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(54) PHYSIOLOGICAL PARAMETER MONITORING

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| *A61B 5/04* | (2006.01) |
| *G06F 17/11* | (2006.01) |

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

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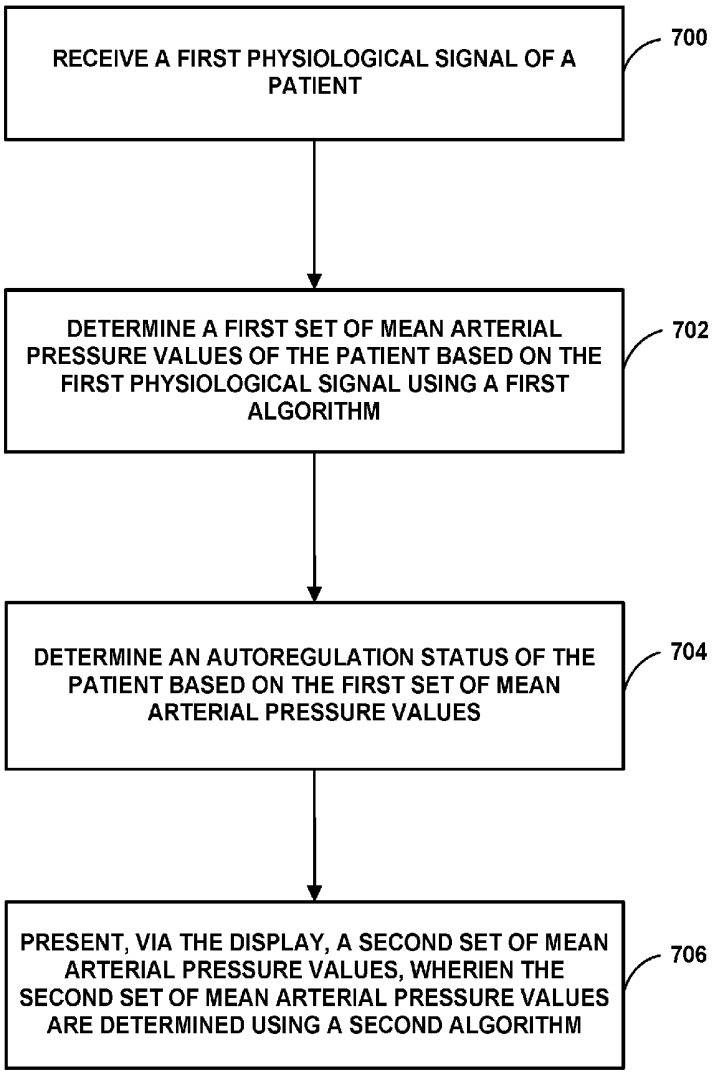
(57) **ABSTRACT**

In some examples, a device includes a display and processing circuitry configured to receive a physiological signal indicative of a physiological parameter of a patient. The processing circuitry is also configured to determine a first set of mean arterial pressure values of the patient for a time period based on the physiological signal using a first algorithm. In some examples, the processing circuitry is further configured to determine an autoregulation status of the patient based on the first set of mean arterial pressure values. In some examples, the processing circuitry is configured to present, via the display, a second set of mean arterial pressure values of the patient for the time period, wherein the second set of mean arterial pressure values are determined using a second algorithm different from the first algorithm.



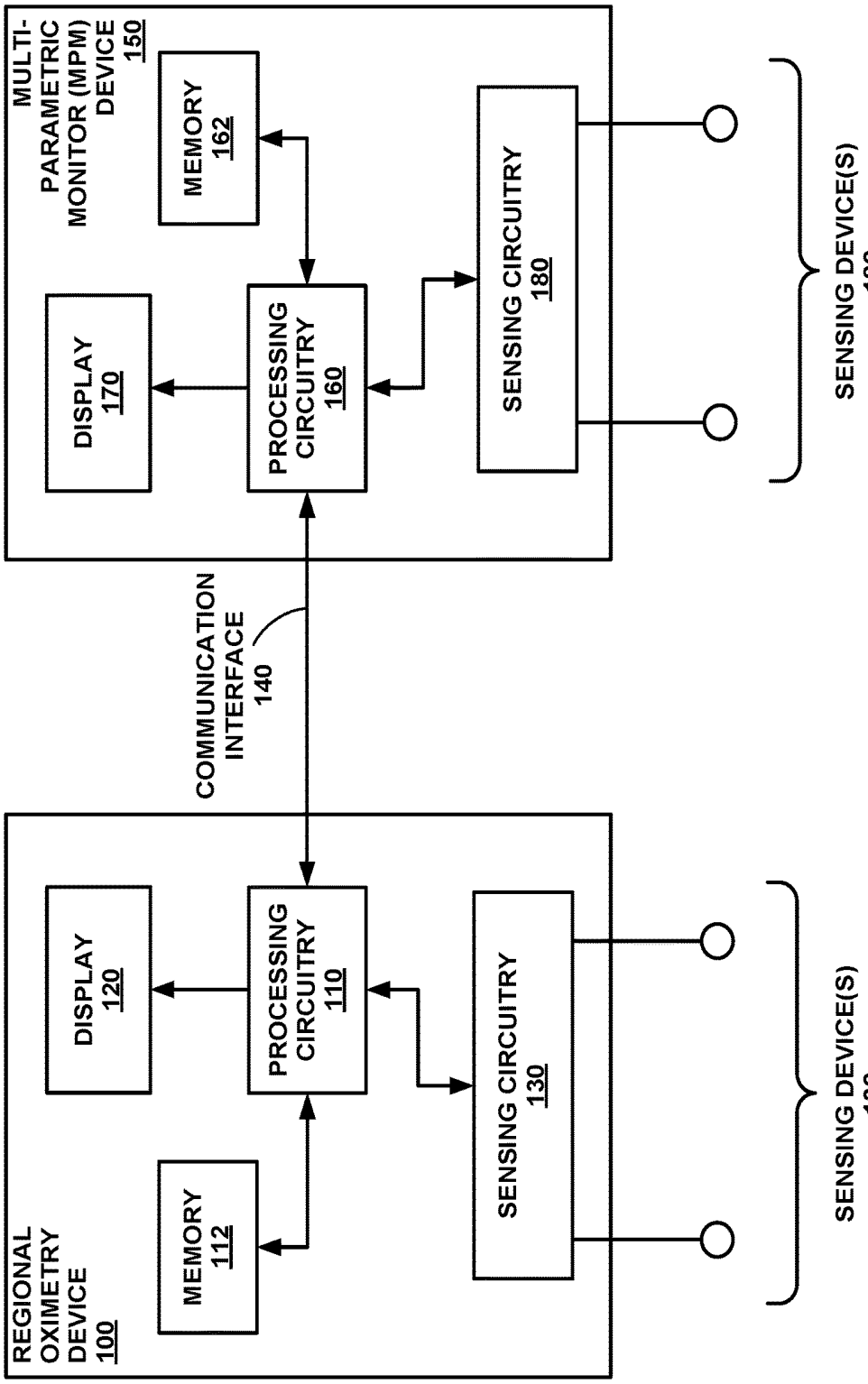

REGIONAL OXIMETRY DEVICE 100
MEMORY 112
DISPLAY 120
PROCESSING CIRCUITRY 110
SENSING CIRCUITRY 130
SENSING DEVICE(S) 132
COMMUNICATION INTERFACE 140
MULTI-PARAMETRIC MONITOR (MPM) DEVICE 150
MEMORY 162
DISPLAY 170
PROCESSING CIRCUITRY 160
SENSING CIRCUITRY 180
SENSING DEVICE(S) 182

FIG. 1

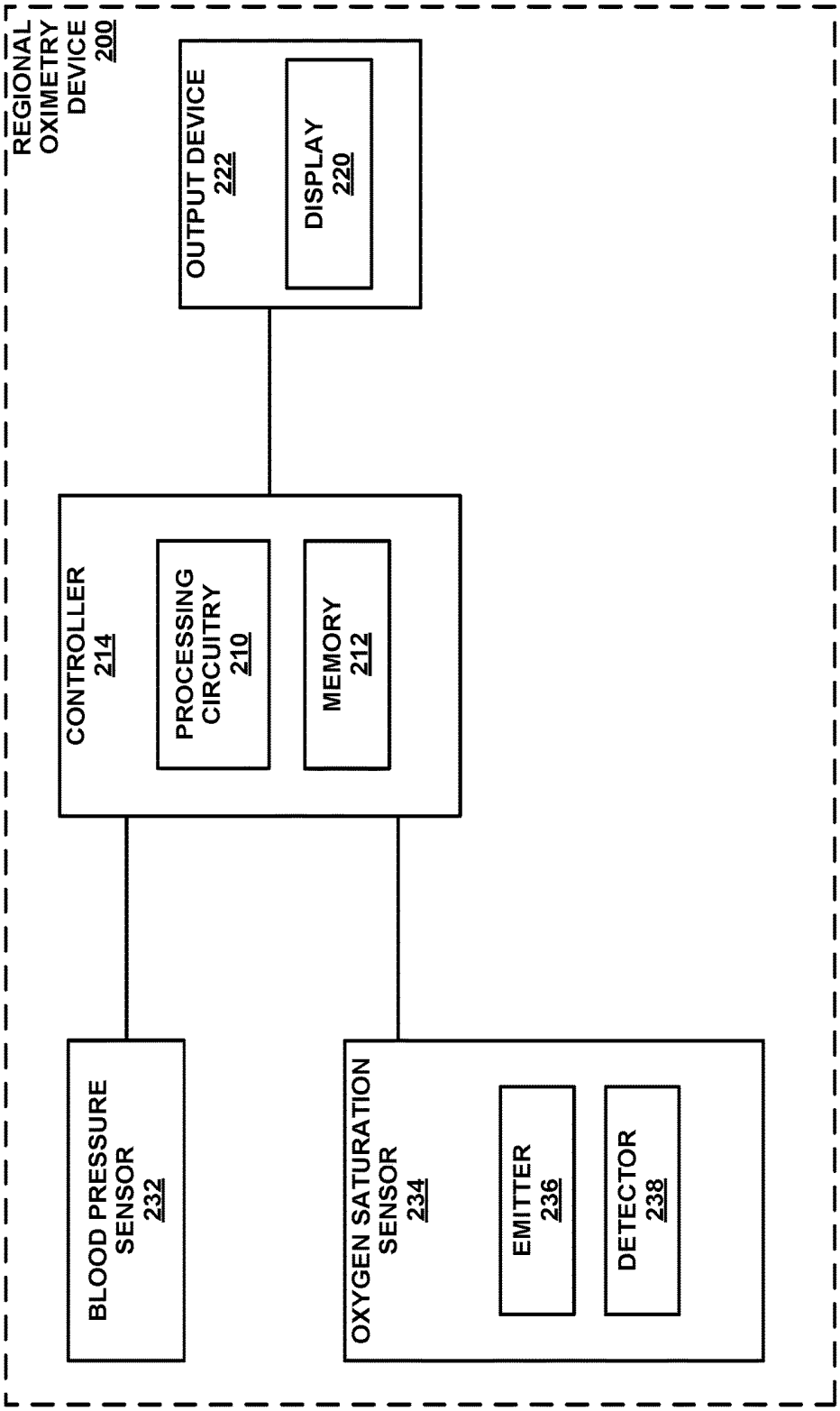

REGIONAL OXIMETRY DEVICE 200
OUTPUT DEVICE 222
DISPLAY 220
CONTROLLER 214
PROCESSING CIRCUITRY 210
MEMORY 212
BLOOD PRESSURE SENSOR 232
OXYGEN SATURATION SENSOR 234
EMITTER 236
DETECTOR 238

