measurement by tracking a reference parameter based upon a slowly varying ("slow") parameter. As such, it is not necessary to continuously or frequently perform complex calculations to derive the physiological measurement. That is, the physiological measurement is a relatively simple function of the reference parameter and the slow parameter. Slow parameter calculations are performed only when conditions are favorable, or alternatively, suspended when conditions are not favorable, as indicated by an update command. The update command may be responsive to conditions such as power consumption goals or the quality of a physiological signal input to name a few.

[0014] In one embodiment, the slow parameter is HbCO or MetHb and the reference parameter is $S_{pa}O_2$. Accordingly, the physiological measurement is $S_{pa}O_2$ corrected for the presence of one or both of these abnormal hemoglobin constituents. In another embodiment, the slow parameter is $\Delta_{av}=S_{pa}O_2-S_vO_2$, a measure of oxygen consumption at a tissue site, and the reference parameter is $S_{pa}O_2$. Accordingly, the physiological measurement is an estimate of S_vO_2.

[0015] Slow Parameter Calculation

[0016] FIG. 1 illustrates a slow parameter calculation embodiment of a physiological parameter tracking system 100 in which the slow parameter 22 is derived from and responsive to a physiological signal 02. The physiological parameter tracking system 100 has a physiological signal 02 input, a reference parameter calculation 10, a slow param-

eter calculation **20** and a tracking function **30** and generates a physiological measurement **08** output. The reference parameter calculation **10** generates a reference parameter **12** from the physiological signal **02**. The slow parameter calculation **20** generates the slow parameter **22** from the physiological signal **02** input. The tracking function **30** generates the physiological measurement **08** from the reference parameter **12** and the slow parameter **22**.

[0017] As shown in **FIG. 1**, the physiological signal **02** is responsive to a physiological condition. In one embodiment, the physiological signal **02** originates from an optical sensor (not shown) attached to a tissue site. The sensor transmits multiple wavelengths of optical energy $\lambda_1, \lambda_2, \ldots, \lambda_n$ into the tissue site and detects corresponding optical energy emerging from the tissue site. The reference parameter calculation **10** may include pulse oximetry algorithms that operate on the physiological signal **02** to generate arterial oxygen saturation, $S_{pa}O_2$, as the reference parameter **12**. A pulse oximetry signal processor and algorithms are described in U.S. Pat. No. 5,632,272 entitled Signal Processing Apparatus which is assigned to Masimo Corporation, Irvine, Calif. and incorporated by reference herein.

[0018] Also shown in **FIG. 1**, the slow parameter calculation **20** generates a slow parameter **22** from the physiological signal input **02** according to an update command **04**. As an example, the slow parameter calculation **20** may include algorithms that operate on the physiological signal **02** to generate a measure of the concentration of abnormal hemoglobin, such as HbCO or MetHb. Multiple wavelength signal processing for measuring abnormal hemoglobin constituents, for example, is described in U.S. Provisional Patent App. No. 60/426,638 entitled "Parameter Compensated Physiological Monitor," U.S. Provisional Patent App. No. 60/428,419 entitled "Blood Parameter Measurement System," and U.S. Pat. No. 6,229,856 entitled "Method and Apparatus for Demodulating Signals in a Pulse Oximetry System, which is assigned to Masimo Corporation, Irvine, Calif., all incorporated by reference herein.

[0019] Further shown in **FIG. 1**, the update command **04** may operate in a sample and hold (S/H) mode. That is, when the update command **04** is asserted, the slow parameter calculation **20** is triggered and the resulting slow parameter **22** value is held until a subsequent calculation. Operation of a physiological parameter tracking system having a S/H update is described with respect to **FIG. 2**, below. Alternatively, the update command **04** may operate in a track and hold (T/H) mode. That is, while the update command **04** is asserted, the slow parameter calculation **20** continues to generate values for the slow parameter **22**. When the update command **04** is not asserted, the last generated value of the slow parameter **22** is held until the update command **04** is once more asserted. Operation of a physiological parameter tracking system having a T/H update is described with respect to **FIG. 3**, below.

