US00RE47882E

(19) **United States**
(12) **Reissued Patent**
Al-Ali

(10) **Patent Number: US RE47,882 E**
(45) **Date of Reissued Patent: *Mar. 3, 2020**

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(54) **ADAPTIVE ALARM SYSTEM**

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(*) Notice: This patent is subject to a terminal disclaimer.

(21) Appl. No.: **16/184,908**

(22) Filed: **Nov. 8, 2018**

Related U.S. Patent Documents

Reissue of:

(64)	Patent No.:	**9,775,570**
	Issued:	**Oct. 3, 2017**
	Appl. No.:	**15/583,718**
	Filed:	**May 1, 2017**

U.S. Applications:

(63) Continuation of application No. 15/881,602, filed on Jan. 26, 2018, now Pat. No. Re. 47,218, which is an

(Continued)

(51) **Int. Cl.**

A61B 5/00	(2006.01)
A61B 5/1455	(2006.01)

(52) **U.S. Cl.**

CPC ***A61B 5/746*** (2013.01); *A61B 5/1455* (2013.01); *A61B 5/14552* (2013.01); *A61B 5/74* (2013.01)

(58) **Field of Classification Search**

CPC ... A61B 5/746; A61B 5/1455; A61B 5/14552; A61B 5/74

(Continued)

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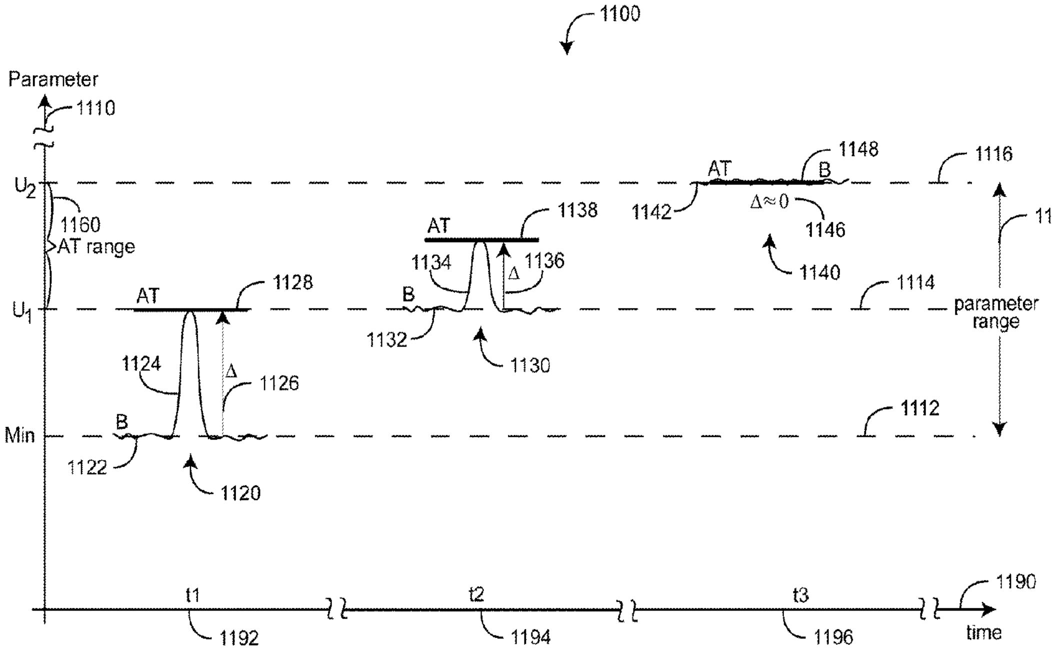
(57) **ABSTRACT**

Systems and electronic processes for reducing electronic alarms in a medical patient monitoring system. For example, a system for reducing electronic alarms can include an optical sensor and one or more hardware processors in electronic communication with the optical sensor. The one or more hardware processors can be programmed to measure oxygen saturation values of a patient over a first period of time, determine if at least one oxygen saturation value obtained over the first period of time exceeds a first alarm threshold, determine whether a first alarm should be triggered based on the determination that the at least one oxygen saturation value obtained over the first period of time exceeds the first alarm threshold, determine a second alarm threshold to be applied during a second period of time subsequent to the first period of time, the second alarm threshold replacing the first alarm threshold.

17 Claims, 14 Drawing Sheets



Related U.S. Application Data

application for the reissue of Pat. No. 9,775,570, which is a continuation of application No. 13/037,184, filed on Feb. 28, 2011, now Pat. No. 9,724,024.

(60) Provisional application No. 61/309,419, filed on Mar. 1, 2010, provisional application No. 61/328,630, filed on Apr. 27, 2010.

(58) **Field of Classification Search**
USPC 600/300, 301, 310, 322, 323, 324, 473, 600/476, 500, 508; 356/41, 573.1
See application file for complete search history.

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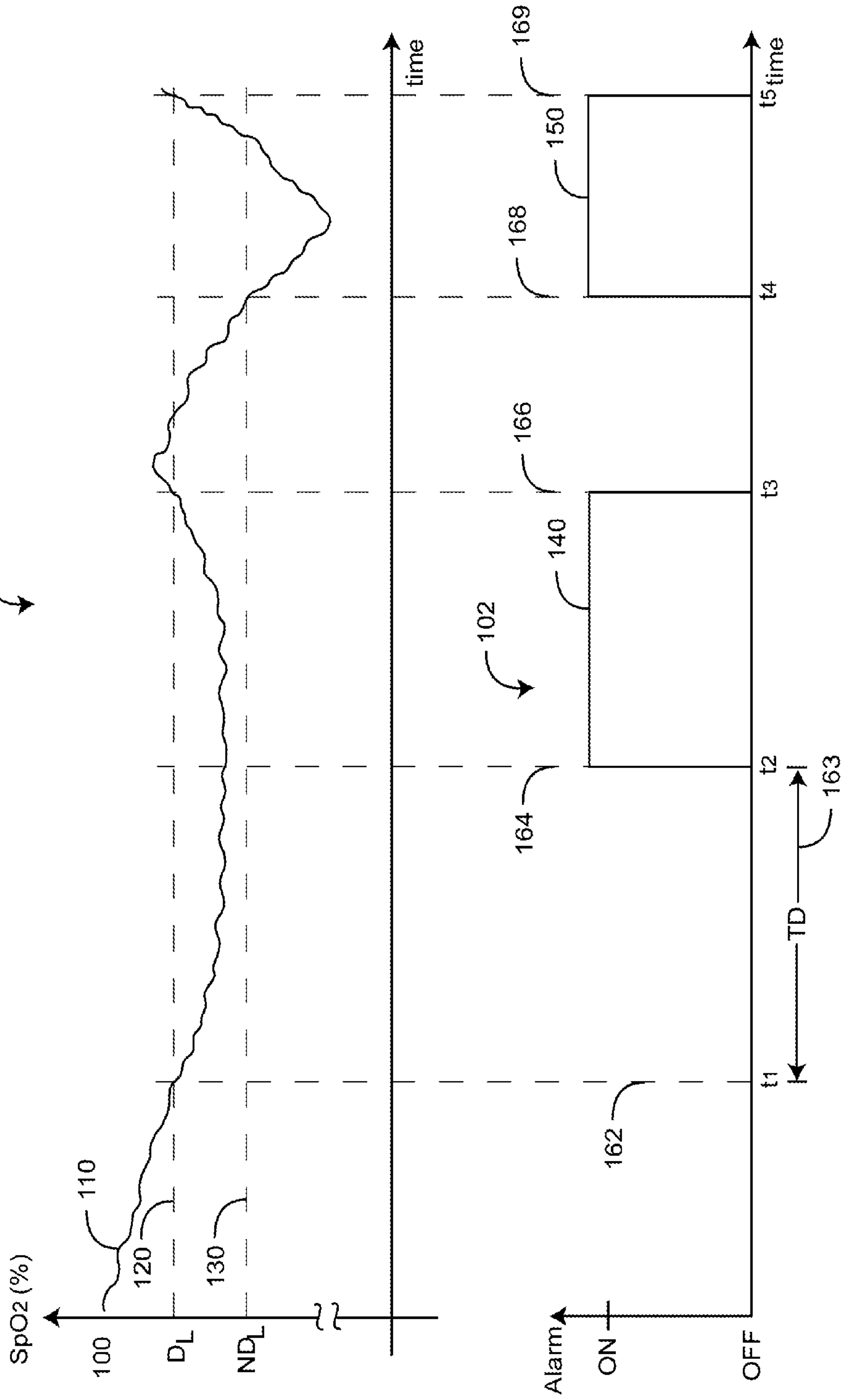
100
SpO2 (%)
100
D_L
ND_L
110
120
130
time
102
140
150
164
166
168
169
Alarm
ON
OFF
162
t1
TD
163
t2
t3
t4
t5
time

FIG 1

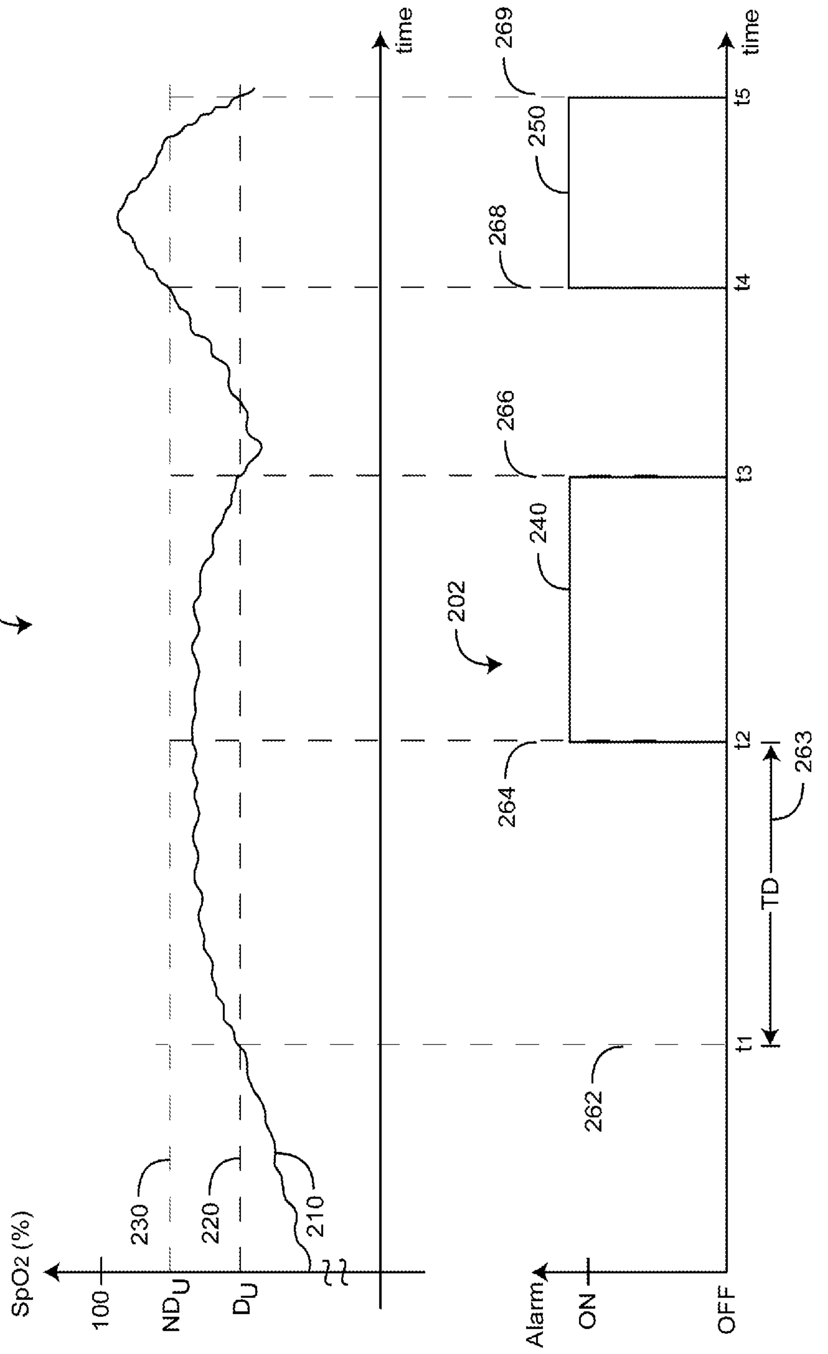
200
SpO2 (%)
100
NDU
DU
230
220
210
time
202
Alarm
ON
OFF
262
263
TD
264
240
266
268
250
269
t1
t2
t3
t4
t5
time