FIG. 2

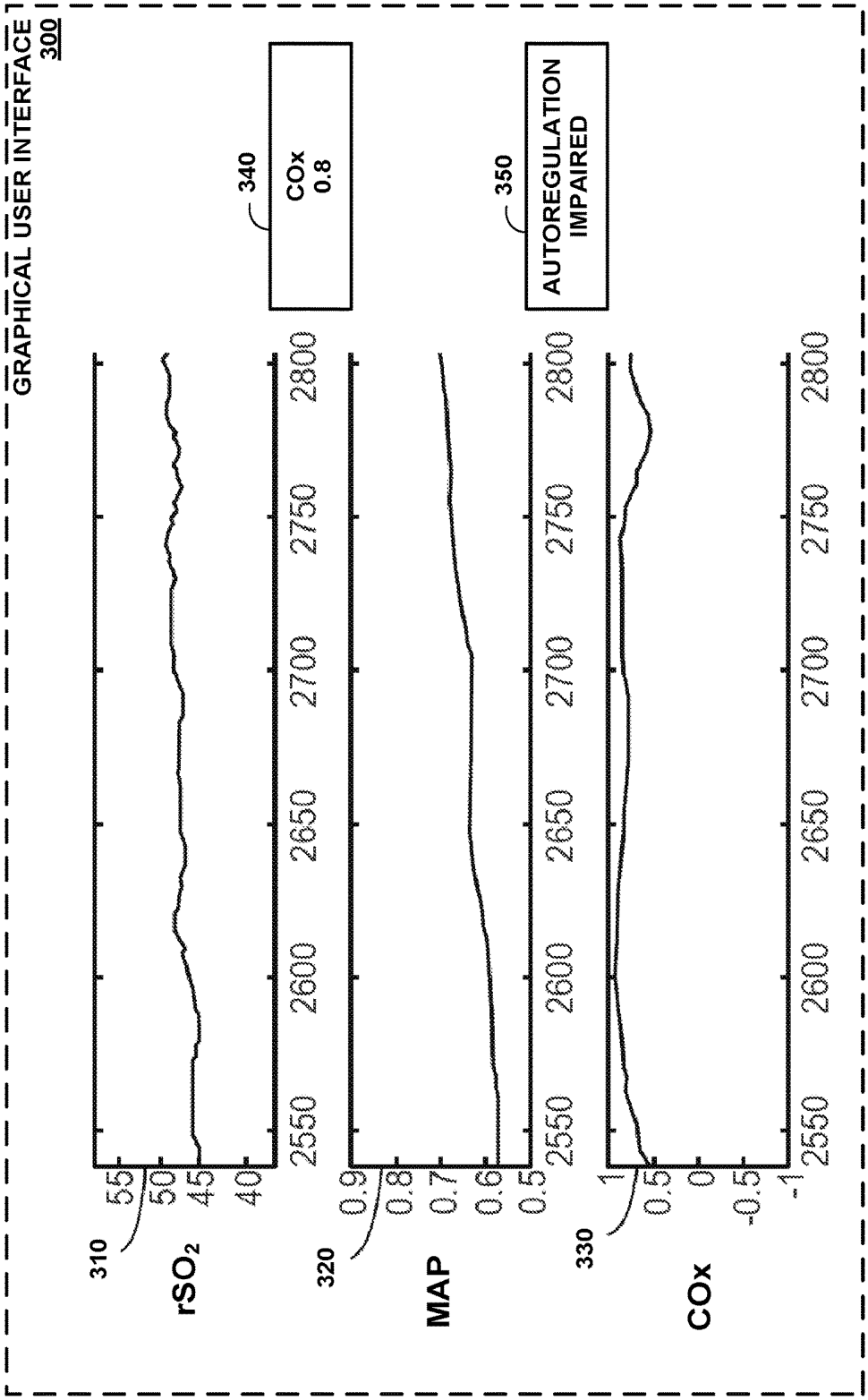

GRAPHICAL USER INTERFACE
300
340
COx
0.8
350
AUTOREGULATION
IMPAIRED
310
rSO2
55
50
45
40
320
MAP
0.9
0.8
0.7
0.6
0.5
330
COx
1
0.5
0
-0.5
-1
2550
2600
2650
2700
2750
2800

FIG. 3

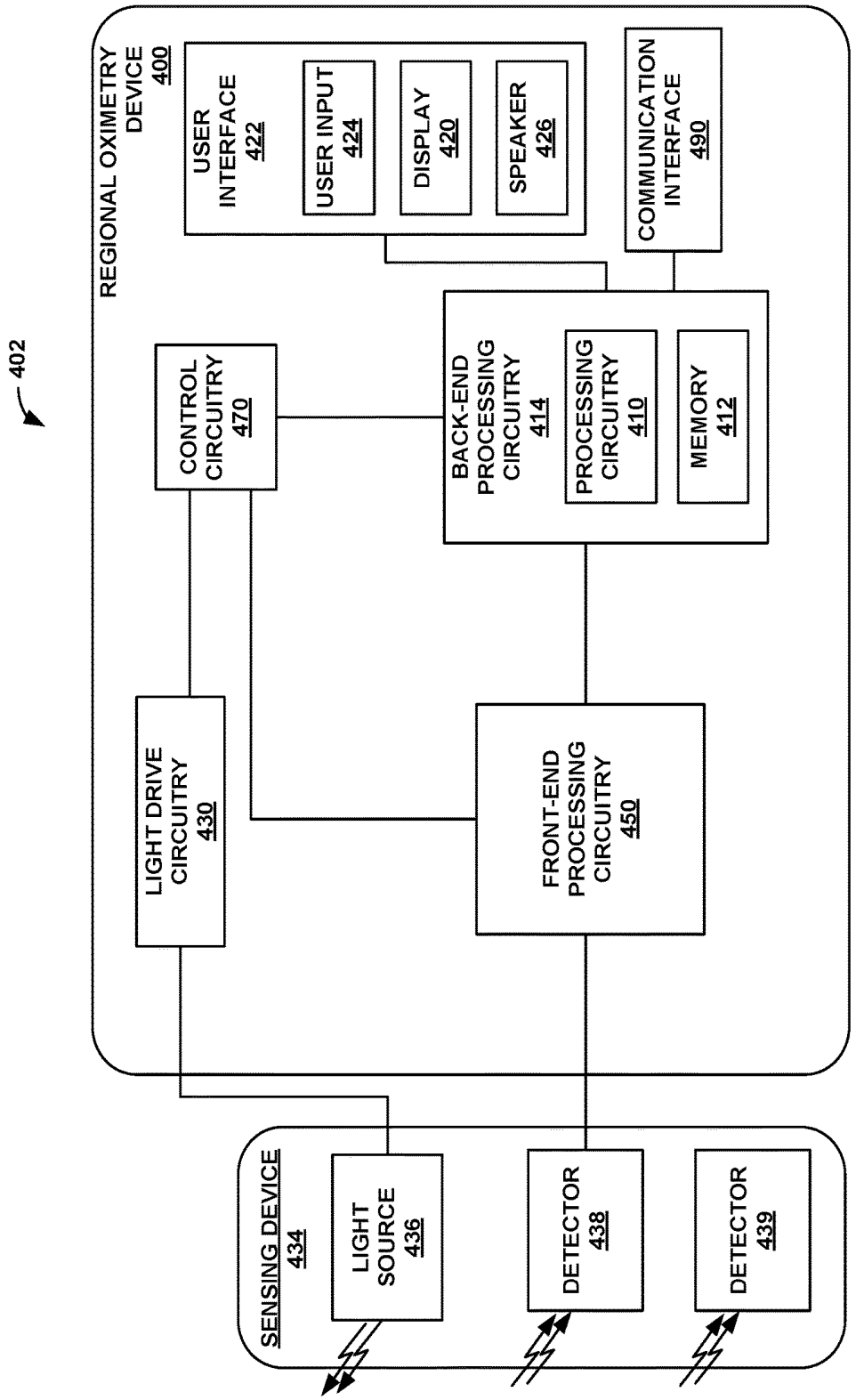
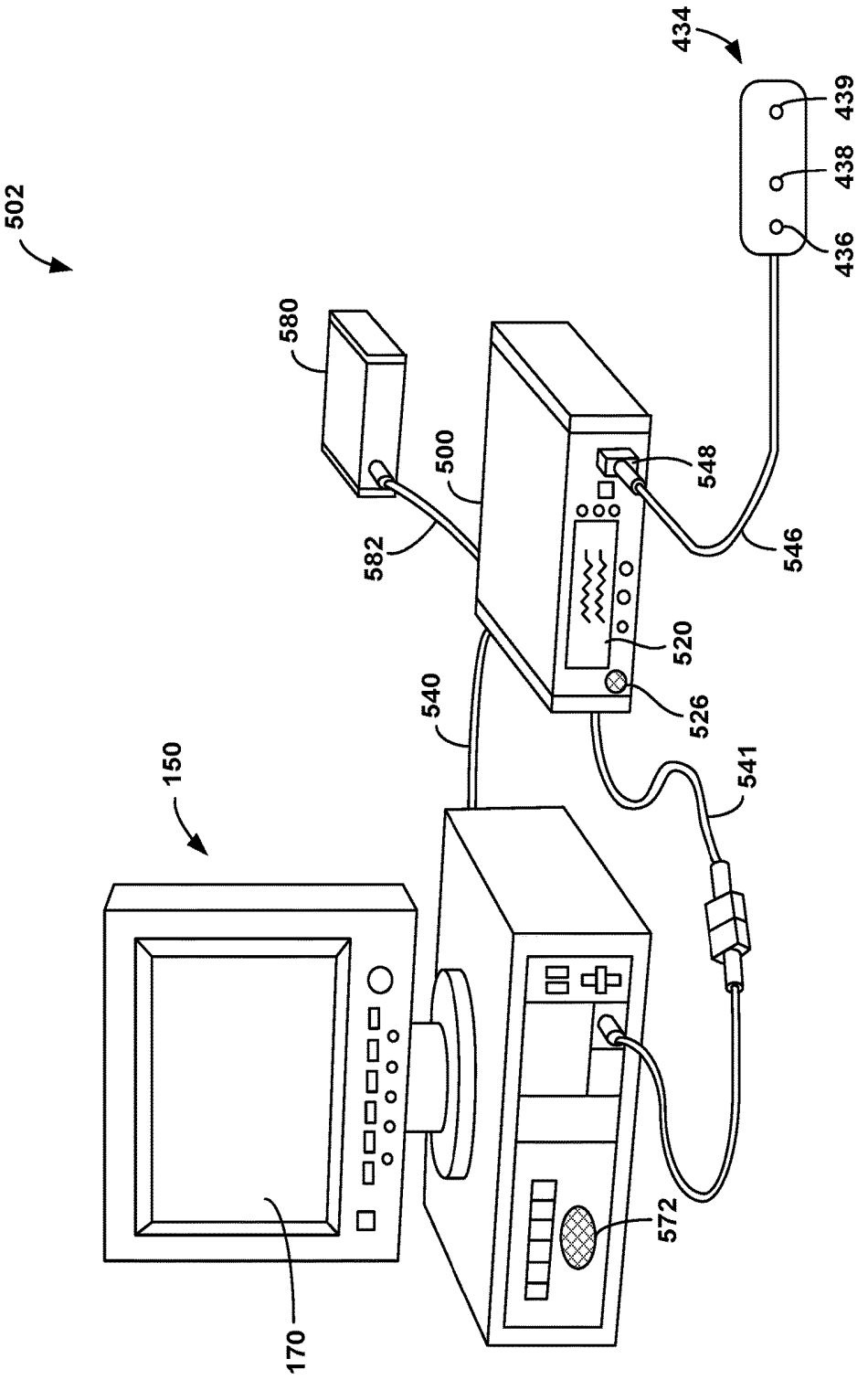

402
REGIONAL OXIMETRY DEVICE 400
USER INTERFACE 422
USER INPUT 424
DISPLAY 420
SPEAKER 426
COMMUNICATION INTERFACE 490
CONTROL CIRCUITRY 470
BACK-END PROCESSING CIRCUITRY 414
PROCESSING CIRCUITRY 410
MEMORY 412
LIGHT DRIVE CIRCUITRY 430
FRONT-END PROCESSING CIRCUITRY 450
SENSING DEVICE 434
LIGHT SOURCE 436
DETECTOR 438
DETECTOR 439

FIG. 4


502
434
439
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436
580
500
548
582
546
520
526
540
541
150
572
170