TRACKING EXAMPLES

[0020] **FIG. 2** is an amplitude versus time graph **200** illustrating operation of a physiological parameter tracking system utilizing a S/H update. The graph **200** illustrates a reference curve **210** corresponding to a reference parameter **12 (FIG. 1)** and a slow parameter curve **220** corresponding to a slow parameter **22 (FIG. 1)**. Below the graph **200** is a

timing diagram **230** corresponding to the update command **04 (FIG. 1)**. A physiological measurement curve **240** corresponds to the physiological measurement **08 (FIG. 1)**.

[0021] As shown in **FIG. 2**, the physiological measurement curve **240** tracks the reference curve **210** according to a tracking function **30 (FIG. 1)**, which in this illustration is the difference between the reference parameter **12 (FIG. 1)** and the slow parameter **22 (FIG. 1)**. A slow parameter **220** value is calculated at sample times **232, 236** and maintained throughout hold periods **234, 238**. In particular, during a first sample time **232**, a slow parameter value **222** of Δ_1 is calculated, and during a second sample time **236**, a slow parameter value **226** of Δ_2 is calculated. As a result, during a first hold period **234**, the physiological measurement curve **240** tracks the reference curve **210** by a difference of Δ_1. Likewise, during a second hold period **238**, the physiological measurement curve **240** tracks the reference curve **210** by a difference of Δ_2. In this manner, the physiological measurement **240** is advantageously displayed with clinical accuracy utilizing only occasional computational resources and reducing power consumption accordingly.

[0022] **FIG. 3** is an amplitude versus time graph **300** illustrating operation of a physiological parameter tracking system utilizing a T/H update. The graph **300** illustrates a reference curve **310** corresponding to a reference parameter **12 (FIG. 1)** and a slow parameter curve **320** corresponding to a slow parameter **22 (FIG. 1)**. Below the graph **300** is a timing diagram **330** corresponding to the update command **04 (FIG. 1)**. A physiological measurement curve **340** corresponds to the physiological measurement **08 (FIG. 1)**.

[0023] As shown in **FIG. 3**, the physiological measurement curve **340** tracks the reference curve **310** according to a tracking function **30 (FIG. 1)**, which, again, is the difference between the reference parameter **12 (FIG. 1)** and the slow parameter **22 (FIG. 1)**. Slow parameter **320** values are calculated throughout track periods **332, 336**, and the last computed values are maintained throughout the corresponding hold periods **334, 338**. In particular, during a first track period **332**, the physiological measurement curve **340** is the reference curve **310** minus the slow parameter curve **320**. At the end of the first track period **332**, a slow parameter value **332** of Δ_1 is maintained throughout the first hold period **334**. As a result, during the first hold period **334**, the physiological measurement curve **340** is the reference curve **310** minus Δ_1 and does not depend on the slow parameter curve **320**. That is, during the first hold period **332**, the physiological measurement curve **340** tracks the reference curve **310** by a difference of Δ_1.

[0024] The "track" periods **332, 336** are so named because the slow parameter calculation **20 (FIG. 1)** in response to the update timing **330** operates in a manner roughly analogous to a conventional track/hold amplifier when its output tracks the input. These are not to be confused with the periods when the physiological measurement curve **340** is "tracking" the reference parameter curve **310**, which actually is during the hold periods **334, 338**, when the slow parameter **22 (FIG. 1)** output is held constant.

[0025] Also shown in **FIG. 3**, during a second track period **336**, the physiological measurement curve **340** is again the reference curve **310** minus the slow parameter curve **320**. At the end of the second track period **336**, a slow parameter value **326** of Δ_2 is maintained throughout the second hold

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period 338. As a result, during the second hold period 338, the physiological measurement curve 340 is the reference curve 310 minus Δ_2 and does not depend on the slow parameter curve 320. That is, during the second hold period 338, the physiological measurement curve 340 tracks the reference curve 310 at a difference of Δ_2.

[0026] Further shown in **FIG. 3**, the hold periods 334, 338 may correspond to slow parameter drop-out periods 324, 328, i.e. periods when the slow parameter cannot be accurately calculated. In this manner, the physiological measurement 340 is advantageously displayed with clinical accuracy even when noise or other signal corruption prevents measurement of the slow parameter 320.