FIG. 2

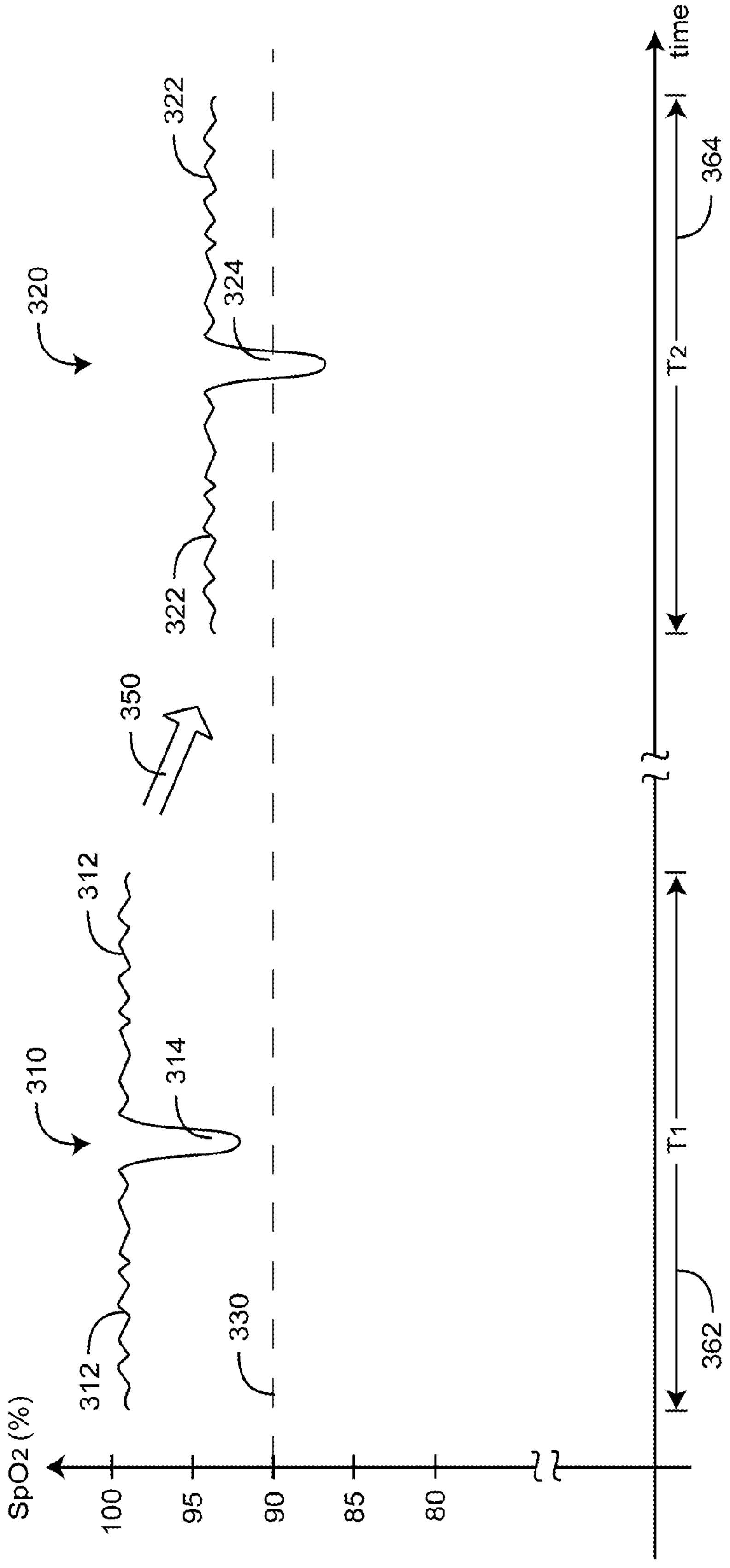
SpO2 (%)
100
95
90
85
80
time
300
310
312
312
314
320
322
322
324
330
350
362
364
T1
T2

FIG. 3

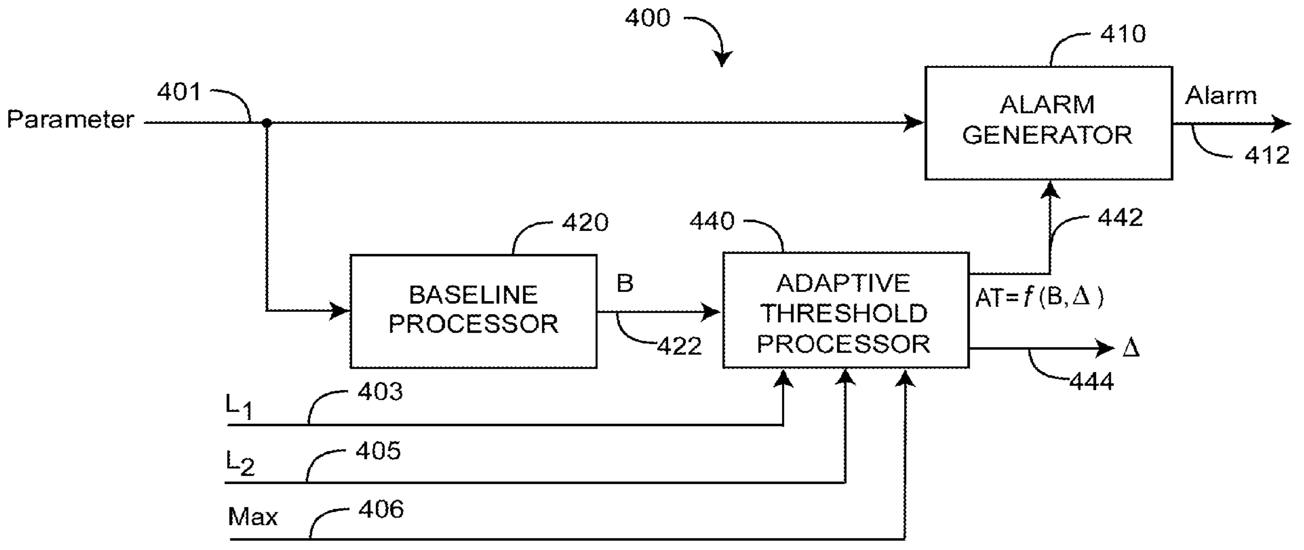
400
401
Parameter
410
ALARM GENERATOR
Alarm
412
420
BASELINE PROCESSOR
B
422
440
ADAPTIVE THRESHOLD PROCESSOR
442
AT=f(B,Δ)
Δ
444
L1
403
L2
405
Max
406

FIG. 4A

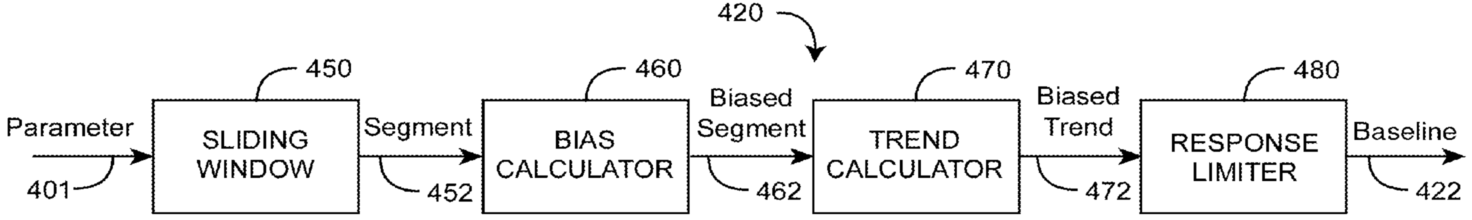
420
Parameter
401
450
SLIDING WINDOW
Segment
452
460
BIAS CALCULATOR
Biased Segment
462
470
TREND CALCULATOR
Biased Trend
472
480
RESPONSE LIMITER
Baseline
422

FIG. 4B

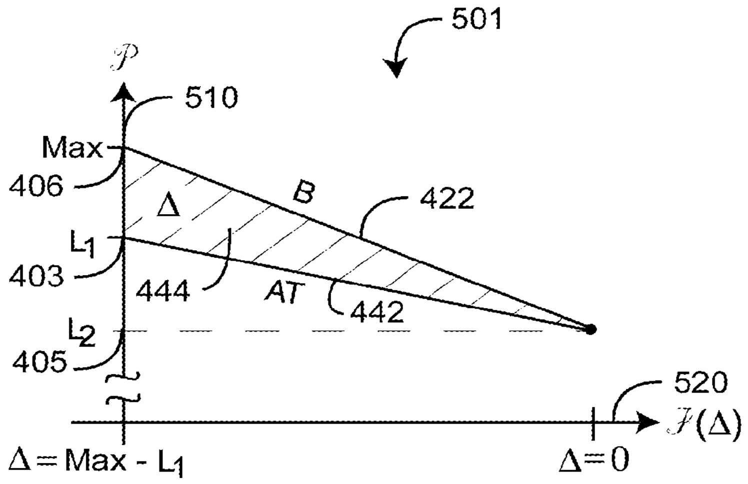
501
$\mathcal{P}$
510
Max
406
Δ
B
422
L_1
403
444
AT
442
L_2
405
520
$\mathcal{F}(\Delta)$
$\Delta = \text{Max} - L_1$
$\Delta = 0$

FIG. 5A

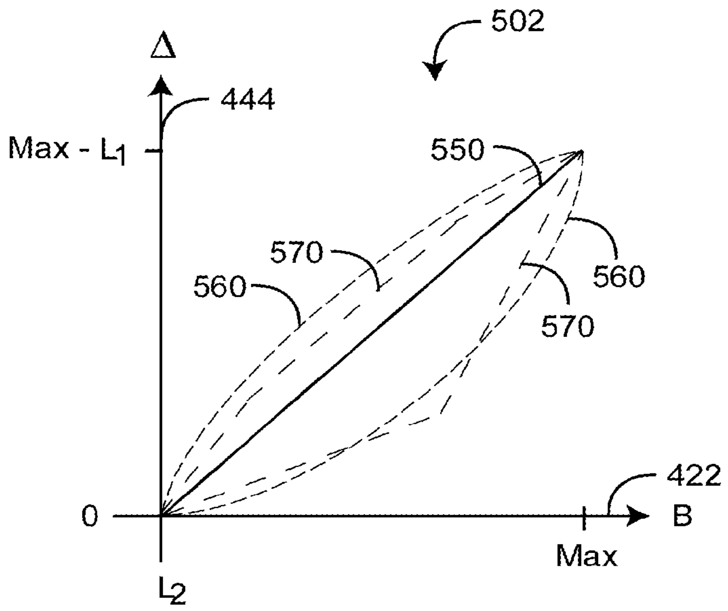
502
Δ
444
Max - L_1
550
570
560
560
570
0
422
B
Max
L_2

FIG. 5B

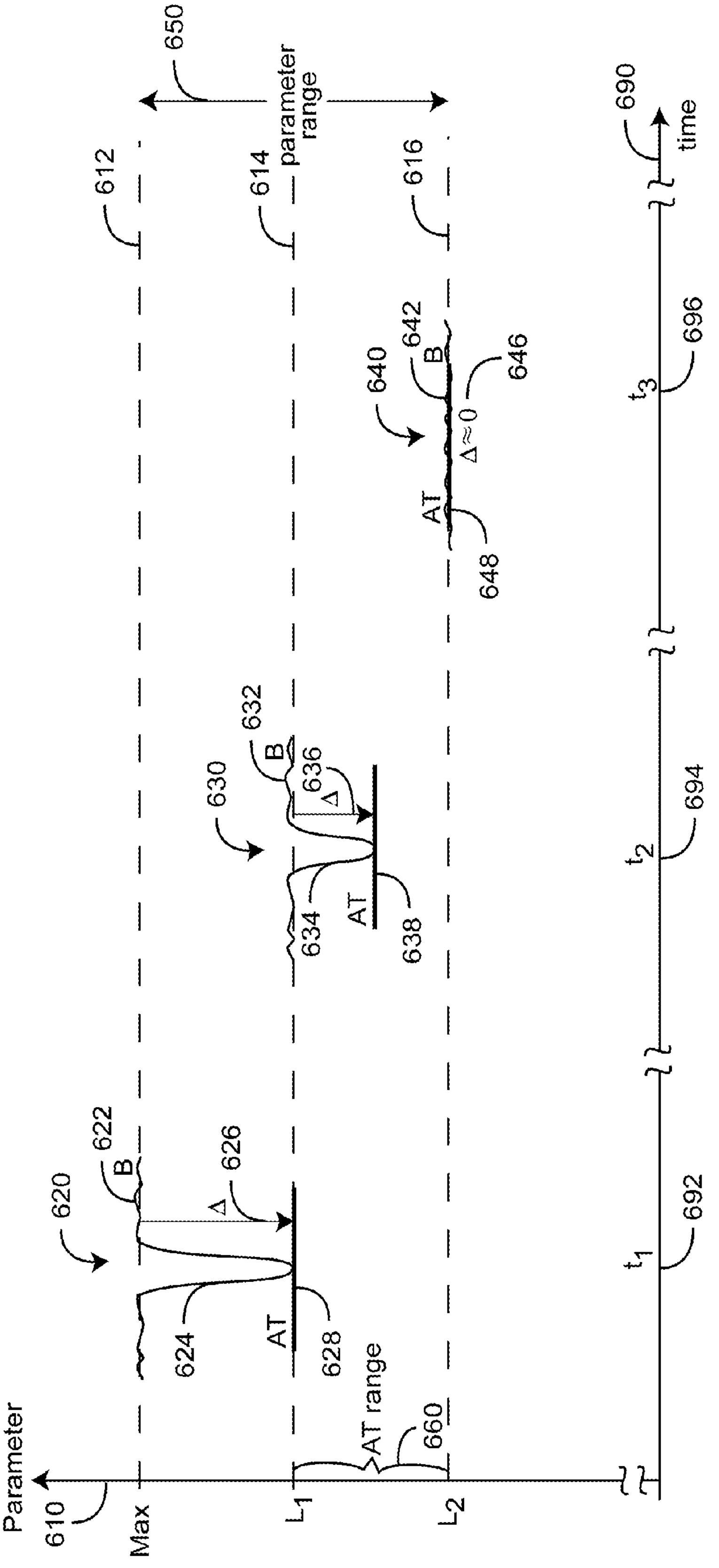
600
Parameter
610
Max
L_1
L_2
612
614
616
650
parameter range
AT range
660
620
B
622
624
Δ
626
AT
628
630
B
632
634
Δ
636
AT
638
640
B
642
Δ≈0
646
AT
648
t_1
692
t_2
694
t_3
696
time
690