FIG. 5

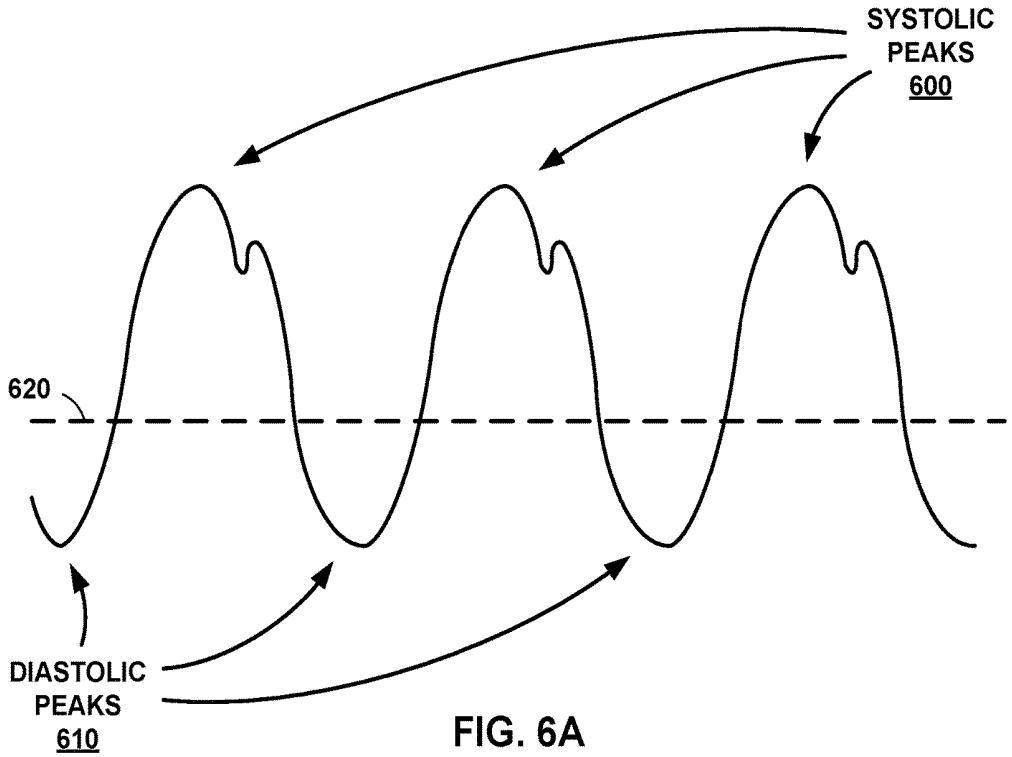


FIG. 6A

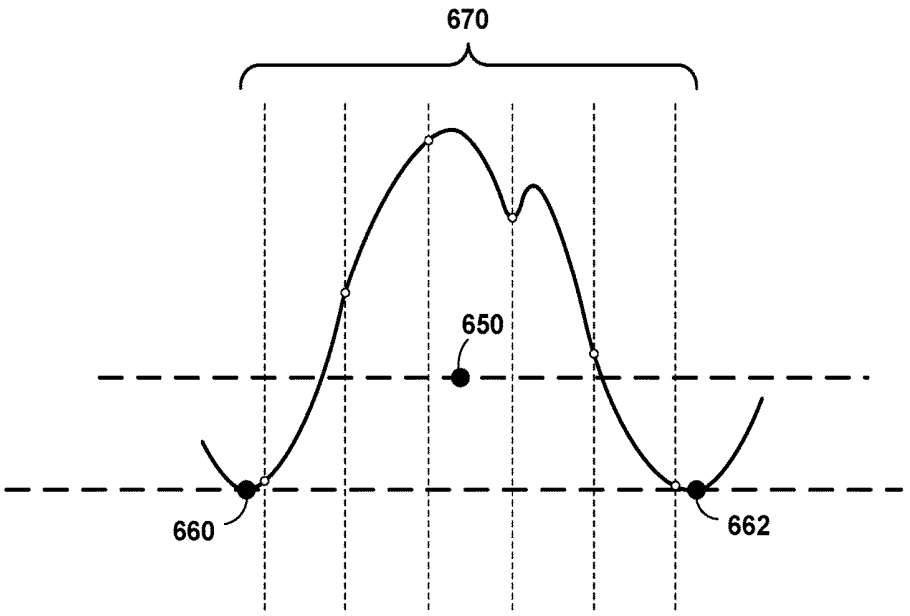


FIG. 6B

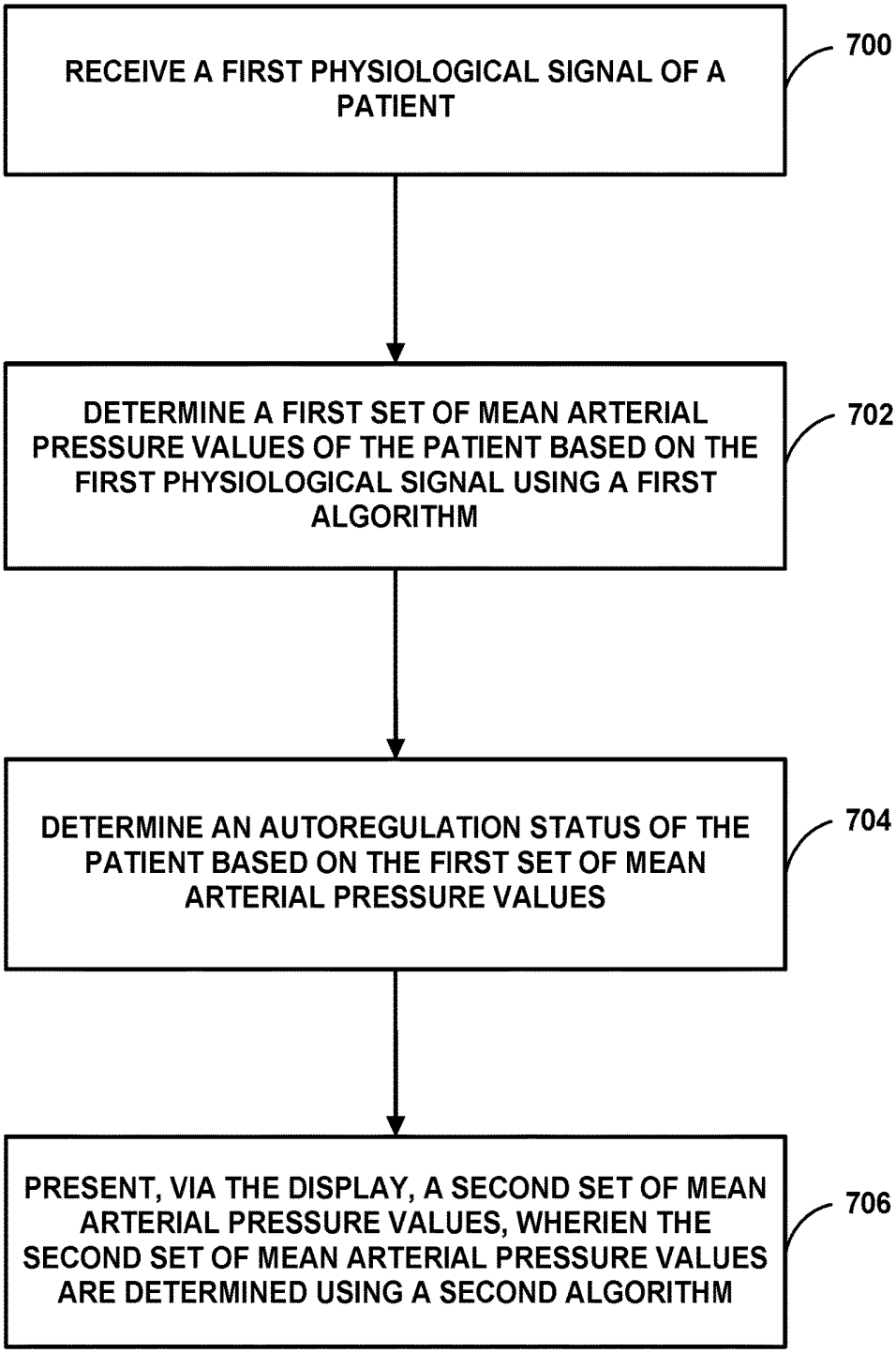
RECEIVE A FIRST PHYSIOLOGICAL SIGNAL OF A PATIENT
700
DETERMINE A FIRST SET OF MEAN ARTERIAL PRESSURE VALUES OF THE PATIENT BASED ON THE FIRST PHYSIOLOGICAL SIGNAL USING A FIRST ALGORITHM
702
DETERMINE AN AUTOREGULATION STATUS OF THE PATIENT BASED ON THE FIRST SET OF MEAN ARTERIAL PRESSURE VALUES
704
PRESENT, VIA THE DISPLAY, A SECOND SET OF MEAN ARTERIAL PRESSURE VALUES, WHERIEN THE SECOND SET OF MEAN ARTERIAL PRESSURE VALUES ARE DETERMINED USING A SECOND ALGORITHM
706

FIG. 7

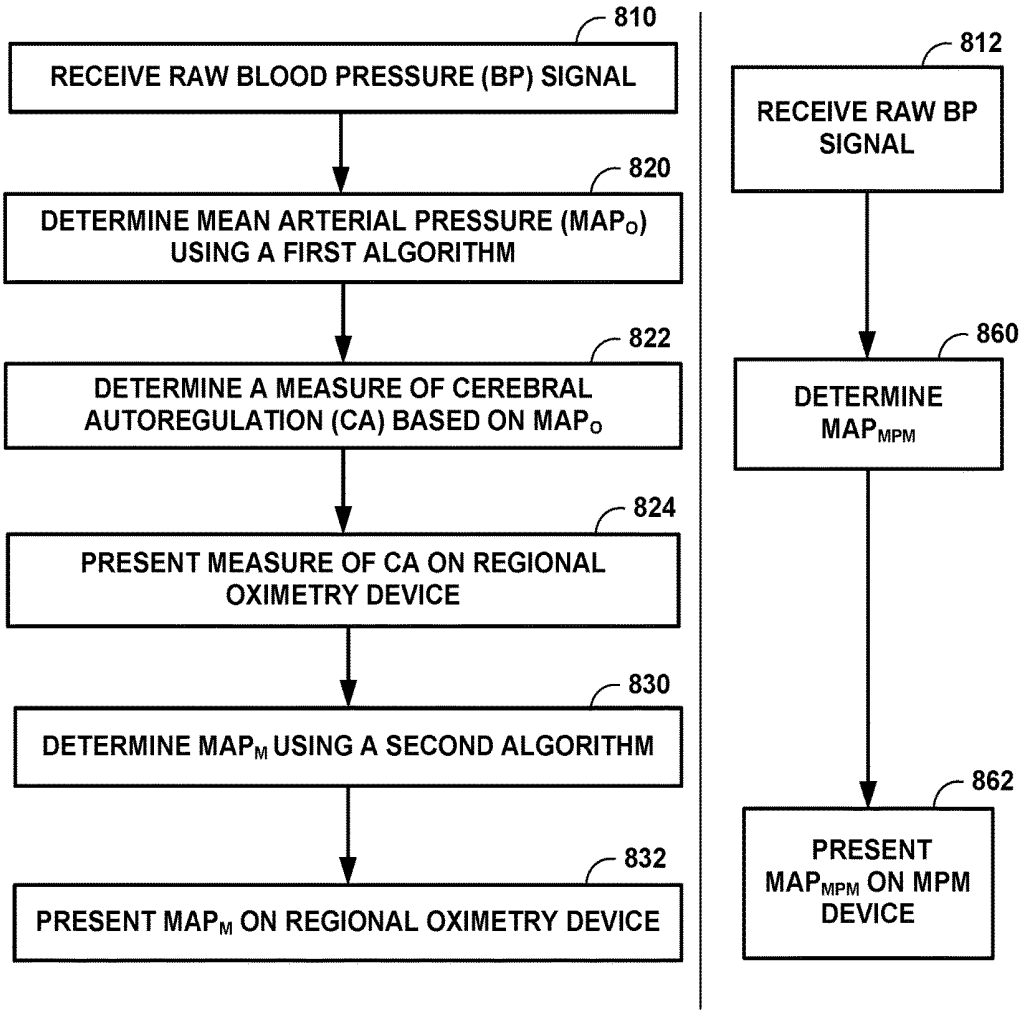
810
RECEIVE RAW BLOOD PRESSURE (BP) SIGNAL
820
DETERMINE MEAN ARTERIAL PRESSURE ($MAP_O$) USING A FIRST ALGORITHM
822
DETERMINE A MEASURE OF CEREBRAL AUTOREGULATION (CA) BASED ON $MAP_O$
824
PRESENT MEASURE OF CA ON REGIONAL OXIMETRY DEVICE
830
DETERMINE $MAP_M$ USING A SECOND ALGORITHM
832
PRESENT $MAP_M$ ON REGIONAL OXIMETRY DEVICE
812
RECEIVE RAW BP SIGNAL
860
DETERMINE $MAP_{MPM}$
862
PRESENT $MAP_{MPM}$ ON MPM DEVICE