[0027] Ancillary Parameter Calculation

[0028] **FIG. 4** illustrates an ancillary parameter calculation embodiment of a physiological parameter tracking system 400 in which the slow parameter 22 is derived from an ancillary parameter 52 in S/H mode. The ancillary parameter 52, in turn, is derived from a physiological signal 02. That is, unlike the slow parameter calculation embodiment 100 (**FIG. 1**), the slow parameter 22 is only indirectly derived from and responsive to the physiological signal 02. The physiological parameter tracking system 400 has a physiological signal 02 input, a reference parameter calculation 10 and a tracking function 30, and, accordingly, generates a physiological measurement 08, similarly as described with respect to **FIG. 1**, above. However, in the ancillary calculation embodiment 400, the slow parameter 22 is a function 60 of the reference parameter 12 and/or an ancillary parameter 52. An ancillary parameter calculation 50 generates the ancillary parameter 52 from the physiological signal input 02 according to a S/H update command 04 input, such as described with respect to **FIG. 2**, above.

[0029] As an example, the ancillary parameter calculation 50 may include algorithms that operate on the physiological signal 02 to intermittently calculate venous oxygen saturation, $S_{pv}O_2$, as determined by a S/H update command 04. A corresponding slow parameter function 60 is the difference between an $S_{pa}O_2$ reference parameter 12 and the $S_{pv}O_2$ ancillary parameter 52 to yield a Δ_{av} slow parameter 22. Then, the tracking function 30 is a difference between the $S_{pa}O_2$ reference parameter 12 and the sampled Δ_{av} slow parameter 22 to generate a $S_{pv}O_2'$ physiological measurement 08. That is, the physiological measurement 08 in this example advantageously provides a continuous measurement of venous saturation $S_{pv}O_2'$ utilizing intermittent calculations of $S_{pv}O_2$. Apparatus and methods for determining $S_{pv}O_2$ from mechanical or ventilator induced perturbation of the venous blood volume are described in U.S. Pat. No. 5,638,816 entitled "Active Pulse Blood Constituent Monitoring" and U.S. Pat. No. 6,334,065 entitled "Stereo Pulse Oximeter," which are assigned to Masimo Corporation, Irvine, Calif. and are incorporated by reference herein. As another example, the ancillary parameter calculation 50 may include algorithms that operate on the physiological signal 02 to intermittently calculate abnormal hemoglobin concentration, such as HbCO and/or MetHb, as determined by a S/H update command 04.

[0030] **FIG. 5** illustrates an ancillary parameter calculation embodiment of a physiological parameter tracking system 500 in which the slow parameter 22 is derived from an ancillary parameter 52 in T/H mode. The ancillary

parameter 52, in turn, is derived from a physiological signal 02. The physiological parameter tracking system 500 has a physiological signal 02 input, a reference parameter calculation 10, an ancillary parameter calculation 50, a slow parameter function 60 and a tracking function 30, and, accordingly, generates a physiological measurement 08, similarly as described with respect to **FIG. 4**, above. However, in this ancillary calculation embodiment 500, the update command 04 operates in a track and hold mode, as described with respect to **FIG. 3**, above. Accordingly, the ancillary calculation embodiment 500 also has an output multiplexer 70 having the tracking function output 32 and the ancillary parameter 52 as inputs and the physiological measurement 08 as an output, as controlled by the update command 04 input. As such, the physiological measurement 08 is the ancillary parameter 52 during a track period 332, 336 (**FIG. 3**) of the update command 04 and is a function of the ancillary parameter 52 and the reference parameter 10 during a hold period 334, 338 (**FIG. 3**) of the update command 04. That is, the physiological measurement 08 is advantageously the ancillary parameter 52 except during a hold period, when the physiological measurement 08 tracks the reference parameter 12 according to the maintained value of the slow parameter 22.

[0031] As an example, the ancillary parameter calculation 50 may continuously calculate venous oxygen saturation, $S_{pv}O_2$, as determined by the update command 04 during track periods, and this calculation is provided as the physiological measurement 08. However, during hold periods of the update command 04, the physiological measurement 08 becomes $S_{pv}O_2'$, i.e. the $S_{pa}O_2$ reference parameter 12 minus a maintained value of the Δ_{av} slow parameter 22. The physiological measurement 08 in this example advantageously provides a measurement of venous saturation that is continuous through drop-out periods.

[0032] A physiological parameter tracking system 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.