FIG. 6

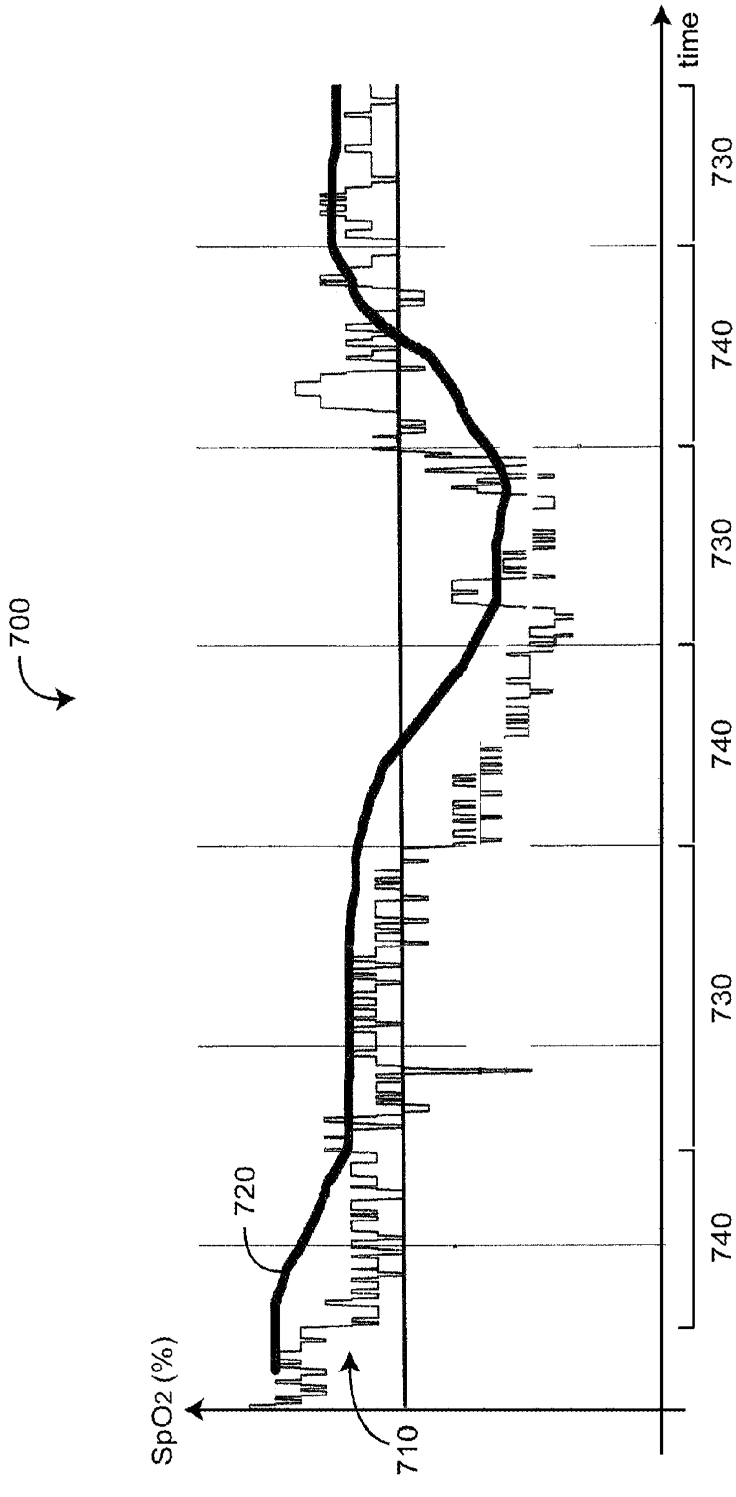

FIG. 7

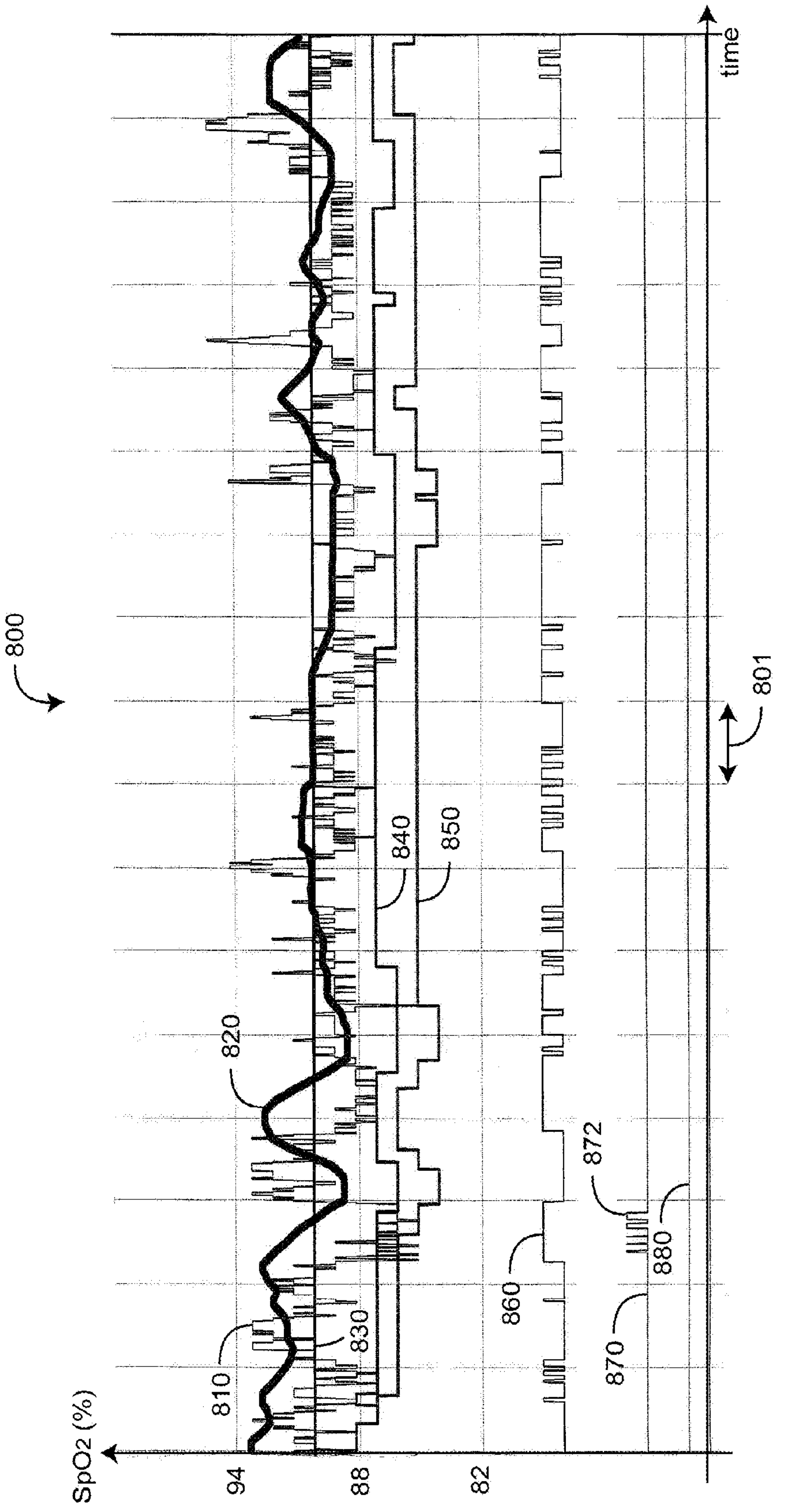

FIG. 8

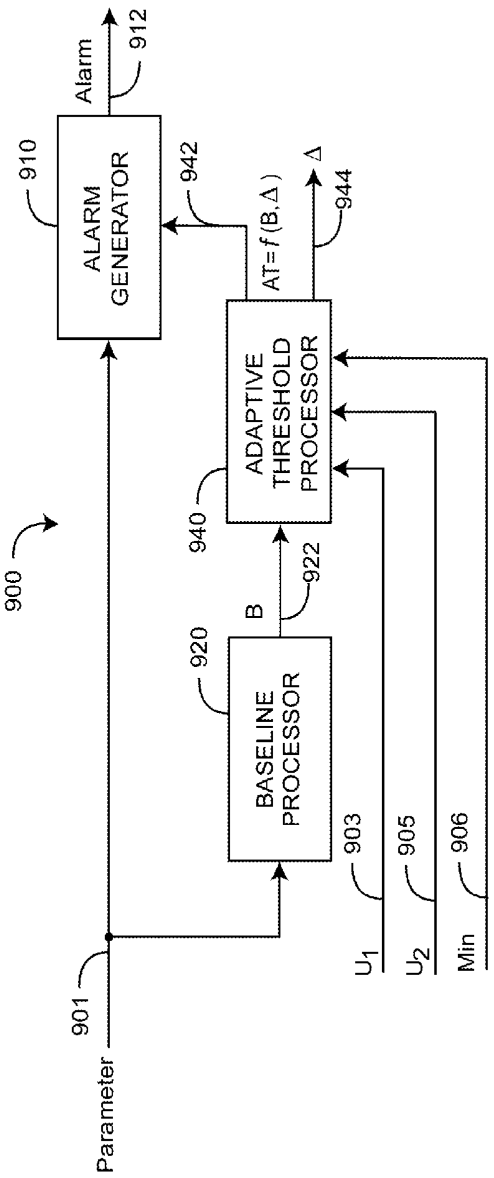
900
Parameter
901
BASELINE PROCESSOR
920
B
922
ADAPTIVE THRESHOLD PROCESSOR
940
U_1
903
U_2
905
Min
906
AT=f(B,Δ)
942
Δ
944
ALARM GENERATOR
910
Alarm
912

FIG. 9A

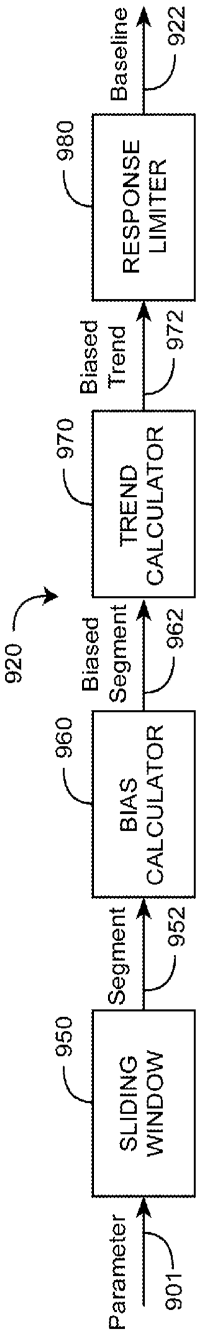
920
Parameter
901
SLIDING WINDOW
950
Segment
952
BIAS CALCULATOR
960
Biased Segment
962
TREND CALCULATOR
970
Biased Trend
972
RESPONSE LIMITER
980
Baseline
922