FIG. 8A

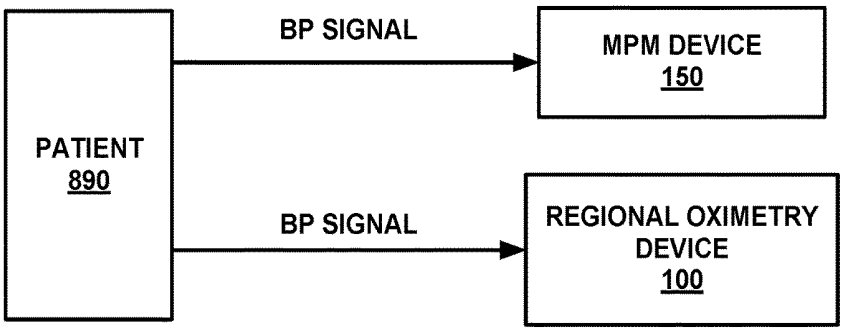
PATIENT
890
BP SIGNAL
MPM DEVICE
150
BP SIGNAL
REGIONAL OXIMETRY DEVICE
100

FIG. 8B

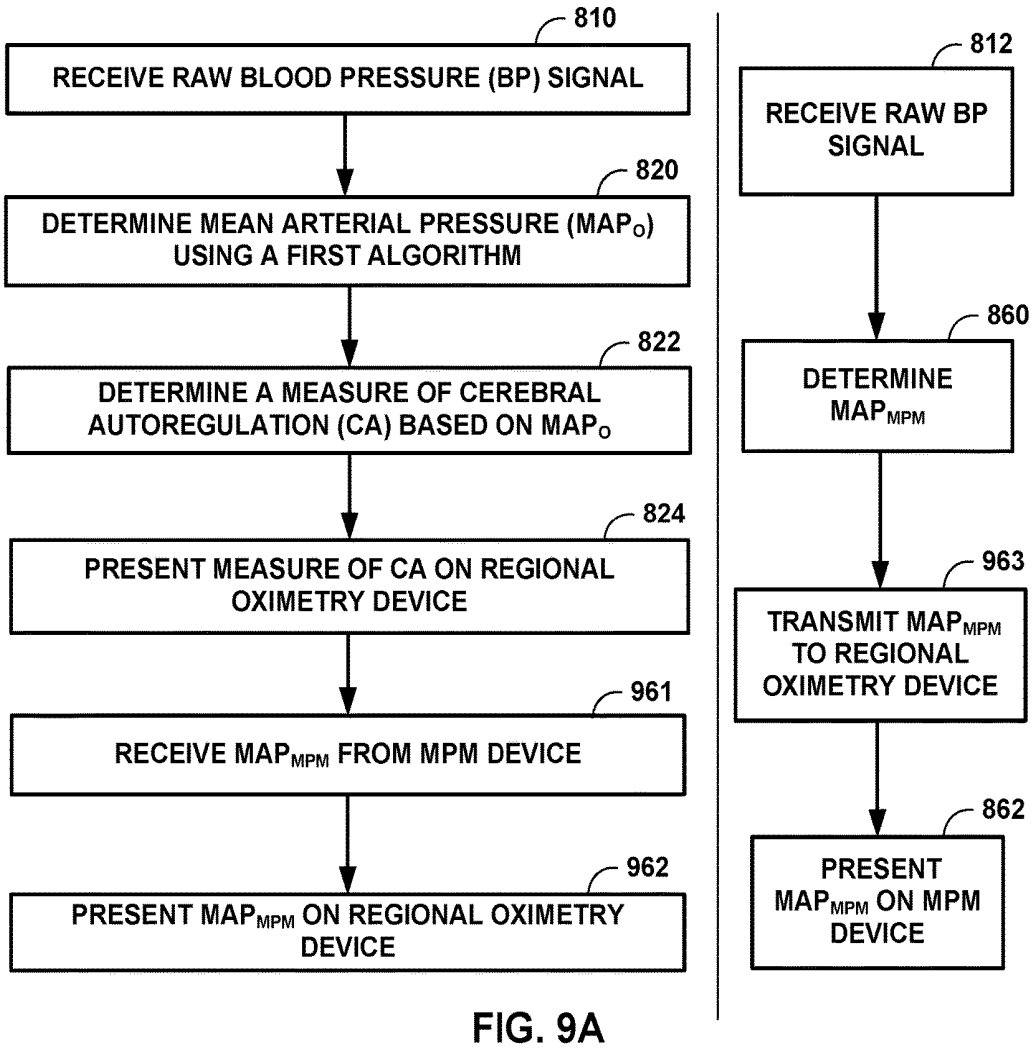
810
RECEIVE RAW BLOOD PRESSURE (BP) SIGNAL
820
DETERMINE MEAN ARTERIAL PRESSURE ($MAP_O$) USING A FIRST ALGORITHM
822
DETERMINE A MEASURE OF CEREBRAL AUTOREGULATION (CA) BASED ON $MAP_O$
824
PRESENT MEASURE OF CA ON REGIONAL OXIMETRY DEVICE
961
RECEIVE $MAP_{MPM}$ FROM MPM DEVICE
962
PRESENT $MAP_{MPM}$ ON REGIONAL OXIMETRY DEVICE
812
RECEIVE RAW BP SIGNAL
860
DETERMINE $MAP_{MPM}$
963
TRANSMIT $MAP_{MPM}$ TO REGIONAL OXIMETRY DEVICE
862
PRESENT $MAP_{MPM}$ ON MPM DEVICE

FIG. 9A

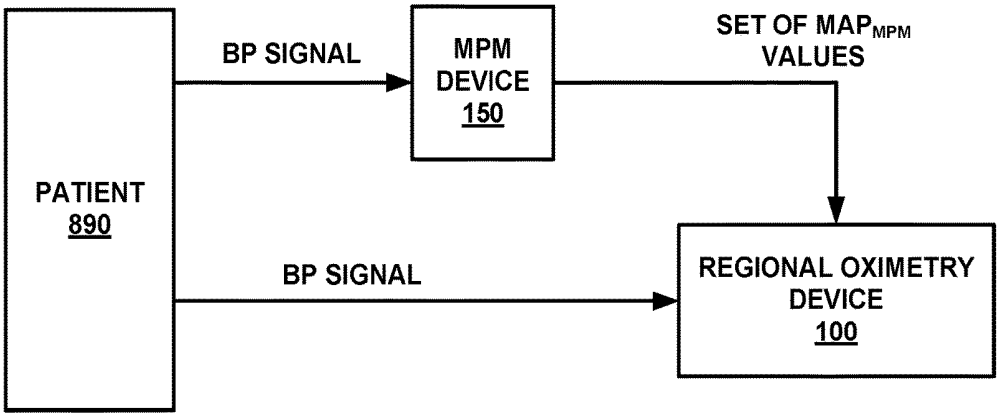
PATIENT
890
BP SIGNAL
MPM DEVICE
150
SET OF $MAP_{MPM}$ VALUES
BP SIGNAL
REGIONAL OXIMETRY DEVICE
100