What is claimed is:

1. A physiological parameter tracking system comprising:

a physiological signal input having at least first and second intensity signal components received from a light-sensitive detector that detects light of at least first and second wavelengths transmitted through body tissue carrying pulsing blood, wherein the first and second intensity signal components are at least partially based on a pulse of the pulsing blood;

a reference parameter responsive to said physiological signal;

an update command;

a slow parameter responsive to said physiological signal according to said update command;

a tracking function responsive to said reference parameter and said slow parameter; and

a physiological measurement output responsive to said tracking function.

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2. The physiological parameter tracking system according to claim 1 further comprising an ancillary parameter responsive to said physiological signal, wherein said slow parameter is responsive to a slow parameter function of said reference parameter and said ancillary parameter.

3. The physiological parameter tracking system according to claim 2 further comprising an output multiplexer configured so that said physiological measurement is responsive to one of said tracking function output and said ancillary parameter according to said update command.

4. The physiological parameter tracking system according to claim 1 wherein said slow parameter is a measure of abnormal hemoglobin, said reference parameter is a measure of oxygen saturation and said physiological measurement is indicative of oxygen saturation corrected for abnormal hemoglobin.

5. The physiological parameter tracking system according to claim 2 wherein said ancillary parameter is a measure of venous oxygen saturation, said reference parameter is a measure of arterial oxygen saturation, said slow parameter is a measure of oxygen consumption and said physiological measurement is indicative of venous oxygen saturation.

6. The physiological parameter tracking system according to claim 1 wherein said update command operates in at least one of a sample and hold mode and a track and hold mode.

7. The physiological parameter tracking system according to claim 1 wherein said tracking function output is responsive to a difference between said reference parameter and said slow parameter.

8. A physiological parameter tracking method comprising the steps of:

inputting a physiological signal;

calculating a reference parameter from said signal;

defining an update command;

tracking said reference parameter according to said update command; and

outputting a physiological measurement responsive to said tracking step.

9. The physiological parameter tracking method according to claim 8 wherein said defining step comprises the substeps of:

indicating one of a sample period and a tracking period for calculating a slow parameter response to said signal; and

indicating a hold period for maintaining a previous calculation of said slow parameter.

10. The physiological parameter tracking method according to claim 9 wherein said tracking step comprises the substep of deriving a tracking function output from said reference parameter and said slow parameter.

11. The physiological parameter tracking method according to claim 10 further comprising the step of calculating an ancillary parameter from said signal.

12. The physiological parameter tracking method according to claim 11 wherein said outputting step comprises the substep of multiplexing said tracking function output and said ancillary parameter according to said update command.

13. The physiological parameter tracking method according to claim 12 wherein said ancillary parameter is venous oxygen saturation and said physiological measurement is said venous oxygen saturation during said tracking period and an estimate of venous oxygen saturation during said hold period.

14. The physiological parameter tracking method according to claim 11 wherein said ancillary parameter is a measure of abnormal hemoglobin.

15. The physiological parameter tracking method according to claim 14 wherein said physiological measurement is arterial oxygen saturation corrected for said abnormal hemoglobin.

16. A physiological parameter tracking method comprising the steps of:

providing a physiological signal;

calculating arterial oxygen saturation from said signal;

calculating a slowly varying parameter during a first period;

holding said slowly varying parameter during a second period; and

outputting a physiological measurement responsive to said arterial oxygen saturation and said slowly varying parameter.

17. The physiological parameter tracking method according to claim 16 wherein said slowly varying parameter is abnormal hemoglobin concentration and said physiological measurement is said arterial oxygen saturation corrected for said abnormal hemoglobin concentration.

18. The physiological parameter tracking method according to claim 16 wherein said slowly varying parameter is a difference between said arterial oxygen saturation and venous oxygen saturation and said physiological measurement is said venous oxygen saturation during said first period and a venous oxygen saturation estimate during said second period.

19. The physiological parameter tracking method according to claim 16 wherein said calculating a slowly varying parameter step comprises the substeps of:

indicating favorable conditions with an update command; and

sampling said slowly varying parameter in response to said command.

20. The physiological parameter tracking method according to claim 16 wherein said holding step comprises the substeps of:

indicating unfavorable conditions with an update command; and

holding said slowly varying parameter in response to said command.

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摘要(译)

生理参数跟踪系统响应于生理信号输入产生参考参数和缓慢变化的参数。根据更新命令生成缓慢变化的参数。提供生理测量输出，其响应于参考参数和缓慢变化的参数的跟踪功能。