FIG. 9B

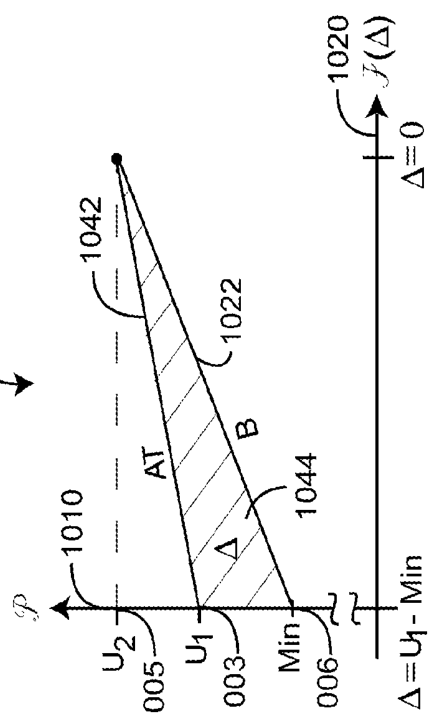

FIG. 10A

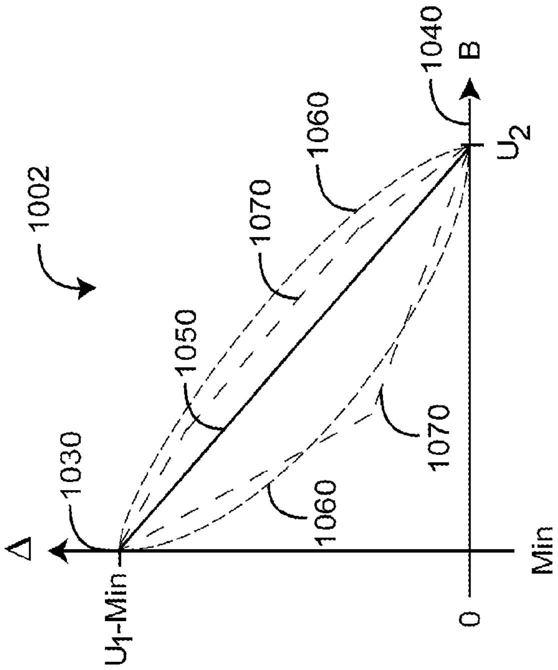

FIG. 10B

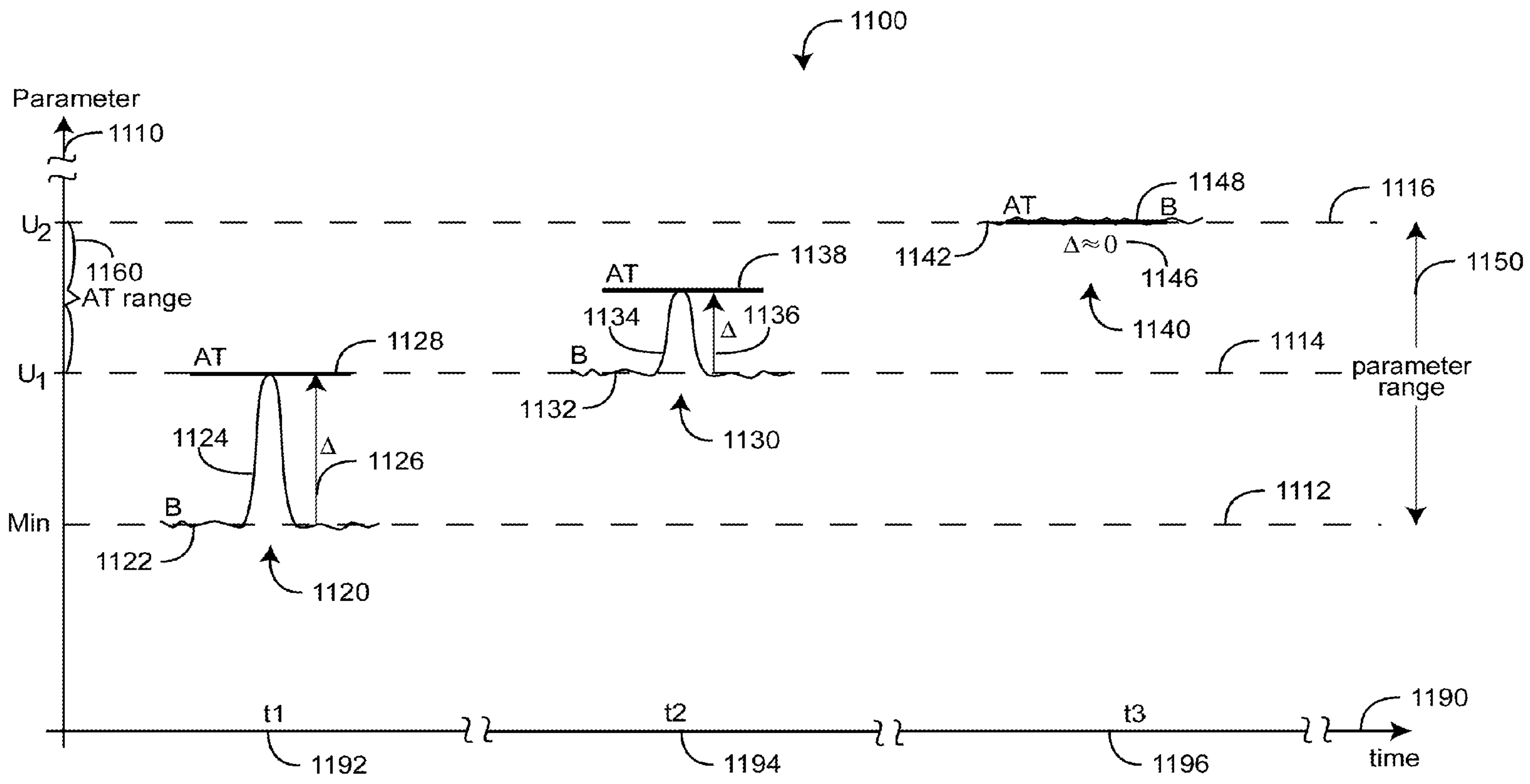
1100
Parameter
1110
U2
1160
AT range
U1
Min
AT
1128
1124
Δ
1126
B
1122
1120
AT
1138
1134
Δ
1136
B
1132
1130
AT
1148
B
1142
Δ≈0
1146
1140
1116
1114
1112
1150
parameter range
t1
1192
t2
1194
t3
1196
1190
time

FIG. 11

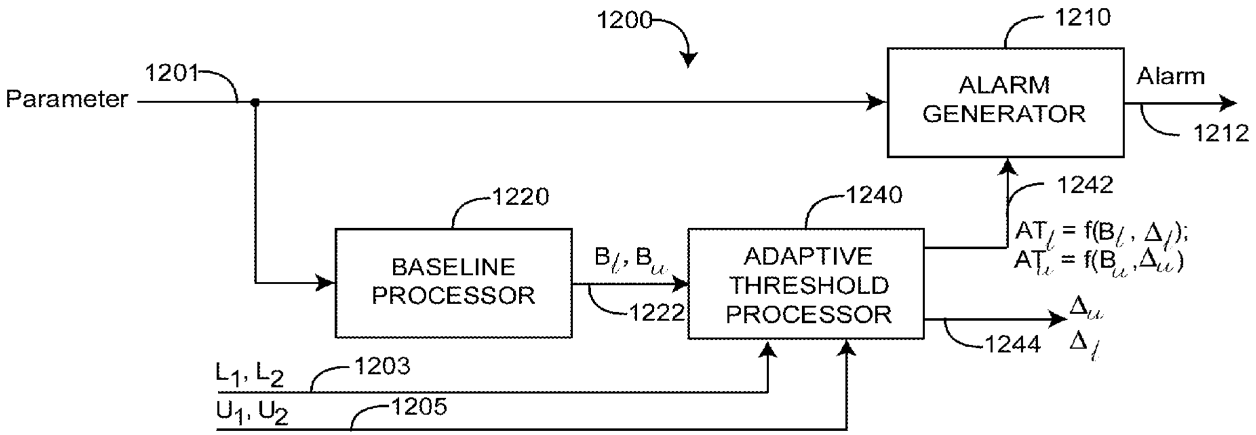

FIG. 12A

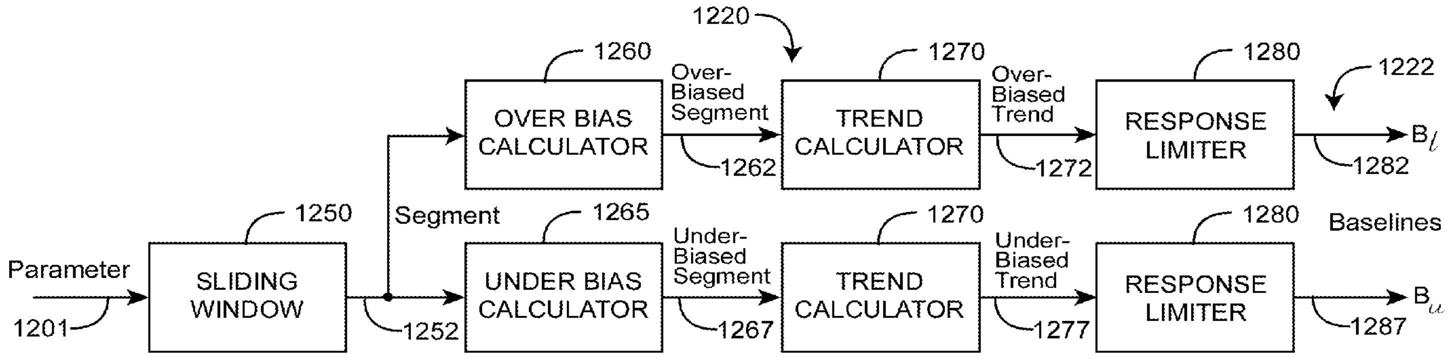

FIG. 12B

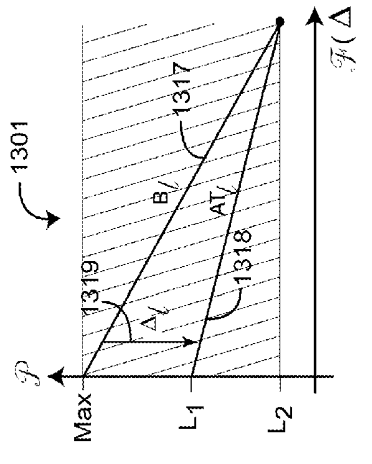

FIG. 13A

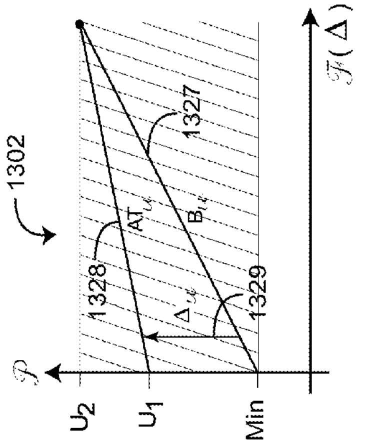

FIG. 13B

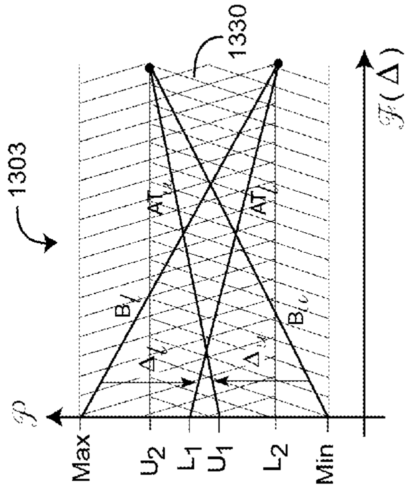

FIG. 13C

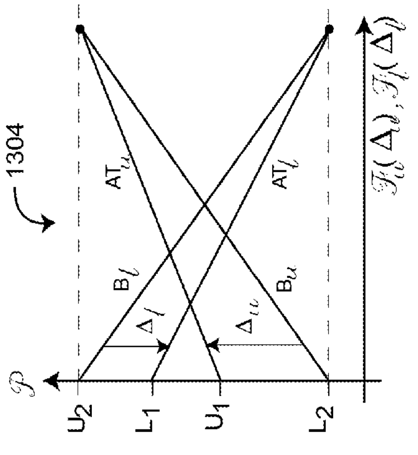

FIG. 13D

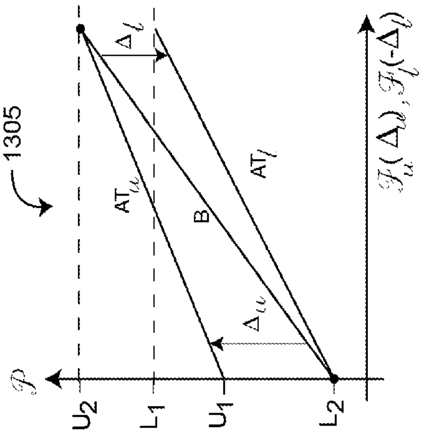

FIG. 13E

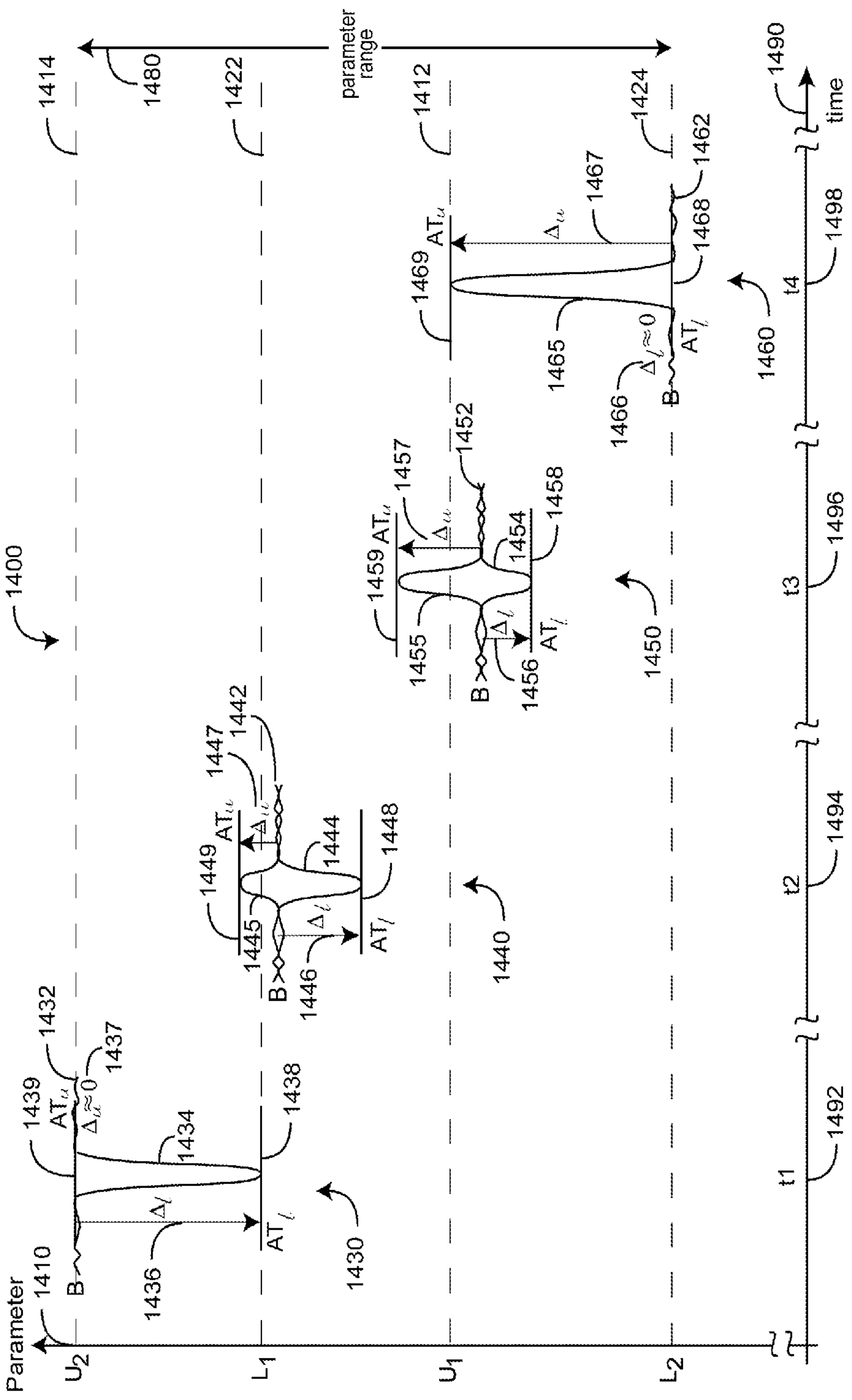
1400
Parameter
1410
U_2
L_1
U_1
L_2
1414
1480
1422
parameter range
1412
1424
1490
time
B
1436
Δ_l
AT_l
1430
1434
1439
AT_u
$\Delta_u \approx 0$
1432
1437
1438
t1
1492
B
1446
1445
Δ_l
AT_l
1440
1449
AT_u
Δ_u
1447
1442
1444
1448
t2
1494
B
1456
1455
Δ_l
AT_l
1450
1459
AT_u
Δ_u
1457
1452
1454
1458
t3
1496
1466
B
$\Delta_l \approx 0$
AT_l
1465
1460
1469
AT_u
Δ_u
1467
1468
1462
t4
1498

FIG. 14

ADAPTIVE ALARM SYSTEM

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

PRIORITY CLAIM TO RELATED PROVISIONAL APPLICATIONS

[The present application claims priority benefit under 35 U.S.C. §119(e) to] *This is a reissue continuation application, meaning it is a reissue of U.S. Pat. No. 9,775,570, and is also a continuation of U.S. patent Reissue application Ser. No. 15/881,602, which is a reissue of U.S. Pat. No. 9,775,570, issued on Oct. 3, 2017 and titled "Adaptive Alarm System," which is a continuation of* U.S. patent application Ser. No. 13/037,184, filed Feb. 18, 2011 titled Adaptive Alarm System; *which claims priority benefit under 35 U.S.C. § 119(e) to* Provisional Patent Application Ser. No. 61/309,419, filed Mar. 1, 2010 titled Adaptive Threshold Alarm System; and U.S. Provisional Patent Application Ser. No. 61/328,630, filed Apr. 27, 2010 titled Adaptive Alarm System; all of the above-cited provisional patent applications are hereby incorporated by reference herein.