FIG. 9B

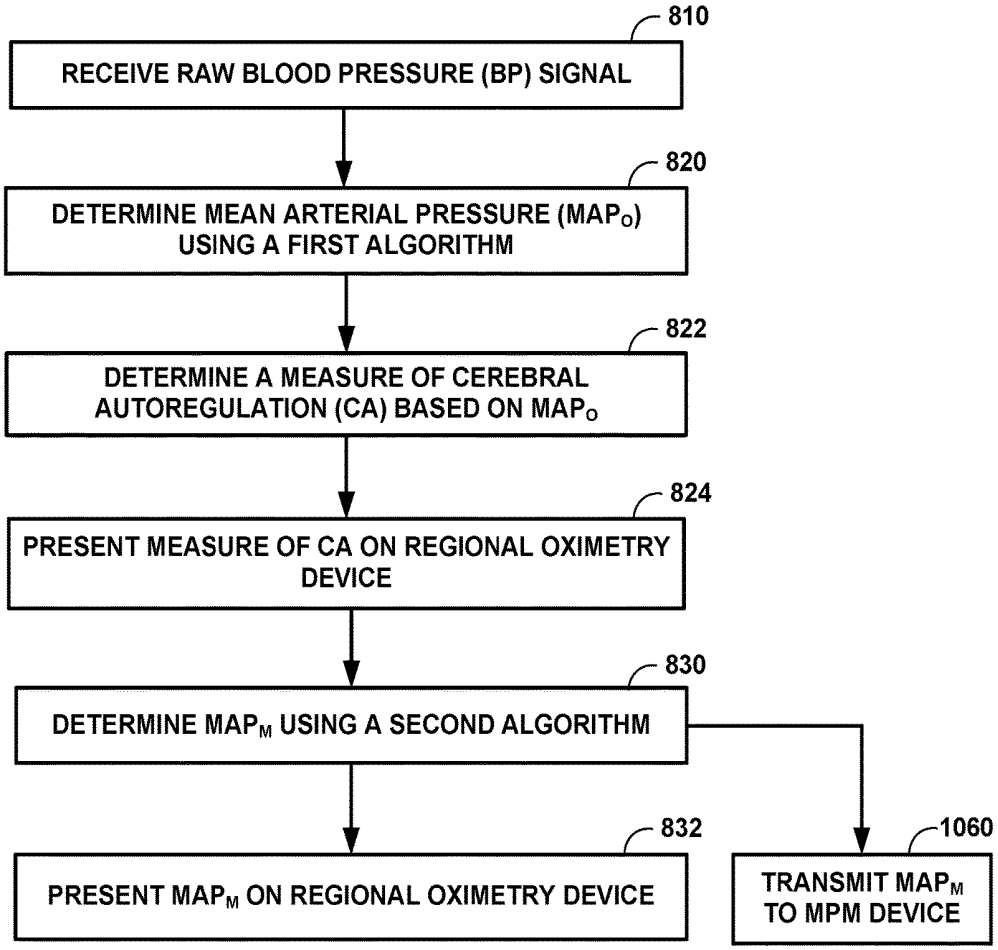


FIG. 10A

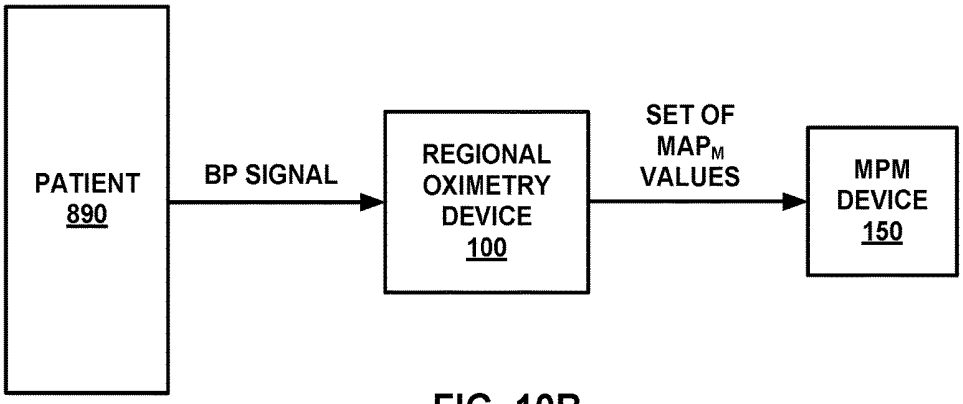


FIG. 10B

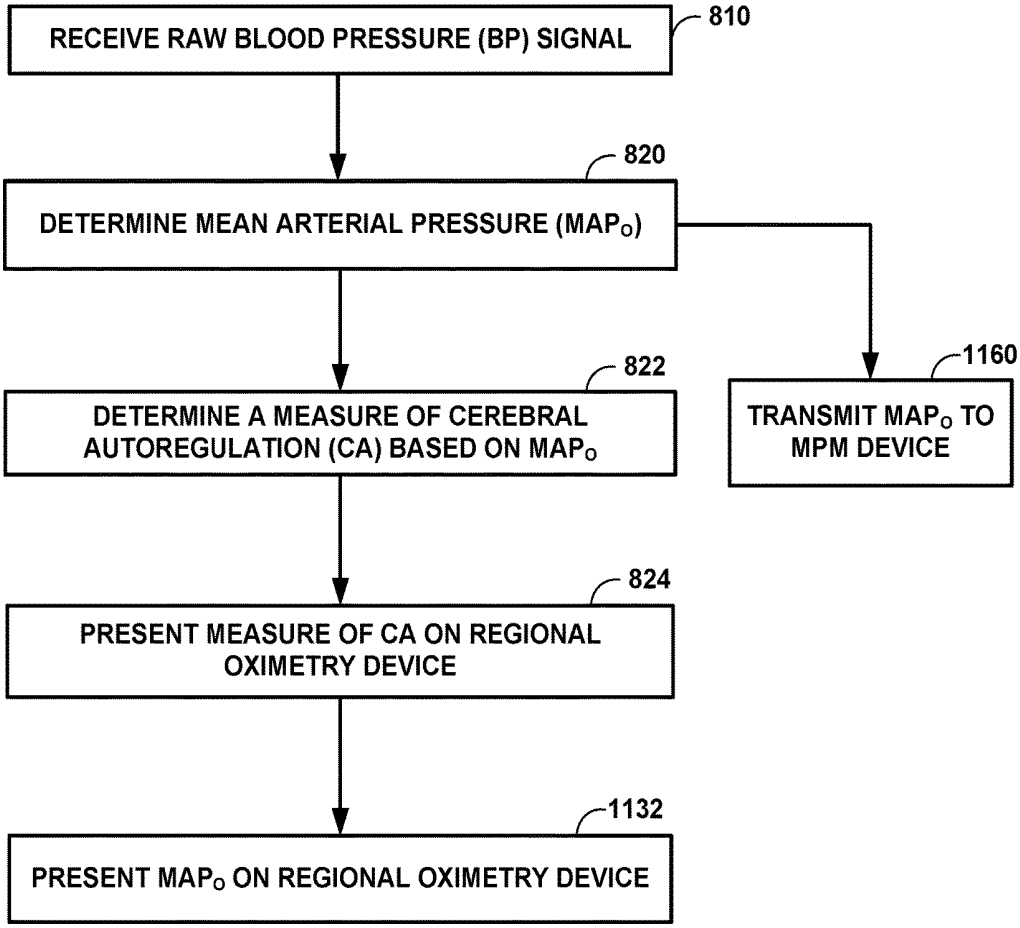


FIG. 11A

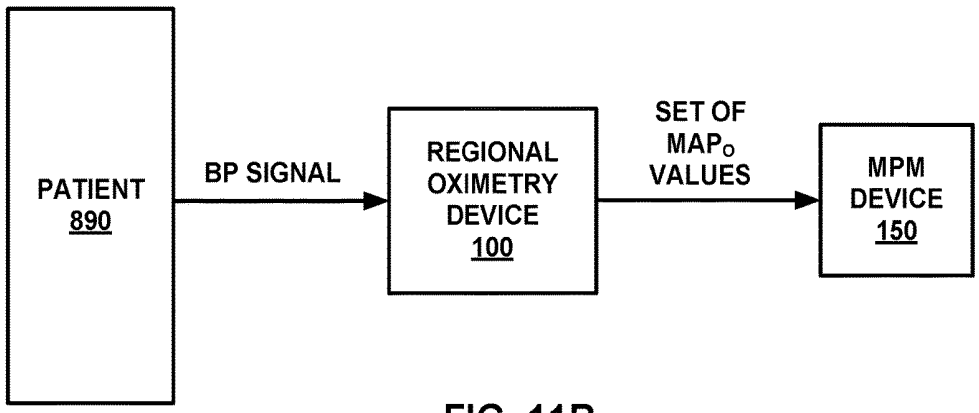


FIG. 11B

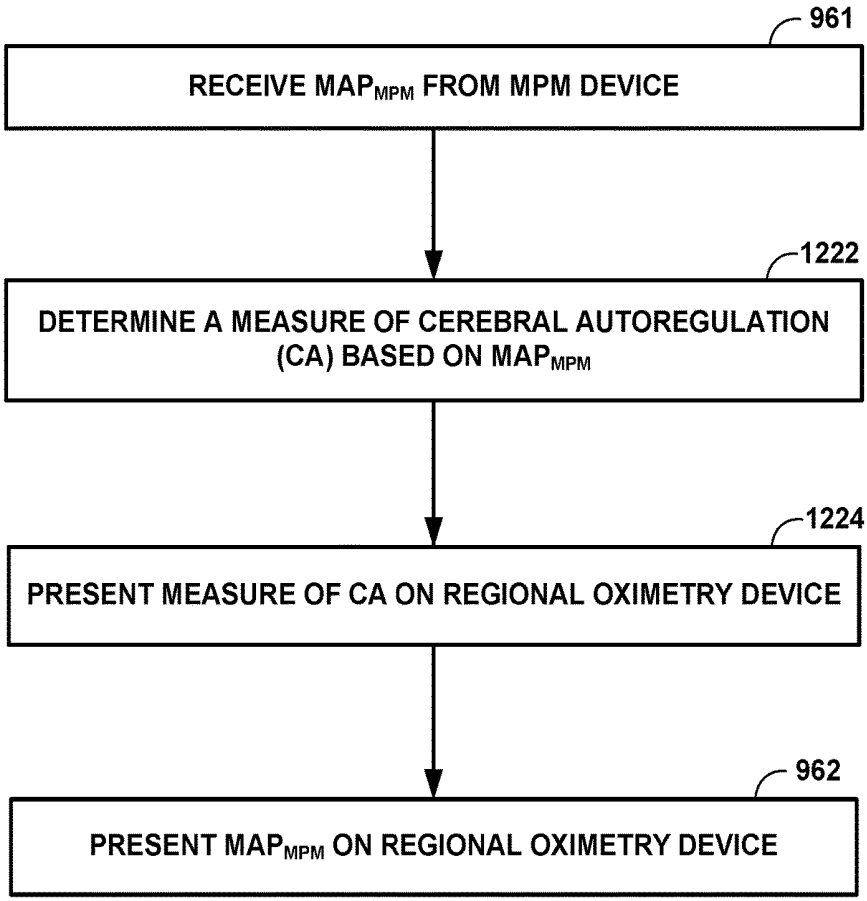


FIG. 12A

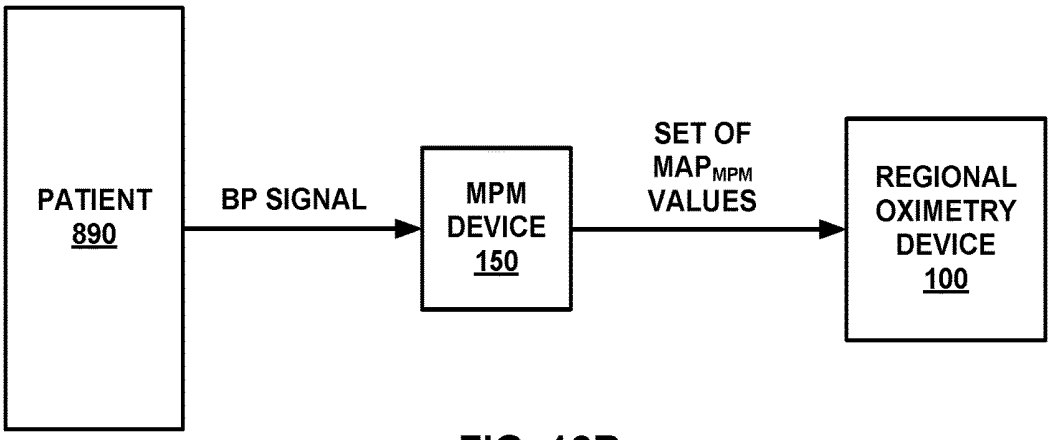


FIG. 12B

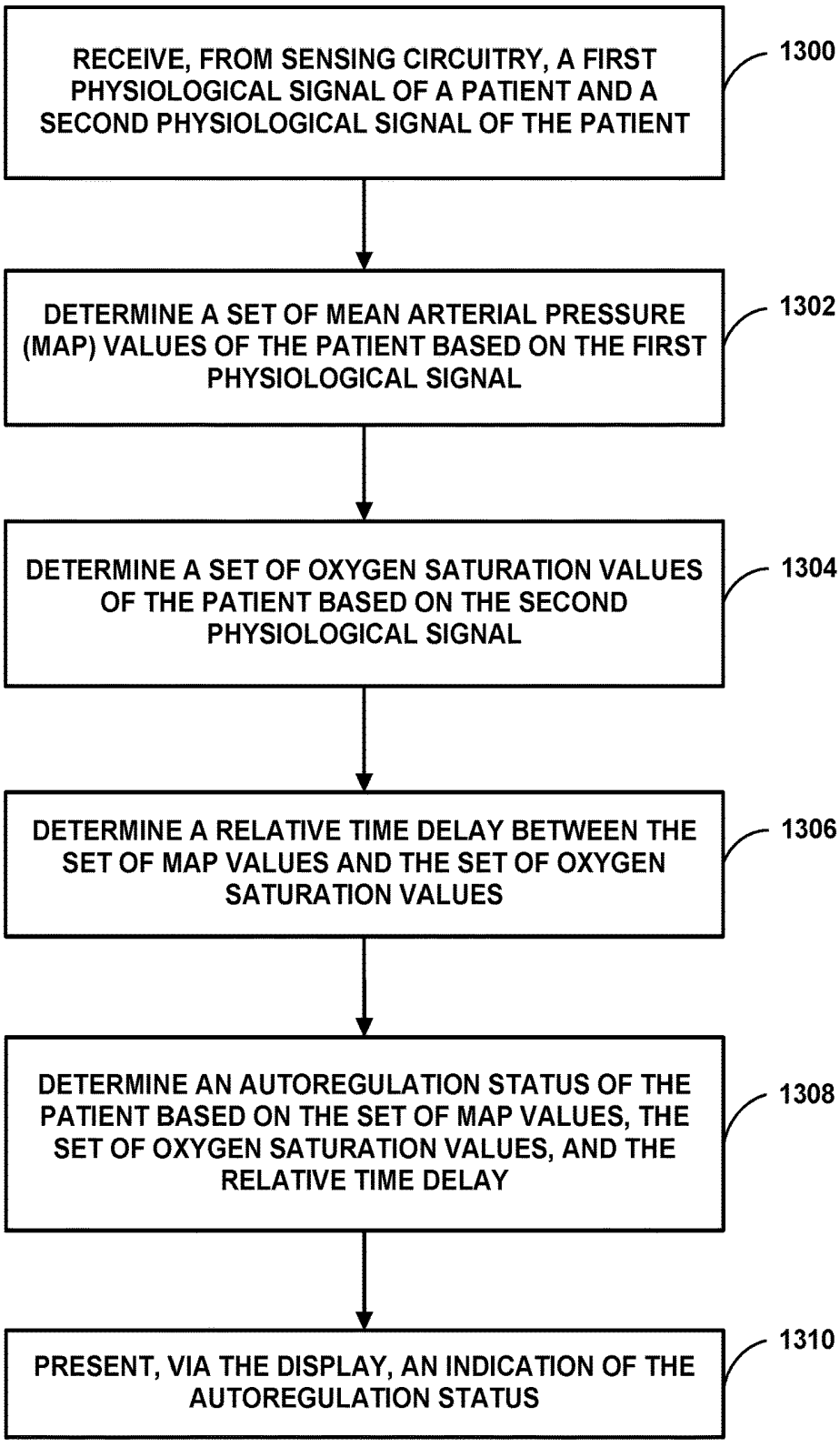
RECEIVE, FROM SENSING CIRCUITRY, A FIRST PHYSIOLOGICAL SIGNAL OF A PATIENT AND A SECOND PHYSIOLOGICAL SIGNAL OF THE PATIENT
1300
DETERMINE A SET OF MEAN ARTERIAL PRESSURE (MAP) VALUES OF THE PATIENT BASED ON THE FIRST PHYSIOLOGICAL SIGNAL
1302
DETERMINE A SET OF OXYGEN SATURATION VALUES OF THE PATIENT BASED ON THE SECOND PHYSIOLOGICAL SIGNAL
1304
DETERMINE A RELATIVE TIME DELAY BETWEEN THE SET OF MAP VALUES AND THE SET OF OXYGEN SATURATION VALUES
1306
DETERMINE AN AUTOREGULATION STATUS OF THE PATIENT BASED ON THE SET OF MAP VALUES, THE SET OF OXYGEN SATURATION VALUES, AND THE RELATIVE TIME DELAY
1308
PRESENT, VIA THE DISPLAY, AN INDICATION OF THE AUTOREGULATION STATUS
1310

FIG. 13

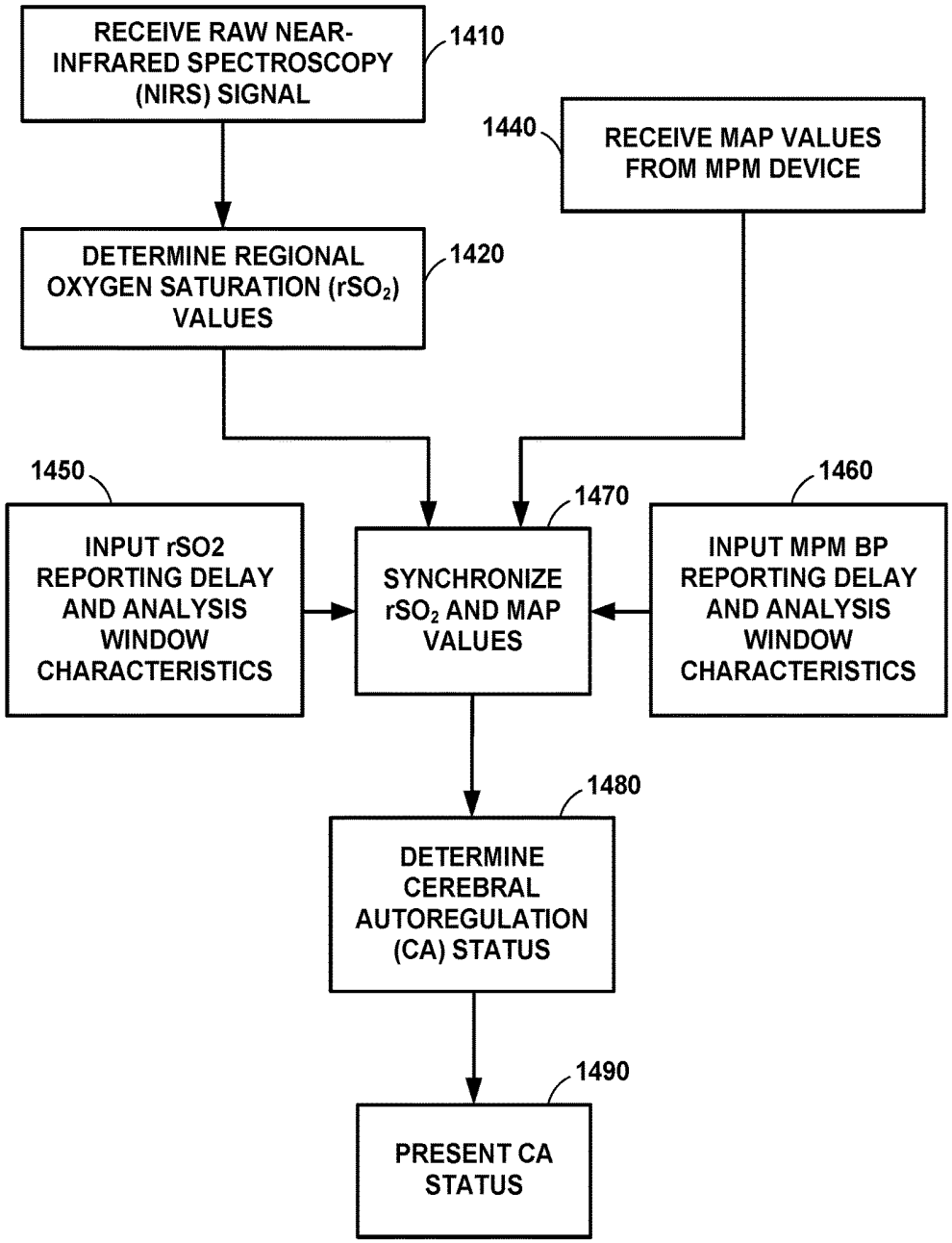
RECEIVE RAW NEAR-INFRARED SPECTROSCOPY (NIRS) SIGNAL
1410
1440
RECEIVE MAP VALUES FROM MPM DEVICE
DETERMINE REGIONAL OXYGEN SATURATION ($rSO_2$) VALUES
1420
1450
INPUT rSO2 REPORTING DELAY AND ANALYSIS WINDOW CHARACTERISTICS
1470
SYNCHRONIZE $rSO_2$ AND MAP VALUES
1460
INPUT MPM BP REPORTING DELAY AND ANALYSIS WINDOW CHARACTERISTICS
1480
DETERMINE CEREBRAL AUTOREGULATION (CA) STATUS
1490
PRESENT CA STATUS

FIG. 14

# PHYSIOLOGICAL PARAMETER MONITORING

## TECHNICAL FIELD

**[0001]** This disclosure relates to physiological parameter monitoring.

## BACKGROUND

**[0002]** Cerebral autoregulation (CA) is the response mechanism by which an organism regulates cerebral blood flow over a wide range of systemic blood pressure changes through complex myogenic, neurogenic, and metabolic mechanisms. Autoregulation dysfunction may result from a number of causes including, stroke, traumatic brain injury, brain lesions, brain asphyxia, or infections of the central nervous system. Intact cerebral autoregulation function occurs over a range of blood pressures defined between a lower limit of autoregulation (LLA) and an upper limit of autoregulation (ULA).

## SUMMARY

**[0003]** This disclosure describes devices, systems, and techniques for determining at least two sets of mean arterial pressure (MAP) values based on a sensed physiological signal of a patient and presenting meaningful information regarding the MAP values to a user. In some examples, a regional oximetry device is configured to determine an autoregulation status of a patient based on a first set of MAP values of the patient. The regional oximetry device may also be configured to present, via a display, a second set of MAP values of the patient. The first and second sets of MAP values of the patient may be representative of the MAP of the patient for the same time period, but may differ from each other, e.g., because the first and second sets of MAP values were determined using different MAP calculation algorithms. In some cases, the first and second sets of MAP values are determined using the same segment of a sensed physiological signal.

**[0004]** In some examples, the regional oximetry device may determine the first set of MAP values and the second set of MAP values and communicate the second set of MAP values to a multi-parametric monitor (MPM) device. In another example, the regional oximetry device may receive the first set of MAP values and/or the second set of MAP values from the MPM device. In a further example, the regional oximetry device may determine the second set of MAP values to mimic the determination of MAP by the MPM device.

**[0005]** Clause 1: In some examples, a device comprises a display and processing circuitry configured to receive a physiological signal indicative of a physiological parameter of a patient and determine a first set of mean arterial pressure values of the patient for a time period based on the physiological signal using a first algorithm. The processing circuitry is also configured to determine an autoregulation status of the patient based on the first set of mean arterial pressure values. The processing circuitry is further configured to present, via the display, a second set of mean arterial pressure values of the patient for the time period, wherein the second set of mean arterial pressure values are determined using a second algorithm different from the first algorithm.

**[0006]** Clause 2: In some examples of clause 1, the processing circuitry is further configured to determine the second set of mean arterial pressure values based on the physiological signal using the second algorithm and communicate the second set of mean arterial pressure values to a multi-parametric monitor device.

**[0007]** Clause 3: In some examples of clause 1 or clause 2, the processing circuitry is further configured to determine the second set of mean arterial pressure values based on the physiological signal using the second algorithm to mimic determination of mean arterial pressure for the time period by a multi-parametric monitor device.

**[0008]** Clause 4: In some examples of clause 3, the processing circuitry is configured to determine the second set of values for mean arterial pressure using the second algorithm to mimic determination of mean arterial pressure by at least determining a weighted average of a systolic peak of the physiological signal and a diastolic peak of the physiological signal. A weighting of the diastolic peak of the physiological signal is greater than or equal to a weighting of the systolic peak of the physiological signal.

**[0009]** Clause 5: In some examples of any of clauses 1-4, the processing circuitry is further configured to receive the second set of mean arterial pressure values from a multi-parametric monitor device.

**[0010]** Clause 6: In some examples of any of clauses 1-5, the physiological parameter of the patient comprises a first physiological parameter, and the processing circuitry is further configured to receive a second physiological signal of the patient, the second physiological signal being indicative of a second physiological parameter different from the first physiological parameter. The processing circuitry is also configured to determine a set of oxygen saturation values of the patient based on the second physiological signal and determine a relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values. The processing circuitry is configured to determine the autoregulation status of the patient based on the first set of mean arterial pressure values, the set of oxygen saturation values, and the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values.

**[0011]** Clause 7: In some examples of clause 6, the processing circuitry is configured to determine the first set of mean arterial pressure values based on a sampling window for the first set of mean arterial pressure values. The processing circuitry is configured to determine the set of oxygen saturation values based on a sampling window for the set of oxygen saturation values. The processing circuitry is configured to determine the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values based on a duration of the sampling window for the first set of mean arterial pressure values and a duration of the sampling window for the set of oxygen saturation values.

**[0012]** Clause 8: In some examples of clause 6 or clause 7, the processing circuitry is configured to determine the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values by at least determining a cross-correlation function for the first physiological signal and the second physiological signal and determining a time lag at which the cross-correlation function has a maximum amplitude.

**[0013]** Clause 9: In some examples of any of clauses 1-8, the processing circuitry is further configured to synchronize the first set of mean arterial pressure values and the set of oxygen saturation values based on the relative time delay. The processing circuitry is configured to determine the autoregulation status of the patient based on the synchronized first set of mean arterial pressure values and the synchronized set of oxygen saturation values.

**[0014]** Clause 10: In some examples of any of clauses 1-9, the processing circuitry is further configured to determine that the autoregulation status is impaired based on the first set of mean arterial pressure values and a set of oxygen saturation values of the patient and generate a notification in response to determining that the autoregulation status is impaired.

**[0015]** Clause 11: In some examples of any of clauses 1-10, the processing circuitry is further configured to determine a signal quality metric based on the difference between the first set of mean arterial pressure values and the second set of mean arterial pressure values. The processing circuitry is also configured to determine that the signal quality metric is greater than or equal to a threshold level and generate a notification in response to determining that the signal quality metric is greater than or equal to the threshold level. The processing circuitry is configured to output the autoregulation status before determining that the signal quality metric is greater than or equal to the threshold level and refrain from further outputting the autoregulation status in response to determining that the signal quality metric is greater than or equal to the threshold level.