BACKGROUND OF THE INVENTION

Pulse oximetry systems for measuring constituents of circulating blood have gained rapid acceptance in a wide variety of medical applications, including surgical wards, intensive care and neonatal units, general wards, home care, physical training, and virtually all types of monitoring scenarios. A pulse oximetry system generally includes an optical sensor applied to a patient, a monitor for processing sensor signals and displaying results and a patient cable electrically interconnecting the sensor and the monitor. A pulse oximetry sensor has light emitting diodes (LEDs), typically one emitting a red wavelength and one emitting an infrared (IR) wavelength, and a photodiode detector. The emitters and detector are typically attached to a finger, and the patient cable transmits drive signals to these emitters from the monitor. The emitters respond to the drive signals to transmit light into the fleshy fingertip tissue. The detector generates a signal responsive to the emitted light after attenuation by pulsatile blood flow within the fingertip. The patient cable transmits the detector signal to the monitor, which processes the signal to provide a numerical readout of physiological parameters such as oxygen saturation (SpO_2) and pulse rate.

SUMMARY OF THE INVENTION

Conventional pulse oximetry assumes that arterial blood is the only pulsatile blood flow in the measurement site. During patient motion, venous blood also moves, which causes errors in conventional pulse oximetry. Advanced pulse oximetry processes the venous blood signal so as to report true arterial oxygen saturation and pulse rate under conditions of patient movement. Advanced pulse oximetry also functions under conditions of low perfusion (small signal amplitude), intense ambient light (artificial or sunlight) and electrosurgical instrument interference, which are scenarios where conventional pulse oximetry tends to fail.

Advanced pulse oximetry is described in at least U.S. Pat. Nos. 6,770,028; 6,658,276; 6,157,850; 6,002,952; 5,769,785 and 5,758,644, which are assigned to Masimo Corporation ("Masimo") of Irvine, Calif. and are incorporated by reference herein. Corresponding low noise optical sensors are disclosed in at least U.S. Pat. Nos. 6,985,764; 6,813,511; 6,792,300; 6,256,523; 6,088,607; 5,782,757 and 5,638,818, which are also assigned to Masimo and are also incorporated by reference herein. Advanced pulse oximetry systems including Masimo SET® low noise optical sensors and read through motion pulse oximetry monitors for measuring SpO_2, pulse rate (PR) and perfusion index (PI) are available from Masimo. Optical sensors include any of Masimo LNOP®, LNCS®, SofTouch™ and Blue™ adhesive or reusable sensors. Pulse oximetry monitors include any of Masimo Rad-8®, Rad-5®, Rad®-5v or SatShare® monitors.

Advanced blood parameter measurement systems are described in at least U.S. Pat. No. 7,647,083, filed Mar. 1, 2006, titled Multiple Wavelength Sensor Equalization; U.S. Pat. No. 7,729,733, filed Mar. 1, 2006, titled Configurable Physiological Measurement System; U.S. Pat. Pub. No. 2006/0211925, filed Mar. 1, 2006, titled Physiological Parameter Confidence Measure and U.S. Pat. Pub. No. 2006/0238358, filed Mar. 1, 2006, titled Noninvasive Multi-Parameter Patient Monitor, all assigned to Masimo Laboratories, Irvine, Calif. (Masimo Labs) and all incorporated by reference herein. An advanced parameter measurement system that includes acoustic monitoring is described in U.S. Pat. Pub. No. 2010/0274099, filed Dec. 21, 2009, titled Acoustic Sensor Assembly, assigned to Masimo and incorporated by reference herein.

Advanced blood parameter measurement systems include Masimo Rainbow® SET, which provides measurements in addition to SpO_2, such as total hemoglobin (SpHb™) oxygen content (SpOC™), methemoglobin (SpMet®), carboxyhemoglobin (SpCO®) and PVI®. Advanced blood parameter sensors include Masimo Rainbow® adhesive, ReSposable™ and reusable sensors. Advanced blood parameter monitors include Masimo Radical-7™, Rad87™ and Rad-57™ monitors, all available from Masimo. Advanced parameter measurement systems may also include acoustic monitoring such as acoustic respiration rate (RRa™) using a Rainbow Acoustic Sensor™ and Rad-87™ monitor, available from Masimo. Such advanced pulse oximeters, low noise sensors and advanced physiological parameter measurement systems have also gained rapid acceptance in a wide variety of medical applications, including surgical wards, intensive care and neonatal units, general wards, home care, physical training, and virtually all types of monitoring scenarios.

FIGS. **1**-**3** illustrate problems and issues associated with physiological parameter measurement systems having fixed threshold alarm schemas. FIG. **1** illustrates a lower-limit, fixed-threshold alarm schema with respect to an oxygen saturation (SpO_2) parameter. Two alarm thresholds, D_L (delay) and ND_L (no delay), are defined. If oxygen saturation falls below D_L for a time delay greater than TD, an alarm is triggered. If oxygen saturation falls below ND_L an alarm is immediately triggered. D_L **120** is typically set around or somewhat above 90% oxygen saturation and ND_L **130** is typically set at 5% to 10% below D_L. For example, say a person's oxygen saturation **110** drops below D_L **120** at $t=t_1$ **162** and stays below D_L for at least a time delay TD **163**. This triggers a delayed alarm **140** at $t=t_2$ **164**, where $t_2=t_1+TD$. The alarm **140** remains active until oxygen saturation **110** rises above D_L **120** at $t=t_3$ **166**. As another example, say that oxygen saturation **110** then drops below ND_L **130**, which triggers an immediate alarm **150** at t=t4 **168**. The alarm **150** remains active until oxygen saturation **110** rises above D_L **120** at $t=t_5$ **169**.

FIG. **2** illustrates an upper-limit, fixed-threshold alarm schema with respect to an oxygen saturation (SpO_2) parameter. This alarm scenario is particularly applicable to the avoidance of ROP (retinopathy of prematurity). Again, two alarm thresholds, D_U (delay) and ND_U (no delay), are defined. D_U **220** might be set at or around 85% oxygen saturation and ND_U **230** might be set at or around 90% oxygen saturation. For example, a neonate's oxygen saturation **210** rises above D_U **220** at $t=t_1$ **262** and stays above D_U for at least a time delay TD **263**. This triggers a delayed alarm **240** at $t=t_2$ **264**, where $t_2=t_1+TD$. The alarm **240** remains active until oxygen saturation **210** falls below D_U **220** at $t=t_3$ **166**. Oxygen saturation **210** then rises above ND_U **230**, which triggers an immediate alarm **250** at $t=t_4$ **268**. The alarm **250** remains active until oxygen saturation **210** falls below D_U **220** at $t=t_5$ **269**.

FIG. **3** illustrates a baseline drift problem with the fixed threshold alarm schema described above. A person's oxygen saturation is plotted on an oxygen saturation (SpO_2) versus time graph **300**. In particular, during a first time interval T_1 **362**, a person has an oxygen saturation **310** with a relatively stable "baseline" **312** punctuated by a shallow, transient desaturation event **314**. This scenario may occur after the person has been on oxygen so that baseline oxygen saturation is near 100%. Accordingly, with a fixed threshold alarm **330** set at, say, 90%, the transient event **314** does not trigger a nuisance alarm. However, the effects of oxygen treatments wear off over time and oxygen saturation levels drift downward **350**. In particular, during a second time interval T_2 **364**, a person has an oxygen saturation **320** with a relatively stable baseline **322**. The later baseline **322** is established at a substantially lower oxygen saturation than the earlier baseline **312**. In this scenario, a shallow, transient desaturation event **324** now exceeds the alarm threshold **330** and results in a nuisance alarm. After many such nuisance alarms, a caregiver may lower the alarm threshold **330** to unsafe levels or turn off alarms altogether, significantly hampering the effectiveness of monitoring oxygen saturation.

A fixed threshold alarm schema is described above with respect to an oxygen saturation parameter, such as derived from a pulse oximeter. However, problematic fixed threshold alarm behavior may be exhibited in a variety of parameter measurement systems that calculate physiological parameters related to circulatory, respiratory, neurological, gastrointestinal, urinary, immune, musculoskeletal, endocrine or reproductive systems, such as the circulatory and respiratory parameters cited above, as but a few examples.

An adaptive alarm system, as described in detail below, advantageously provides an adaptive threshold alarm to solve false alarm and missed true alarm problems associated with baseline drift among other issues. For example, for a lower limit embodiment, an adaptive alarm system adjusts an alarm threshold downwards when a parameter baseline is established at lower values. Likewise, for an upper limit embodiment, the adaptive alarm system adjusts an alarm threshold upwards in accordance with baseline drift so as to avoid nuisance alarms. In an embodiment, the rate of baseline movement is limited so as to avoid masking of transients. In an embodiment, the baseline is established along upper or lower portions of a parameter envelop so as to provide a margin of safety in lower limit or upper limit systems, respectively.

One aspect of an adaptive alarm system is responsive to a physiological parameter so as to generate an alarm threshold that adapts to baseline drift in the parameter and reduce false alarms without a corresponding increase in missed true alarms. The adaptive alarm system has a parameter derived from a physiological measurement system using a sensor in communication with a living being. A baseline processor calculates a parameter baseline from an average value of the parameter. Parameter limits specify an allowable range of the parameter. An adaptive threshold processor calculates an adaptive threshold from the parameter baseline and the parameter limits. An alarm generator is responsive to the parameter and the adaptive threshold so as to trigger an alarm indicative of the parameter crossing the adaptive threshold. The adaptive threshold is responsive to the parameter baseline so as to increase in value as the parameter baseline drifts to a higher parameter value and to decrease in value as the parameter baseline drifts to a lower parameter value.

In various embodiments, the baseline processor has a sliding window that identifies a time slice of parameter values. A trend calculator determines a trend from an average of the parameter values in the time slice. A response limiter tracks only the relatively long-term transitions of the trend. A bias calculator deletes the highest parameter values in the time slice or the lowest parameter values in the time slice so as to adjust the baseline to either a lower value or a higher value, respectively. The adaptive threshold becomes less response to baseline drift as the baseline approaches a predefined parameter limit. A first adaptive threshold is responsive to lower parameter limits and a second adaptive threshold is responsive to upper parameter limits. The alarm generator is responsive to both positive and negative transients from the baseline according to the first adaptive threshold and the second adaptive threshold. The first adaptive threshold is increasingly responsive to negative transients and the second adaptive threshold is decreasingly responsive to positive transients as the baseline trends toward lower parameter values.

Another aspect of an adaptive alarm system measures a physiological parameter, establishes a baseline for the parameter, adjusts an alarm threshold according to drift of the baseline and triggers an alarm in response to the parameter measurement crossing the alarm threshold. In various embodiments, the baseline is established by biasing a segment of the parameter, calculating a biased trend from the biased segment and restricting the transient response of the biased trend. The alarm threshold is adjusted by setting a parameter limit and calculating a delta difference between the alarm threshold and the baseline as a linear function of the baseline according to the parameter limit. The delta difference is calculated by decreasing delta as the baseline drifts toward the parameter limit and increasing delta as the baseline drifts away from the parameter limit. A parameter limit is set by selecting a first parameter limit in relation to a delayed alarm and selecting a second parameter limit in relation to an un-delayed alarm. A segment of the parameter is biased by windowing the parameter measurements, removing a lower value portion of the windowed parameter measurements and averaging a remaining portion of the windowed parameter measurements. An upper delta difference between an upper alarm threshold and the baseline is calculated and a lower delta difference between a lower alarm threshold and the baseline is calculated.

A further aspect of an adaptive alarm system has a baseline processor that inputs a parameter and outputs a baseline according to a trend of the parameter. An adaptive threshold processor establishes an alarm threshold at a delta difference from the baseline. An alarm generator triggers an alarm based upon a parameter transient from the baseline crossing the alarm threshold. In various embodiments, a trend calculator outputs a biased trend and the baseline is responsive to the biased trend so as to reduce the size of a transient that triggers the alarm. A response limiter reduces baseline movement due to parameter transients. The adaptive threshold processor establishes a lower alarm threshold below the baseline and an upper alarm threshold above the baseline so that the alarm generator is responsive to both positive and negative transients from the baseline. The baseline processor establishes a lower baseline biased above the parameter trend and an upper baseline biased below the parameter trend. The lower alarm threshold is increasingly responsive to negative transients and the upper alarm threshold is decreasingly responsive to positive transients as the baseline trends toward lower parameter values.

DESCRIPTION OF THE DRAWINGS

FIGS. **1-3** are exemplar graphs illustrating problems and issues associated with physiological parameter measurement systems having fixed threshold alarm schemas;

FIGS. **4**A-B are general block diagrams of an adaptive alarm system having lower parameter limits;

FIGS. **5**A-B are a graph of a physiological parameter versus delta space and a graph of delta versus baseline, respectively, illustrating the relationship between a baseline, a lower-limit adaptive threshold and a variable difference delta between the baseline and the adaptive threshold;

FIG. **6** is an exemplar graph of a physiological parameter versus time illustrating an adaptive alarm system having a lower-limit adaptive threshold;

FIG. **7** is a graph of oxygen saturation versus time illustrating a baseline for determining an adaptive threshold;

FIG. **8** is a graph of oxygen saturation versus time comparing adaptive-threshold alarm performance with fixed-threshold alarm performance;

FIGS. **9**A-B are general block diagrams of an adaptive alarm system having upper parameter limits;

FIGS. **10**A-B are a graph of a physiological parameter versus delta space and a graph of delta versus baseline, respectively, illustrating the relationship between a baseline, an upper-limit adaptive threshold and a variable delta difference between the baseline and the adaptive threshold;

FIG. **11** is an exemplar graph of a physiological parameter versus time illustrating an adaptive alarm system having an upper-limit adaptive threshold;

FIGS. **12**A-B are general block diagrams of an adaptive alarm system having both lower alarm limits and upper alarm limits;

FIGS. **13**A-E are physiological parameter versus delta space graphs illustrating a lower-limit adaptive threshold, an upper-limit adaptive threshold, and a combined lower- and upper-limit adaptive threshold in various delta spaces; and

FIG. **14** is an exemplar graph of a physiological parameter versus time illustrating an adaptive alarm system having both lower and upper alarm limits.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. **4**A-B illustrate an adaptive alarm system **400** embodiment having lower parameter limits L_1 and L_2. As shown in FIG. **4**A, the adaptive alarm system **400** has parameter **401**, first limit (L_1) **403**, second limit (L_2) **405** and maximum parameter value (Max) **406** inputs and generates a corresponding alarm **412** output. The parameter **401** input is generated by a physiological parameter processor, such as a pulse oximeter or an advanced blood parameter processor described above, as examples. The adaptive alarm system **400** has an alarm generator **410**, a baseline processor **420**, and an adaptive threshold processor **440**. The alarm generator **410** has parameter **401** and adaptive threshold (AT) **442** inputs and generates the alarm **412** output accordingly. A baseline processor **420** has the parameter **401** input and generates a parameter baseline (B) **422** output. The baseline processor **420**, is described in detail with respect to FIG. **4**B, below. An adaptive threshold processor **440** has parameter baseline (B) **422**, L_1 **403**, L_2 **405** and Max **406** inputs and generates the adaptive threshold (AT) **442**. The adaptive threshold processor **440** is described in detail with respect to FIGS. **5**A-B, below.

As shown in FIG. **4**A, in an embodiment L_1 **403** and L_2 **405** may correspond to conventional fixed alarm thresholds with and without an alarm time delay, respectively. For an adaptive threshold schema, however, L_1 **403** and L_2 **405** do not determine an alarm threshold per se, but are reference levels for determining an adaptive threshold (AT) **442**. In an embodiment, L_1 **403** is an upper limit of the adaptive alarm threshold AT when the baseline is near the maximum parameter value (Max), and L_2 **405** is a lower limit of the adaptive alarm threshold, as described in detail with respect to FIGS. **5**A-B, below. In an exemplar embodiment when the parameter is oxygen saturation, L_1 **403** is set at or around 90% and L_2 **405** is set at 5 to 10% below L_1, i.e. at 85% to 80% oxygen saturation. Many other L_1 and L_2 values may be used for an adaptive threshold schema as described herein.

Also shown in FIG. **4**A, in an embodiment the alarm **412** output is triggered when the parameter **401** input falls below AT **442** and ends when the parameter **401** input rises above AT **442** or is otherwise cancelled. In an embodiment, the alarm **412** output is triggered after a time delay (TD), which may be fixed or variable. In an embodiment, the time delay (TD) is a function of the adaptive threshold (AT) **442**. In an embodiment, the time delay (TD) is zero when the adaptive threshold (AT) is at the second lower limit (L_2) **405**.

As shown in FIG. **4**B, a baseline processor **420** embodiment has a sliding window **450**, a bias calculator **460**, a trend calculator **470** and a response limiter **480**. The sliding window **450** inputs the parameter **401** and outputs a time segment **452** of the parameter **401**. In an embodiment, each window incorporates a five minute span of parameter values. The bias calculator **460** advantageously provides an upward shift in the baseline (B) **422** for an additional margin of error over missed true alarms. That is, a baseline **422** is generated that tracks a higher-than-average range of parameter values, effectively raising the adaptive threshold AT slightly above a threshold calculated based upon a true parameter average, as shown and described in detail with respect to FIGS. **7-8**, below. In an embodiment, the bias calculator **460** rejects a lower range of parameter values from each time segment **452** from the sliding window so as to generate a biased time segment **462**.

Also shown in FIG. **4**B, the trend calculator **470** outputs a biased trend **472** of the remaining higher range of parameter values in each biased segment **462**. In an embodiment, the biased trend **462** is an average of the values in the biased time segment **462**. In other embodiments, the biased trend **462** is a median or mode of the values in the biased time segment **462**. The response limiter **480** advantageously limits the extent to which the baseline **422** output tracks the biased trend **472**. Accordingly, the baseline **422** tracks only relatively longer-lived transitions of the parameter, but does not track (and hence mask) physiologically significant parameter events, such as oxygen desaturations for a SpO_2 parameter to name but one example. In an embodiment, the response limiter **480** has a low pass transfer function. In an embodiment, the response limiter **480** is a slew rate limiter.

FIGS. **5**A-B further illustrate an adaptive threshold processor **440** (FIG. **4**A) having a baseline (B) **422** input and generating an adaptive threshold (AT) **442** output and a delta (Δ) **444** ancillary output according to parameter limits L_1 **403**, L_2 **405** and Max **406**, as described above. As shown in FIG. **5**A, as the baseline (B) **422** decreases (increases) the adaptive threshold (AT) **444** monotonically decreases (increases) between L_1 **403** and L_2 **405**. Further, as the baseline (B) **422** decreases (increases) the delta (Δ) **444** difference between the baseline (B) **422** and the adaptive threshold (AT) **442** monotonically decreases (increases) between $Max-L_1$ and zero.

As shown in FIG. **5**B, the relationship between the delta (Δ) **444** and the baseline (B) **444** may be linear **550** (solid line), non-linear **560** (small-dash lines) or piecewise-linear (large-dash lines), to name a few. In an embodiment, the adaptive threshold processor **440** (FIG. **4**A) calculates an adaptive threshold (AT) **442** output in response to the baseline (B) **422** input according to a linear relationship. In a linear embodiment, the adaptive threshold processor **440** (FIG. **4**A) calculates the adaptive threshold (AT) **442** according to EQS. 1-2:

$$\Delta = -\left(\frac{\mathrm{Max} - L_1}{\mathrm{Max} - L_2}\right)(\mathrm{Max} - B) + (\mathrm{Max} - L_1) \tag{1}$$

$$AT = B - \Delta \tag{2}$$

where $\Delta = \mathrm{Max} - L_1$ @ $B = \mathrm{Max}$; $\Delta = 0$ @ $B = L_2$ and where $AT = L_1$ @ $B = \mathrm{Max}$; $AT = L_2$ @ $B = L_2$, accordingly.

FIG. **6** illustrates the operational characteristics an adaptive alarm system **400** (FIG. **4**A) having parameter limits Max **612**, L_1 **614** and L_2 **616** and an alarm responsive to a baseline (B) **622**, **632**, **642**; an adaptive threshold (AT) **628**, **638**, **648**; and a corresponding Δ **626**, **636**, **646** according to EQS. 1-2, above. In particular, a physiological parameter **610** is graphed versus time **690** for various time segments t_1, t_2, t_3 **692-696**. The parameter range (PR) **650** is:

$$PR = \mathrm{Max} - L_2 \tag{3}$$

and the adaptive threshold range (ATR) **660** is:

$$ATR = L_1 - L_2 \tag{4}$$

As shown in FIG. **6**, during a first time period t_1 **692**, a parameter segment **620** has a baseline (B) **622** at about Max **612**. As such, Δ **626**=$\mathrm{Max}-L_1$ and the adaptive threshold (AT) **628** is at about L_1 **614**. Accordingly, a transient **624** having a size less than Δ **626** does not trigger the alarm **412** (FIG. **4**A).

Also shown in FIG. **6**, during a second time period t_2 **694**, a parameter segment **630** has a baseline (B) **632** at about L_1 **614**. As such, Δ **636** is less than $\mathrm{Max}-L_1$ and the adaptive threshold (AT) **638** is between L_1 and L_2. Accordingly, a smaller transient **634** will trigger the alarm as compared to a transient **624** in the first time segment.

Further shown in FIG. **6**, during a third time period t_3 **696**, a parameter segment **640** has a baseline (B) **642** at about L_2 **616**. As such, Δ **646** is about zero and the adaptive threshold (AT) **648** is at about L_2. Accordingly, even a small negative transient will trigger the alarm. As such, the behavior of the alarm threshold AT **628**, **638**, **648** advantageously adapts to higher or lower baseline values so as to increase or decrease the size of negative transients that trigger or do not trigger the alarm **412** (FIG. **4**A).

FIG. **7** is a parameter versus time graph **700** illustrating the characteristics of an adaptive alarm system **400** (FIGS. **4**A-B), as described with respect to FIGS. **4**-**6**, above, where the parameter is oxygen saturation (SpO_2). The graph **700** has a SpO_2 trace **710** and a superimposed baseline trace **720**. The graph **700** also delineates tracking periods **730**, where the baseline **720** follows the upper portions of SpO_2 values, and lagging periods **740**, where the baseline **720** does not follow transient SpO_2 events. The tracking time periods **730** illustrate that the baseline **720** advantageously tracks at the higher range of SpO_2 values **710** during relatively stable (flat) periods, as described above. Lagging time periods **740** illustrate that the baseline **720** is advantageously limited in response to transient desaturation events so that significant desaturations fall below an adaptive threshold (not shown) and trigger an alarm accordingly.

FIG. **8** is a parameter versus time graph **800** illustrating characteristics of an adaptive alarm system **400** (FIGS. **4**A-B), as described with respect to FIGS. **4**-**6**, above, where the parameter is oxygen saturation (SpO_2). Vertical axis (SpO_2) resolution is 1%. The time interval **801** between vertical hash marks is five minutes. The graph **800** has a SpO_2 trace **810** and a baseline trace **820**. The graph **800** also has a fixed threshold trace **830**, a first adaptive threshold (AT) trace **840** and a second AT trace **850**. The graph **800** further has a fixed threshold alarm trace **860**, a first adaptive threshold alarm trace **870** and a second adaptive threshold alarm trace **880**. In this example, L_1 is 90% and L_2 is 85% for the first AT trace **840** and first AT alarm trace **870**. L_2 is 80% for a second AT trace **850** and a second AT alarm trace **880**. The fixed threshold **830** results in many nuisance alarms **860**. By comparison, the adaptive threshold alarm with L_2=85% has just one time interval of alarms **872** during a roughly 6% desaturation period (from 92% to 86%). The adaptive threshold alarm with L_2=80%, has no alarms during the 1 hour 25 minute monitoring period.

FIGS. **9**A-B illustrate an adaptive alarm system **900** embodiment having upper parameter limits U_1 and U_2. As shown in FIG. **9**A, the adaptive alarm system **900** has parameter **901**, first limit (U_1) **903**, second limit (U_2) **905** and minimum parameter value (Min) **906** inputs and generates a corresponding alarm **912** output. The parameter **901** input is generated by a physiological parameter processor, such as a pulse oximeter or an advanced blood parameter processor described above, as examples. The adaptive alarm system **900** has an alarm generator **910**, a baseline processor **920**, and an adaptive threshold processor **940**. The alarm generator **910** has parameter **901** and adaptive threshold (AT) **942** inputs and generates the alarm **912** output accordingly. A baseline processor **920** has the parameter **901** input and generates a parameter baseline (B) **922** output. The baseline processor **920**, is described in detail with respect to FIG. **9**B, below. An adaptive threshold processor **940** has parameter baseline (B) **922**, U_1 **903**, U_2 **905** and Min **906** inputs and generates the adaptive threshold (AT) **942**. The adaptive threshold processor **940** is described in detail with respect to FIGS. **10**A-B, below.

As shown in FIG. **9**A, in an embodiment U_1 **903** and U_2 **905** may correspond to conventional fixed alarm thresholds with and without an alarm time delay, respectively. For an adaptive threshold schema, however, U_1 **903** and U_2 **905** do not determine an alarm threshold per se, but are reference levels for determining an adaptive threshold (AT) **942**. In an embodiment, U_1 **903** is a lower limit of the adaptive alarm threshold AT when the baseline is near the minimum parameter value (Min), and U_2 **905** is an upper limit of the adaptive alarm threshold, as described in detail with respect to FIGS. **10**A-B, below. In an exemplar embodiment when the parameter is oxygen saturation, U_1 **903** is set at or around 85% and U_2 **905** is set at or around 90% oxygen saturation. Many other U_1 and U_2 values may be used for an adaptive threshold schema as described herein.

Also shown in FIG. **9**A, in an embodiment the alarm **912** output is triggered when the parameter **901** input rises above AT **942** and ends when the parameter **901** input falls below AT **942** or is otherwise cancelled. In an embodiment, the alarm **912** output is triggered after a time delay (TD), which may be fixed or variable. In an embodiment, the time delay (TD) is a function of the adaptive threshold (AT) **942**. In an embodiment, the time delay (TD) is zero when the adaptive threshold (AT) is at the second upper limit (U_2) **905**.