**[0016]** Clause 12: In some examples, a method comprises receiving, by processing circuitry, a physiological signal indicative of a physiological parameter of a patient. The method also comprises determining, by the processing circuitry, a first set of mean arterial pressure values of the patient for a time period based on the physiological signal using a first algorithm. The method further comprises determining, by the processing circuitry, an autoregulation status of the patient based on the first set of mean arterial pressure values. The method also comprises presenting, via a display, a second set of mean arterial pressure values of the patient for the time period, wherein the second set of mean arterial pressure values are determined using a second algorithm different from the first algorithm.

**[0017]** Clause 13: In some examples of clause 12, the method further comprises determining the second set of mean arterial pressure values based on the physiological signal using the second algorithm and communicating the second set of mean arterial pressure values to a multi-parametric monitor device.

**[0018]** Clause 14: In some examples of clause 12 or clause 13, the method further comprises receiving the second set of mean arterial pressure values from a multi-parametric monitor device.

**[0019]** Clause 15: In some examples of any of clauses 12-14, the method further comprises receiving, from the sensing circuitry, a second physiological signal of the patient, the second physiological signal being indicative of a second physiological parameter different from the first physiological parameter. The method also comprises determining a set of oxygen saturation values of the patient based on the second physiological signal. The method further comprises determining a relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values. Determining the autoregulation status of the patient is based on the first set of mean arterial pressure values, the set of oxygen saturation values, and the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values.

**[0020]** Clause 16: In some examples of clause 15, determining the first set of mean arterial pressure values is further based on a sampling window for the first set of mean arterial pressure values. Determining the set of oxygen saturation values is further based on a sampling window for the set of oxygen saturation values. Determining the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values based on a duration of the sampling window for the first physiological signal and a duration of the sampling window for the second physiological signal.

**[0021]** Clause 17: In some examples of clause 15 or clause 16, determining the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values comprises determining a cross-correlation function for the first physiological signal and the second physiological signal and determining a time lag at which the cross-correlation function has a maximum amplitude.

**[0022]** Clause 18: In some examples, a device comprises a display and processing circuitry configured to receive a first physiological signal indicative of a physiological parameter of a patient and determine a first set of mean arterial pressure values of the patient for a time period based on the first physiological signal. The processing circuitry is also configured to transmit the first set of mean arterial pressure values to a multi-parametric monitor device and determine an autoregulation status of the patient based on the first set of mean arterial pressure values. The processing circuitry is further configured to present, via the display, the first set of mean arterial pressure values of the patient for the time period.

**[0023]** Clause 19: In some examples of clause 18, the physiological parameter of the patient comprises a first physiological parameter, and the processing circuitry is further configured to receive a second physiological signal of the patient, the second physiological signal being indicative of a second physiological parameter different from the first physiological parameter. The processing circuitry is also configured to determine a set of oxygen saturation values of the patient based on the second physiological signal and determine a relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values. The processing circuitry is configured to determine the autoregulation status of the patient based on the first set of mean arterial pressure values, the set of oxygen saturation values, and the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values.

**[0024]** Clause 20: In some examples of clause 18 or clause 19, the processing circuitry is configured to determine the first set of mean arterial pressure values based on a sampling window for the first set of mean arterial pressure values. The processing circuitry is configured to determine the set of oxygen saturation values based on a sampling window for the set of oxygen saturation values. The processing circuitry is configured to determine the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values based on a duration of the sam-

pling window for the first set of mean arterial pressure values and a duration of the sampling window for the set of oxygen saturation values.

**[0025]** Clause 21: In some examples, a system comprises means for receiving a physiological signal indicative of a physiological parameter of a patient; means for determining a first set of mean arterial pressure values of the patient for a time period based on the physiological signal using a first algorithm; means for determining an autoregulation status of the patient based on the first set of mean arterial pressure values; and means for presenting a second set of mean arterial pressure values of the patient for the time period, wherein the second set of mean arterial pressure values are determined using a second algorithm different from the first algorithm.

**[0026]** Clause 22: In some examples, a device comprises a display and processing circuitry configured to receive a first physiological signal of a patient and a second physiological signal of the patient, the first and second physiological signals being indicative of different physiological parameters of the patient. The processing circuitry is also configured to determine a set of mean arterial pressure values of the patient based on the first physiological signal and determine a set of oxygen saturation values of the patient based on the second physiological signal. The processing circuitry is further configured to determine a relative time delay between the set of mean arterial pressure values and the set of oxygen saturation values and determine an autoregulation status of the patient based on the set of mean arterial pressure values, the set of oxygen saturation values, and the relative time delay between the set of mean arterial pressure values and the set of oxygen saturation values. The processing circuitry is configured to present, via the display, an indication of the autoregulation status.

**[0027]** Clause 23: In some examples of clause 22, the processing circuitry is configured to determine the set of mean arterial pressure values based on a sampling window for the set of mean arterial pressure values. The processing circuitry is also configured to determine the set of oxygen saturation values based on a sampling window for the set of oxygen saturation values. The processing circuitry is configured to determine the relative time delay between the set of mean arterial pressure values and the set of oxygen saturation values based on a duration of the sampling window for the set of mean arterial pressure values and a duration of the sampling window for the set of oxygen saturation values.

**[0028]** Clause 24: In some examples of clause 23, the processing circuitry is configured to determine the relative time delay between the set of mean arterial pressure values and the set of oxygen saturation values by at least determining a cross-correlation function for the first physiological signal and the second physiological signal; and determining a time lag at which the cross-correlation function has a maximum amplitude.

**[0029]** Clause 25: In some examples of any of clauses 22-24, the processing circuitry is further configured to synchronize the set of mean arterial pressure values and the set of oxygen saturation values based on the relative time delay. The processing circuitry is also configured to determine the autoregulation status of the patient based on the synchronized set of mean arterial pressure values and the synchronized set of oxygen saturation values.

**[0030]** Clause 26: In some examples, a method comprises receiving, by processing circuitry, a first physiological signal of a patient and a second physiological signal of the patient, the first and second physiological signals being indicative of different physiological parameters of the patient. The method further comprises determining, by the processing circuitry, a set of mean arterial pressure values of the patient based on the first physiological signal and determine a set of oxygen saturation values of the patient based on the second physiological signal; determining, by the processing circuitry, a relative time delay between the set of mean arterial pressure values and the set of oxygen saturation values and determine an autoregulation status of the patient based on the set of mean arterial pressure values, the set of oxygen saturation values, and the relative time delay between the set of mean arterial pressure values and the set of oxygen saturation values. The method may further comprise presenting, via a display, an indication of the autoregulation status.

**[0031]** Clause 27: In some examples, a system comprises means for receiving a first physiological signal of a patient and a second physiological signal of the patient, the first and second physiological signals being indicative of different physiological parameters of the patient. The system further comprises means for determining a set of mean arterial pressure values of the patient based on the first physiological signal and determine a set of oxygen saturation values of the patient based on the second physiological signal; means for determining a relative time delay between the set of mean arterial pressure values and the set of oxygen saturation values and determine an autoregulation status of the patient based on the set of mean arterial pressure values, the set of oxygen saturation values, and the relative time delay between the set of mean arterial pressure values and the set of oxygen saturation values. The system may further comprise means for presenting an indication of the autoregulation status.

**[0032]** The details of one or more examples are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

## BRIEF DESCRIPTION OF DRAWINGS

**[0033]** FIG. **1** is a conceptual block diagram illustrating an example regional oximetry device and an example multi-parametric (MPM) device.

**[0034]** FIG. **2** is a conceptual block diagram illustrating an example regional oximetry device configured to monitor the autoregulation status of a patient.

**[0035]** FIG. **3** illustrates an example graphical user interface including autoregulation information presented on a display.

**[0036]** FIG. **4** is a conceptual block diagram illustrating an example physiological parameter monitoring system.

**[0037]** FIG. **5** is a perspective-view diagram illustrating an example physiological parameter monitoring system.

**[0038]** FIGS. **6**A and **6**B illustrate example blood-pressure waveforms.

**[0039]** FIG. **7** is a flow diagram illustrating example techniques for presenting mean arterial pressure (MAP) values.

**[0040]** FIGS. **8**A and **8**B are a flow diagram and a conceptual block diagram, respectively, illustrating an example technique performed by a regional oximetry device to deter-

mine and display MAP to mimic the MAP determined by an MPM device, as well as a corresponding example technique performed by the MPM device.

**[0041]** FIGS. **9**A and **9**B are a flow diagram and a conceptual block diagram illustrating an example technique performed by regional oximetry device to receive and display MAP values determined by an MPM device, as well as a corresponding example technique performed by the MPM device.

**[0042]** FIGS. **10**A and **10**B are a flow diagram and a conceptual block diagram illustrating an example technique performed by regional oximetry device to determine, display, and communicate MAP values to an MPM device using two algorithms.

**[0043]** FIGS. **11**A and **11**B are a flow diagram and a conceptual block diagram illustrating an example technique performed by regional oximetry device to determine, display, and communicate MAP values to an MPM device using one algorithm.

**[0044]** FIGS. **12**A and **12**B are a flow diagram and a conceptual block diagram illustrating an example technique performed by regional oximetry device to receive and display MAP values determined by an MPM device.

**[0045]** FIG. **13** is a flow diagram illustrating an example technique for synchronizing MAP values and oxygen saturation values.

**[0046]** FIG. **14** is a flow diagram illustrating an example regional oximetry device including processing circuitry configured to synchronize regional oxygen saturation ($rSO_2$) and MAP signals.

## DETAILED DESCRIPTION

**[0047]** This disclosure describes devices, systems, and techniques for presenting mean arterial pressure (MAP) values of a patient, e.g., for autoregulation monitoring. A system may include a regional oximetry device configured to present, via a display of the regional oximetry device, a set of MAP values of a patient for a time period. The system may also include a multi-parametric monitor (MPM) device different from the regional oximetry device and configured to present, via a display of the MPM device, a set of MAP values of the patient. In some cases, the regional oximetry device and the MPM device may present MAP values for the same time period (e.g., based on the same raw blood pressure signal and/or determined blood pressure values) that differ from each other. These differences may be due to, for example, the regional oximetry device and the MPM device using different algorithms to determine MAP values. Thus, even if the regional oximetry device and the MPM device determine MAP values for the same time period and using the same raw blood pressure signal, the regional oximetry device and the MPM device may display different MAP values.

**[0048]** If both the regional oximetry device and the MPM device are used to monitor a patient at the same time, e.g., during a medical procedure, then it may be undesirable for the regional oximetry device and the MPM device to present MAP values for the same time period that differ substantially. For example, a clinician may lose confidence in the MAP values presented by the devices or be uncertain of which set of MAP values to rely on during a medical procedure. The devices, systems, and techniques of this disclosure may help address these issues and improve the operation of a regional oximetry device and/or a MPM device by increasing the consistency between the MAP values presented by the regional oximetry device and MAP values presented by an MPM device.

**[0049]** The devices, systems, and techniques of this disclosure may enable more nuanced coordination between the presentation of MAP values by two devices. In contrast, a MPM device and regional oximetry device that merely use the same raw blood pressure signal to determine sets of MAP values, without any other coordination between the two devices, may result in larger differences between the MAP values presented by the MPM device and the regional oximetry device. The devices, systems, and techniques of this disclosure may reduce the likelihood that a clinician will receive different MAP values from the two devices. This may, for example, result in devices that provide the clinician with an improved user interface (including the MAP values), and reduce the time that the clinician takes to decide whether the blood pressure of the patient is in the intact region of autoregulation.

**[0050]** In some examples, the devices, systems, and techniques of this disclosure may also improve the accuracy of the regional oximetry device by synchronizing (in time) a set of MAP values and a set of regional oxygen saturation ($rSO_2$) values that the regional oximetry device uses to determine the autoregulation status of the patient. For example, the regional oximetry device may determine the set of MAP values based on a first physiological signal received from the patient and may determine the set of $rSO_2$ values based on a second physiological signal received from the patient, the first and second physiological signals being indicative of different physiological parameters of the patient. The two physiological signals may not necessarily be synchronized (in time) because of the different sensor circuitry for sensing the physiological parameters and generating the physiological signals change as a function of the respective physiological parameter. In addition, the regional oximetry device may use sampling windows of different time durations for each physiological signal, which may result in unsynchronized MAP and $rSO_2$ values. The MAP and $rSO_2$ values may be synchronized in time if the MAP and $rSO_2$ values are matched up exactly in time or represent values measured within less than one second of each other, such as within 0.5 seconds. In some examples, the MAP values may be offset from the $rSO_2$ values by a relative time delay, which may cause the regional oximetry device to determine an autoregulation status based on a MAP value at time X and a $rSO_2$ value at time X plus the relative time delay. This may result in a less accurate determination of a patient's autoregulation status. The devices, systems, and techniques of some examples described herein may help address these issues.