As shown in FIG. **9**B, a baseline processor **920** embodiment has a sliding window **950**, a bias calculator **960**, a trend calculator **970** and a response limiter **980**. The sliding window **950** inputs the parameter **901** and outputs a time segment **952** of the parameter **901**. In an embodiment, each window incorporates a five minute span of parameter values. The bias calculator **960** advantageously provides a downward shift in the baseline (B) **922** for an additional margin of error over missed true alarms. That is, a baseline **922** is generated that tracks a lower-than-average range of parameter values, effectively lowering the adaptive threshold AT slightly below a threshold calculated based upon a true parameter average. In an embodiment, the bias calculator **960** rejects an upper range of parameter values from each time segment **952** from the sliding window so as to generate a biased time segment **962**.

Also shown in FIG. **9**B, the trend calculator **970** outputs a biased trend **972** of the remaining lower range of parameter values in each biased segment **962**. In an embodiment, the biased trend **962** is an average of the values in the biased time segment **962**. In other embodiments, the biased trend **962** is a median or mode of the values in the biased time segment **962**. The response limiter **980** advantageously limits the extent to which the baseline **922** output tracks the biased trend **972**. Accordingly, the baseline **922** tracks only relatively longer-lived transitions of the parameter, but does not track (and hence mask) physiologically significant parameter events, such as oxygen desaturations for a SpO_2 parameter to name but one example. In an embodiment, the response limiter **980** has a low pass transfer function. In an embodiment, the response limiter **980** is a slew rate limiter.

FIGS. **10**A-B further illustrate an adaptive threshold processor **940** (FIG. **9**A) having a baseline (B) **922** input and generating an adaptive threshold (AT) **942** output and a delta (Δ) **944** ancillary output according to parameter limits U_1 **903**, U_2 **905** and Min **906**, as described above. As shown in FIG. **10**A, as the baseline (B) **922** decreases (increases) the adaptive threshold (AT) **944** monotonically decreases (increases) between U_1 **903** and U_2 **905**. Further, as the baseline (B) **922** decreases (increases) the delta (Δ) **944** difference between the baseline (B) **922** and the adaptive threshold (AT) **942** monotonically decreases (increases) between Min−U_1 and zero.

As shown in FIG. **10**B, the relationship between the delta (Δ) **944** and the baseline (B) **944** may be linear **550** (solid line), non-linear **560** (small-dash lines) or piecewise-linear (large-dash lines), to name a few. In an embodiment, the adaptive threshold processor **940** (FIG. **9**A) calculates an adaptive threshold (AT) **942** output in response to the baseline (B) **922** input according to a linear relationship. In a linear embodiment, the adaptive threshold processor **940** (FIG. **9**A) calculates the adaptive threshold (AT) **942** according to EQS. 5-6:

$$\Delta = -\left(\frac{U_1 - \text{Min}}{U_2 - \text{Min}}\right)(B - \text{Min}) + (U_1 - \text{Min}) \tag{5}$$

$$AT = B + \Delta \tag{6}$$

where $\Delta = U_1 - \text{Min}$ @ $B = \text{Min}$; $\Delta = 0$ @ $B = U_2$
and where $AT = U_1$ @ $B = \text{Min}$; $AT = U_2$ @ $B = U_2$, accordingly.

FIG. **11** illustrates the operational characteristics an adaptive alarm system **900** (FIG. **9**A) having parameter limits Min **1112**, U_1 **1114** and U_2 **1116** and an alarm responsive to a baseline (B) **1122**, **1132**, **1142**; an adaptive threshold (AT) **1128**, **1138**, **1148**; and a corresponding Δ **1126**, **1136**, **1146** according to EQS. 5-6, above. In particular, a physiological parameter **1110** is graphed versus time **1190** for various time segments t_1, t_2, t_3 **1192**-**1196**. The parameter range (PR) **1150** is:

$$PR = U_2 - \text{Min} \tag{7}$$

and the adaptive threshold range (ATR) **1160** is:

$$ATR = U_2 - U_1 \tag{8}$$

As shown in FIG. **11**, during a first time period t_1 **1192**, a parameter segment **1120** has a baseline (B) **1122** at about Min **1112**. As such, Δ **1126**=U_1−Min and the adaptive threshold (AT) **1128** is at about U_1 **1114**. Accordingly, a transient **1124** having a size less than Δ **1126** does not trigger the alarm **912** (FIG. **9**A).

Also shown in FIG. **11**, during a second time period t_2 **1194**, a parameter segment **1130** has a baseline (B) **1132** at about U_1 **1114**. As such, Δ **1136** is less than U_1−Min and the adaptive threshold (AT) **1138** is between U_1 and U_2. Accordingly, a smaller transient **1134** will trigger the alarm as compared to a transient **1124** in the first time segment.

Further shown in FIG. **11**, during a third time period t_3 **1196**, a parameter segment **1140** has a baseline (B) **1142** at about U_2 **1116**. As such, Δ **1146** is about zero and the adaptive threshold (AT) **1148** is at about U_2. Accordingly, even a small positive transient will trigger the alarm. As such, the behavior of the alarm threshold AT **1128**, **1138**, **1148** advantageously adapts to higher or lower baseline values so as to increase or decrease the size of positive transients that trigger or do not trigger the alarm **912** (FIG. **9**A).

FIGS. **12**A-B illustrate an adaptive alarm system **1200** embodiment having lower limits L_1, L_2 **1203**, such as described with respect to FIGS. **4**A-B above, or upper limits U_1, U_2 **1205** such as described with respect to FIGS. **9**A-B above, or both. As shown in FIG. **12**A, the adaptive alarm system **1200** has parameter **1201**, lower limit **1203** and upper limit **1205** inputs and generates a corresponding alarm **1212** output. The parameter **1201** input is generated by a physiological parameter processor, such as a pulse oximeter or an advanced blood parameter processor described above, as examples. The adaptive alarm system **1200** has an alarm generator **1210**, a baseline processor **1220** and an adaptive threshold processor **1240**. The alarm generator **1210** has parameter **1201** and adaptive threshold (AT) **1242** inputs and generates the alarm **1212** output accordingly. A baseline processor **1220** has the parameter **1201** input and generates one or more parameter baseline **1222** outputs. The baseline processor **1220**, is described in detail with respect to FIG.

12B, below. An adaptive threshold processor **1240** has parameter baseline **1222**, lower limit L_1, L_2 **1203** and upper limit U_1, U_2 **1205** inputs and generates lower and upper adaptive threshold AT_l, AT_u **1242** outputs. The adaptive threshold processor **1240** also generates ancillary upper and lower delta **1244** outputs. The adaptive threshold processor **1240** is described in detail with respect to FIGS. **13**A-E, below.

As shown in FIG. **12**A, in an embodiment L_1, L_2 **1203** and U_1, U_2 **1205** may correspond to conventional fixed alarm thresholds with an alarm delay (L_1, U_1) and without an alarm delay (L_2, U_2). For an adaptive threshold schema, however, these limits **1203**, **1205** do not determine an alarm threshold per se, but are reference levels for determining lower and upper adaptive thresholds AT_l, AT_u **1242**.

Also shown in FIG. **12**A, in an embodiment the alarm **1212** output is triggered when the parameter **1201** input falls below AT_l **1242** and ends when the parameter **1201** input rises above AT_l **1242** or the alarm is otherwise cancelled. Further, the alarm **1212** output is triggered when the parameter **1201** input rises above AT_u **1242** and ends when the parameter **1201** input falls below AT_u **1242** or the alarm is otherwise cancelled. In an embodiment, the alarm **1212** output is triggered after a time delay (TD), which may be fixed or variable. In an embodiment, the time delay (TD) is a function of the adaptive thresholds (AT_l, AT_u) **1242**. In an embodiment, the time delay (TD) is zero when the lower adaptive threshold (AT_l) **1242** is at the second lower limit (L_2) **1203** or when the upper adaptive alarm threshold AT_u **1242** is at the second upper limit (U_2) **1205**.

As shown in FIG. **12**B, a baseline processor **1220** embodiment has a sliding window **1250**, an over-bias calculator **1260**, an under-bias calculator **1265**, trend calculators **1270** and response limiters **1280**. The sliding window **1250** inputs the parameter **1201** and outputs a time segment **1252** of the parameter **1201**. In an embodiment, each window incorporates a five minute span of parameter **1201** values.

Also shown in FIG. **12**B, the over-bias calculator **1260** advantageously provides an upward shift in the lower baseline (B_l) **1282** for an additional margin of error over missed lower true alarms. That is, a lower baseline (B_l) **1282** is generated that tracks a higher-than-average range of parameter values, effectively raising the lower adaptive threshold AT_l slightly above a threshold calculated based upon a true parameter average. In an embodiment, the over-bias calculator **1260** rejects a lower range of parameter values from each time segment **1252** of the sliding window **1250** so as to generate an over-biased time segment **1262**.

Further shown in FIG. **12**B, the under-bias calculator **1265** advantageously provides a downward shift in the upper baseline (B_u) **1287** for an additional margin of error over missed upper true alarms. That is, an upper baseline (B_u) **1287** is generated that tracks a lower-than-average range of parameter values, effectively lowering the upper adaptive threshold AT_u slightly below a threshold calculated based upon a true parameter average. In an embodiment, the under-bias calculator **1267** rejects an upper range of parameter values from each time segment **1252** of the sliding window **1250** so as to generate an under-biased time segment **1267**.

Additionally shown in FIG. **12**B, the trend calculator **1270** outputs an over-biased trend **1272** of the remaining higher range of parameter values in each over-biased segment **1262**. Further, the trend calculator **1270** outputs an under-biased trend **1277** of the remaining lower range of parameter values in each under-biased segment **1267**. In an embodiment, the biased trends **1272**, **1277** are each an average of the values in the corresponding biased time segments **1262**, **1267**. In other embodiments, the biased trends **1272**, **1277** are each a median or mode of the values in the corresponding biased time segments **1262**, **1267**. The response limiter **1280** advantageously limits the extent to which the baseline **1222** outputs track the biased trends **1272**, **1277**. Accordingly, the baseline **1222** outputs track only relatively longer-lived transitions of the parameter **1201**, but do not track (and hence mask) physiologically significant parameter events. In an embodiment, the response limiter **1280** has a low pass transfer function. In an embodiment, the response limiter **1280** is a slew rate limiter.

FIGS. **13**A-E illustrate parameter (P) operating ranges and ideal ranges in view of both lower and upper parameter limits. As shown in FIG. **13**A, as the baseline (B_l) **1317** decreases (increases) the adaptive threshold (AT_l) **1318** monotonically decreases (increases) between L_1 and L_2. Further, as the baseline (B_l) **1317** decreases (increases) the delta (Δ_l) **1319** difference between the baseline (B_l) **1317** and the adaptive threshold (AT_l) **1318** monotonically decreases (increases) between Max$-L_1$ and 0.

As shown in FIG. **13**B, as the baseline (B_u) **1327** increases (decreases) the adaptive threshold (AT_u) **1328** monotonically increases (decreases) between U_1 and U_2. Further, as the baseline (B_u) **1327** increases (decreases) the delta (Δ_u) **1329** difference between the adaptive threshold (AT_u) **1328** and the baseline (B_u) **1327** monotonically decreases (increases) between Min$-U_1$ and 0.

As shown in FIG. **13**C, combining FIGS. **13**A-B, the parameter (P) operating range is bounded by the overlapping regions of **13**A and **13**B **1330** having an upper bound of U_2 and a lower bound of L_2. In particular, L_1, L_2 are the upper and lower limits of the lower adaptive alarm threshold AT_l; and U_2, U_1 are the upper and lower limits of the upper adaptive alarm threshold AT_u.

FIG. **13**D illustrates parameter (P) versus the overlapping independent delta domains F_u, F_l for upper and lower baselines B_u, B_l; adaptive thresholds AT_u, AT_l and deltas Δ_u, Δ_l, based upon FIGS. **13**A-C. FIG. **13**E illustrates parameter (P) versus the overlapping independent delta domains F_u, F_l (reversed); for upper and lower baselines B_u, B_l; adaptive thresholds AT_u, AT_l and deltas Δ_u, Δ_l,

As shown in FIG. **13**E, the equations for bi-lateral adaptive thresholds are:

$$\Delta_u = -\left(\frac{U_1 - L_2}{U_2 - L_2}\right)(B - L_2) + (U_1 - L_2) \tag{9}$$

$$AT_u = B + \Delta_u \tag{10}$$

where $\Delta_u = U_1 - L_2$ @ $B = L_2$; and $\Delta_u = 0$ @ $B = U_2$; and where $AT_u = U_1$ @ $B = L_2$; and $AT_u = U_2$ @ $B = U_2$. Further:

$$\Delta_l = \left(\frac{U_2 - L_1}{U_2 - L_2}\right)(B - L_2) \tag{11}$$

$$AT_l = B - \Delta_l \tag{12}$$

where $\Delta_l = U_2 - L_1$ @ $B = U_2$; and $\Delta_l = 0$ @ $B = L_2$; and where $AT_l = L_1$ @ $B = U_2$; $AT_l = L_2$ @ $B = L_2$.

Although shown as a linear relationship, in general:

$$\Delta_l = f_1(B); \Delta_u = f_2(B)$$

That is, Δ_l and Δ_u can each be a linear function of B, a non-linear function of B or a piecewise linear function of B, to name a few, in a manner similar to that described with respect to FIGS. **5**B and **10**B, above.

FIGS. **14**A-B illustrate the operational characteristics an adaptive alarm system **1200** (FIGS. **12**A-B) having upper limits U_1, U_2 **1412**, **1414** and lower limits L_1, L_2 **1422**, **1424**. An alarm **1212** (FIG. **12**A) output is responsive to a baseline (B) **1432**, **1442**, **1452**, **1462**; an upper delta (Δ_u) **1437**, **1447**, **1457**, **1467**; and a corresponding upper adaptive threshold (AT_u) **1439**, **1449**, **1459**, **1469**, according to EQS. 9-10, above. Further, the alarm **1212** (FIG. **12**A) output is responsive to a lower delta (Δ_l) **1436**, **1446**, **1456**, **1466** and a corresponding lower adaptive threshold (AT_l) **1438**, **1448**, **1458**, **1468**, according to EQS. 11-12, above.

As shown in FIGS. **14**A-B, a physiological parameter **1410** is graphed versus time **1490** for various time segments t_1, t_2, t_3, t_4 **1492-1498**. The parameter range (PR) **1480** is:

$$PR=U_2-L_2 \tag{13}$$

the lower adaptive threshold AT_l range is:

$$ATR_l=L_1-L_2 \tag{14}$$

the upper adaptive threshold AT_U range is:

$$ATR_l=U_2-U_1 \tag{15}$$

As shown in FIG. **14**A, during a first time period t_1 **1492**, a parameter segment **1430** has a baseline (B) **1432** at about U_2 **1414**. As such, Δ_l **1436**$=U_2-L_1$; Δ_u **1437**$=0$; AT_l **1438**$=L_1$; AT_u **1439**$=U_2$. Accordingly, a negative transient **1434** having a size less than U_2-L_1 does not trigger an alarm.

Also shown in FIG. **14**A, during a second time period t_2 **1494**, a parameter segment **1440** has a baseline (B) **1442** less than U_2. As such, Δ_l **1446** is less than U_1-L_1 and the adaptive threshold (AT_u) **1447** is between U_1 and U_2. Accordingly, a smaller negative transient **1444** will trigger the alarm as compared to the negative transient **1434** in the first time segment **1430**.

Further shown in FIG. **14**A, during a third time period t_3 **1496**, a parameter segment **1450** has a baseline (B) **1452** less than U_1 **1412**. As such, a smaller negative transient **1454** will trigger the alarm as compared to the negative transient **1444** in the second time segment **1440**. However, a larger positive transient **1455** is needed to trigger the alarm as compared to the positive transient **1445** in the second time segment **1440**.

Additionally shown in FIG. **14**A, during a fourth time period t_4 **1460**, a parameter segment **1460** has a baseline (B) **1462** at about L_2 **1424**. As such, Δ_l **1466**$=0$; Δ_u **1467**$=U_1-L_2$; AT_l **1468**$=L_2$; AT_u **1469**$=U_1$. Accordingly, a positive transient **1465** having a size less than U_1-L_2 does not trigger an alarm.

An adaptive alarm 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 system for reducing electronic alarms in a medical patient monitoring system, the system comprising:

an optical sensor configured to transmit optical radiation into a tissue site of a patient and detect attenuated optical radiation indicative of at least one physiological parameter of a patient; and

one or more hardware processors in electronic communication with the optical sensor, the one or more hardware processors configured to:

measure oxygen saturation values of a patient over a first period of time;

determine if at least one oxygen saturation value obtained over the first period of time exceeds a first alarm threshold;

determine whether a first alarm should be triggered based on the determination that the at least one oxygen saturation value obtained over the first period of time exceeds the first alarm threshold;

determine a second alarm threshold to be applied during a second period of time subsequent to the first period of time, the second alarm threshold replacing the first alarm threshold, the second alarm threshold being determined by:

comparing at least a first oxygen saturation value obtained during the first time period with a lower limit associated with oxygen saturation; and

computing a second alarm threshold based on the comparison where the second alarm threshold is computed to be at a value less than the at least first oxygen saturation value and greater than the lower limit and at an offset from the first oxygen saturation value, wherein the offset is configured to diminish as a difference between the at least first oxygen saturation value and the lower limit diminishes;

measure oxygen saturation values of a patient over the second period of time to determine at least a second oxygen saturation value; and

determine whether a second alarm should be triggered by determining if at least one oxygen saturation value obtained during the second period of time exceeds the second alarm threshold and triggering an alarm if it is determined the second alarm should be triggered.]

[**2**. The system of claim **1**, wherein the one or more hardware processors are configured to calculate a first baseline measurement from the measured oxygen saturation values over the first period of time and wherein the at least one oxygen saturation value obtained during the first period of time corresponds to the first baseline measurement.]

[**3**. The system of claim **2**, wherein the one or more hardware processors are configured to calculate a second baseline measurement from the measured oxygen saturation values over the second period of time and wherein the at least one oxygen saturation value obtained during the second period of time corresponds to the second baseline measurement.]

[**4**. The system of claim **1**, wherein the lower limit is predefined and corresponds to a minimum parameter value for oxygen saturation.]

[**5**. The system of claim **1**, wherein the one or more hardware processors are further configured to wait for a time delay prior to the triggering of the second alarm, and wherein the time delay is a function of the second alarm threshold.]

[**6**. The system of claim **5**, wherein the time delay decreases as the difference between the at least first oxygen saturation value and the lower limit diminishes.]

[**7**. The system of claim **1**, wherein the first alarm threshold is predetermined.]

[**8**. A system for reducing electronic alarms in a medical patient monitoring system including a pulse oximeter in communication with an optical sensor, the system comprising one or more hardware processors configured to:

measure oxygen saturation values of a patient over a first period of time;

determine if at least one oxygen saturation value obtained over the first period of time exceeds a first alarm threshold;

determine whether a first alarm should be triggered based on the determination that the at least one oxygen saturation value obtained over the first period of time exceeds the first alarm threshold;

compare at least a first oxygen saturation value obtained during the first time period with a lower limit associated with oxygen saturation;

compute a second alarm threshold based on the comparison;

determine a time delay based on the computed second alarm threshold, wherein the time delay approaches zero as the first oxygen saturation value approaches the lower limit;

measure oxygen saturation values of a patient over the second period of time to determine at least a second oxygen saturation value; and

determine whether a second alarm should be triggered by determining if at least one oxygen saturation value obtained during the second period of time exceeds the second alarm threshold for the time delay and triggering an alarm if it is determined the second alarm should be triggered.**]**

[9. The system of claim **8**, wherein the first alarm threshold is predetermined.**]**

[10. The system of claim **8**, wherein the lower limit is predefined and corresponds to a minimum parameter value for oxygen saturation.**]**

[11. The system of claim **8**, where the second alarm threshold is computed to be at a value less than the at least first oxygen saturation value and greater than the lower limit and at an offset from the first oxygen saturation value, wherein the offset is configured to diminish as a difference between the at least first oxygen saturation value and the lower limit diminishes.**]**

[12. An electronic method for reducing electronic alarms in a medical patient monitoring system, the electronic method comprising:

measuring oxygen saturation values of a patient over a first period of time;

determining if at least one oxygen saturation value determined over the first period of time exceeds a first alarm threshold;

determining whether a first alarm should be triggered based on the determination that at least one oxygen saturation value obtained during the first period of time exceeds the first alarm threshold;

comparing at least a first oxygen saturation value obtained during the first time period with a lower limit associated with oxygen saturation;

computing the second alarm threshold based on the comparison where the second alarm threshold is computed to be at a value less than the at least first oxygen saturation value and greater than the lower limit and at an offset from the first oxygen saturation value, wherein the offset is configured to diminish as a difference between the at least first oxygen saturation value and the lower limit diminishes and wherein the second alarm threshold is configured to be applied during a second period of time subsequent to the first period of time, the second alarm threshold replacing the first alarm threshold;

measuring oxygen saturation values of a patient over the second period of time to determine at least a second oxygen saturation value; and

determining whether a second alarm should be triggered by determining if at least one oxygen saturation value obtained during the second period of time exceeds the second alarm threshold and triggering an alarm if it is determined the second alarm should be triggered.**]**

[13. The electronic method of claim **12**, wherein the one or more hardware processors are configured to calculate a first baseline measurement from the measured oxygen saturation values over the first period of time and wherein the at least one oxygen saturation value obtained during the first period of time corresponds to the first baseline measurement.**]**

[14. The electronic method of claim **13**, wherein the one or more hardware processors are configured to calculate a second baseline measurement from the measured oxygen saturation values over the second period of time and wherein the at least one oxygen saturation value obtained during the second period of time corresponds to the second baseline measurement.**]**

[15. The electronic method of claim **12**, wherein the lower limit is predefined and corresponds to a minimum parameter value for oxygen saturation.**]**

[16. The electronic method of claim **12**, wherein the one or more hardware processors are further configured to wait for a time delay prior to the triggering of the second alarm, and wherein the time delay is a function of the second alarm threshold.**]**

[17. The electronic method of claim **16**, wherein the time delay decreases as the difference between the at least first oxygen saturation value and the lower limit diminishes.**]**

[18. The electronic method of claim **12**, wherein the first alarm threshold is predetermined.**]**

19. A system for reducing electronic alarms in a patient monitoring system, the system comprising:

an optical sensor configured to transmit optical radiation into a tissue site of a patient and detect attenuated optical radiation indicative of an oxygen saturation of a patient; and

one or more hardware processors in electronic communication with the optical sensor, the one or more hardware processors configured to:

determine, over a first period of time, whether a first alarm should be triggered based on a first oxygen saturation value obtained in the first period of time crossing a first alarm limit;

access a second alarm limit to be applied during a second period of time subsequent to the first period of time, the second alarm limit replacing the first alarm limit, wherein the second alarm limit has a value less than the first oxygen saturation value and greater than a lower limit and at an offset from the first oxygen saturation value, wherein the offset decreases as a difference between the first oxygen saturation value and the lower limit diminishes;

determine oxygen saturation values of the patient over the second period of time; and

trigger a second alarm based on at least one value of the oxygen saturation values obtained over the second period of time crossing the second alarm limit.

20. The system of claim 19, wherein the difference diminishes in response to a decrease in the patient's oxygen saturation until it reaches zero.

21. The system of claim 20, wherein the diminishment is proportional to the difference.

22. The system of claim 20, wherein the diminishment is a stepwise function of discrete diminishment steps.

23. The system of claim 19, wherein the system automatically determines the second alarm limit.

24. The system of claim 19, wherein the system automatically determines the first alarm limit.

25. The system of claim 19, wherein the lower limit is predetermined and corresponds to a minimum parameter value for oxygen saturation.

26. The system of claim 19, wherein the one or more hardware processors are further configured to wait for a time delay prior to triggering of the second alarm, and wherein the time delay is a function of the second alarm limit.

27. An electronic method of reducing electronic alarms in a patient monitoring system, the electronic method comprising:

determining, over a first period of time, whether a first alarm should be triggered based on a first oxygen saturation value obtained in the first period of time crossing a first alarm limit;

accessing a second alarm limit to be applied during a second period of time subsequent to the first period of time, the second alarm limit replacing the first alarm limit, wherein the second alarm limit has a value less than the first oxygen saturation value and greater than a lower limit and at an offset from the first oxygen saturation value, wherein the offset decreases as a difference between the first oxygen saturation value and the lower limit diminishes;

determining oxygen saturation values of the patient over the second period of time; and

triggerring a second alarm based on at least one value of the oxygen saturation values obtained over the second period of time crossing the second alarm limit.

28. The electronic method of claim 27, wherein the difference diminishes in response to a decrease in the patient's oxygen saturation until it reaches zero.

29. The electronic method of claim 28, wherein the diminishment is proportional to the difference.

30. The electronic method of claim 28, wherein the diminishment is a stepwise function of discrete diminishment steps.

31. The electronic method of claim 27, further comprising automatically determines the second alarm limit.

32. The electronic method of claim 27, further comprising automatically determines the first alarm limit.

33. The electronic method of claim 27, wherein the lower limit is predetermined and corresponds to a minimum parameter value for oxygen saturation.

34. The electronic method of claim 27, further comprising waiting for a time delay prior to triggering of the second alarm, and wherein the time delay is a function of the second alarm limit.

35. A system for reducing electronic alarms in a patient monitoring system, the system comprising one or more hardware processors configured to:

determine, over a first period of time, whether a first alarm should be triggered based on a first oxygen saturation value obtained in the first period of time crossing a first alarm limit;

access a second alarm limit to be applied during a second period of time subsequent to the first period of time, the second alarm limit replacing the first alarm limit, wherein the second alarm limit has a value less than the first oxygen saturation value and greater than a lower limit and at an offset from the first oxygen saturation value, wherein the offset decreases as a difference between the first oxygen saturation value and the lower limit diminishes;

determine oxygen saturation values of the patient over the second period of time; and

trigger a second alarm based on at least one value of the oxygen saturation values obtained over the second period of time crossing the second alarm limit.

* * * * *

patsnap

专利名称(译)	自适应警报系统		
公开(公告)号	USR47882	公开(公告)日	2020-03-03
申请号	US16/184908	申请日	2018-11-08
[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	AL ALI AMMAR		
发明人	AL-ALI, AMMAR		
IPC分类号	A61B5/00 A61B5/1455		
CPC分类号	A61B5/14551 A61B5/746 A61B2560/0276 G08B29/26 A61B5/1455 A61B5/14552 A61B5/74		
优先权	61/309419 2010-03-01 US 61/328630 2010-04-27 US		
外部链接	Espacenet USPTO		

摘要(译)

用于减少医疗病人监视系统中的电子警报的系统和电子过程。 例如，用于减少电子警报的系统可以包括光学传感器和与光学传感器进行电子通信的一个或多个硬件处理器。 可以对一个或多个硬件处理器进行编程，以在第一时间段内测量患者的氧饱和度值，确定在第一时间段内获得的至少一个氧饱和度值是否超过第一警报阈值，确定第一警报是否 应基于确定在第一时间段内获得的至少一个氧饱和度值超过第一警报阈值来触发，确定在第一时间段之后的第二时间段内要应用的第二警报阈值， 第二警报阈值代替第一警报阈值。