**[0051]** A regional oximetry device using synchronized MAP and $rSO_2$ values may provide a more accurate determination of autoregulation status, e.g., as compared to a device using unsynchronized MAP and $rSO_2$ values to determine autoregulation status. By synchronizing the MAP and $rSO_2$ values, the regional oximetry device may determine the autoregulation status of the patient based on more coherent data. For example, the regional oximetry device may determine cerebral oximetry index (COx) values for the MAP and $rSO_2$ values by determining a set of data points. Each data point may be associated with a MAP value at a particular time and a $rSO_2$ value at the particular time. If the MAP and $rSO_2$ values are synchronized, then each data point

may be associated with a MAP value at a particular time and a $rSO_2$ value at the same particular time. In contrast, if the MAP and $rSO_2$ values are unsynchronized, then each data point may be associated with a MAP value at a particular time and a $rSO_2$ value at the particular time plus or minus a relative time delay. The relative time delay may cause the regional oximetry device to determine an autoregulation status of a patient using data representative of patient states at different times. Using data that represents patient states at different times may introduce error into a technique used to determine the autoregulation status. For example, using data representing patient states at different times can introduce error into the determination of COx values, which can be used to determine the autoregulation status of a patient.

**[0052]** The autoregulation status may be an indication that the cerebral autoregulation control mechanism of a patient is intact (e.g., functioning properly) or impaired. Cerebral blood flow (CBF) may be regulated over a range of systemic blood pressures by the CA control mechanism. This range may lie within the lower and upper limits of autoregulation (LLA and ULA), beyond which blood pressure drives CBF, and CA function may be considered impaired. One method to determine the limits of autoregulation (the LAs) noninvasively using near-infrared spectroscopy (NIRS) technology may be via the COx measure: a moving correlation index between MAP and $rSO_2$. In an intact region of CA, there may be no correlation between these variables whereas in an impaired region of CA, the correlation index should approximate unity. In practice, however, the data may be noisy and/or the intact region may exhibit a slightly positive relationship.

**[0053]** FIG. **1** is a conceptual block diagram illustrating an example patient monitoring system that includes an example regional oximetry device **100** and an example multi-parametric (MPM) device **150**. Regional oximetry device **100** includes processing circuitry **110**, memory **112**, display **120**, sensing circuitry **130**, and sensing device(s) **132**. MPM device **150** includes processing circuitry **160**, display **170**, sensing circuitry **180**, and sensing device(s) **182**. In some examples, regional oximetry device **100** may be configured to determine and display the autoregulation status of a patient, e.g., during a medical procedure or for more long-term monitoring, such as monitoring of prenatal infants. A clinician may receive information regarding the autoregulation status of a patient via display **120** and adjust treatment or therapy to the patient based on the autoregulation status information.

**[0054]** Each of processing circuitry **110** and **160** may include one or more processors. Processing circuitry **110** and **160** may include any combination of integrated circuitry, discrete logic circuitry, analog circuitry, such as one or more microprocessors, digital signal processors (DSPs), application specific integrated circuits (ASICs), or field-programmable gate arrays (FPGAs). In some examples, processing circuitry **110** and **160** may include multiple components, such as any combination of one or more microprocessors, one or more DSPs, one or more ASICs, or one or more FPGAs, as well as other discrete or integrated logic circuitry, and/or analog circuitry.

**[0055]** Displays **120** and **170** may be configured to present information to a user (e.g., a clinician). One or both of displays **120** and **170** may be configured to present a graphical user interface to a user, where each graphical user interface may include indications of one or more physiological parameters. For example, processing circuitry **110** may be configured to present MAP values and an indication of autoregulation status of a patient via display **120**. In some examples, if processing circuitry **110** determines that the autoregulation status of the patient is impaired, then processing circuitry **110** may present a notification (e.g., an alert) indicating the impaired autoregulation status via display **120**. As another example, processing circuitry **110** or processing circuitry **160** may present, via the respective displays **120** and **170**, estimates of $rSO_2$ for a patient, an estimate of the blood oxygen saturation ($SpO_2$) determined by the respective processing circuitry **110** or **160**, pulse rate information, respiration rate information, blood pressure, any other patient parameters, or any combination thereof.

**[0056]** Displays **120** and **170** may each include a monitor, cathode ray tube display, a flat panel display such as a liquid crystal (LCD) display, a plasma display, or a light emitting diode (LED) display, personal digital assistant, mobile phone, tablet computer, laptop computer, any other suitable display device, or any combination thereof. Devices **100** and **150** may also include means for projecting audio to a user, such as speaker(s).

**[0057]** Sensing circuitry **130** and **180** may be configured to receive physiological signals sensed by respective sensing device(s) **132** and **182** and communicate the physiological signals to the respective processing circuitry **110** and **160**. Sensing device(s) **132** and **182** may include any sensing hardware configured to sense a physiological parameter of a patient, such as, but not limited to, one or more electrodes, optical receivers, blood pressure cuffs, or the like. Sensing circuitry **130** and **180** may convert the physiological signals to usable signals for processing circuitry **110** and **160**. Sensing circuitry **130** and **180** may receive signals indicating physiological parameters from a patient, such as, but not limited to, blood pressure, $rSO_2$, heart rate, and respiration. Sensing circuitry **130** and **180** may include, but are not limited to, blood pressure sensing circuitry, $rSO_2$ sensing circuitry, heart rate sensing circuitry, temperature sensing circuitry, electrocardiography (ECG) sensing circuitry, electroencephalogram (EEG) sensing circuitry, or any combination thereof. In some examples, sensing circuitry **130** and **180** and/or processing circuitry **110** and **160** may include signal processing circuitry such as an analog-to-digital converter.

**[0058]** Processing circuitry **110** may be configured to receive one or more physiological signals generated by sensing circuitry **130**. The physiological signals may include a signal indicating blood pressure and/or a signal indicating oxygen saturation of a patient. Processing circuitry **110** may be configured to determine a first set of MAP values of a patient for a time period based on a first physiological signal. Processing circuitry **110** may also be configured to determine a set of $rSO_2$ values based on a second physiological signal indicative of a physiological parameter different from the first physiological parameter. For example, the first physiological parameter may be indicative of blood pressure of a patient and the second physiological parameter may be indicative of regional oxygen saturation of a target tissue site of the patient. In some examples, processing circuitry **110** is configured to determine a relative time delay between the MAP values and the oxygen saturation values. As discussed in further detail below with respect to FIGS. **13** and **14**, processing circuitry **110** may use the relative time delay to

synchronize the MAP values and the oxygen saturation values and/or to determine the autoregulation status of the patient.

**[0059]** Processing circuitry **110** may be configured to determine an autoregulation status of the patient based on the first set of MAP values using any suitable technique. For example, processing circuitry **110** may be configured to determine a set of COx values based on the MAP and $rSO_2$ values, and determine the LLA and ULA for the patient based on the set of COx values. Processing circuitry **110** may be configured to then determine the autoregulation status of the patient based on whether a current MAP value is between or outside of the LLA and the ULA. Additional example details of determining LA's and autoregulation status may be found in commonly assigned U.S. Patent Application Publication No. 2018/0014791 filed on Jul. 13, 2017, and entitled "Systems and Methods of Monitoring Autoregulation," and commonly assigned U.S. Provisional Patent Application No. 62/510,303 filed on May 24, 2017, and entitled "Determining a Limit of Autoregulation," the entire contents of each of which are incorporated herein by reference.

**[0060]** In some examples, processing circuitry **110** is configured to display determined MAP values of a patient, for example, in real-time or nearly in real-time (e.g., delays of less than five or ten seconds), via display **120**. Processing circuitry **160** of MPM device **150** may also be configured to display determined MAP values of the patient via display **170**. The MAP values used by processing circuitry **110** to determine a regional oximetry value may differ from the MAP values presented on display **170**, though the MAP values presented on display **170** may be representative of MAP values for the same, overlapping time periods (e.g., a particular point in time, such as 12:00 p.m. on the same day) as those used by processing circuitry **110** to determine a regional oximetry value. The MAP values may be different because processing circuitry **110** may be configured to use a different algorithm to determine MAP values than an algorithm used by processing circuitry **160** to determine MAP values for presentation via display **170**.

**[0061]** Processing circuitry **110** may be configured to use an algorithm to determine MAP values that is specifically tailored to autoregulation monitoring because the blood pressure signals of patients that undergo autoregulation monitoring may exhibit unique waveforms. In some examples, to determine MAP values, processing circuitry **110** may use an algorithm that is more robust to blood pressure artifacts than an algorithm used by processing circuitry **160** to determine MAP values. Processing circuitry **160** may be configured to report MAP values even when such artifacts are present. Examples of blood pressure artifacts include changes in blood pressure due to electrocautery, damping of blood pressures due to catherization, changes in sensed blood pressure due to probe movement, and changes in sensed blood pressure due to line flushing. Processing circuitry **160** may be more likely than processing circuitry **110** to incorrectly determine MAP values during artifact events, and incorrect MAP values may adversely affect autoregulation determinations. When an artifact event occurs such as a line flushing event, a clinician may know about the artifact event and ignore the presentation of MAP values on a MPM display **170**. Presenting incorrect MAP values and/or incorrect autoregulation status information can reduce clinician confidence in a monitoring device. Other sources of differences in MAP values determined by processing circuitry **110** and processing circuitry **160** include one or more of window averaging, rounding to nearest integer, and incorrect implementation of the integration of the pulses, which can lead to an error that depends on the heart-rate of the subject.

**[0062]** In some examples, processing circuitry **110** of regional oximetry device **100** is configured to present, via display **120**, a set of MAP values that is coherent with the MAP values presented on display **170** by processing circuitry **160** of MPM device **150**. For example, the set of MAP values that is presented by processing circuitry **110** may be coherent and consistent because processing circuitry **110** or **160** may determine and communicate a set of MAP values to the other of processing circuitry **110** and **160** via communication interface **140**. In this way, both of regional oximetry device **100** and MPM device **150** may present the same set of MAP values via the respective displays **120**, **170**.

**[0063]** In other examples, each of processing circuitry **110** and **160** may determine and present separate sets of MAP values based on the same raw blood pressure signal generated by sensing circuitry **180** of MPM device **150** or based on different raw blood pressure signals, e.g., generated by respective sensing circuitries **130** and **180** or by another sensing device separate from regional oximetry device **100** and MPM device **150**. In some of these examples, processing circuitry **110** may determine a set of MAP values to mimic the determination of MAP by processing circuitry **160** by using an algorithm that is similar to, or the same as, the algorithm used by processing circuitry **160**. Thus, processing circuitry **110** and **160** may independently determine sets of MAP values (for the same time period) using the same or similar algorithms. By mimicking the determination of MAP by processing circuitry **160**, processing circuitry **110** may improve the consistency between the MAP values presented on display **120** and the MAP values presented on display **170** and, therefore, generate an improved graphical user interface that includes MAP values for a patient.

**[0064]** Using any of the techniques or combination of techniques described above, devices **100** and **150** may share MAP values with each other and/or mimic the presentation of MAP values (mimic the values presented by the other device) to reduce or eliminate the differences between the MAP values presented by the different devices **100**, **150**. By presenting coherent MAP values on displays **120** and **170**, processing circuitry **110** and **160** may minimize or eliminate any inconsistencies between the two sets of MAP values, resulting in an improved graphical user interface. The presentation of coherent MAP values on displays **120** and **170** may result in increased confidence in the displayed MAP values by a clinician viewing the presented sets of MAP values, which may lead to more informed decision making by the clinician.

**[0065]** In some examples, the MAP values displayed by processing circuitry **110** of regional oximetry device **100** via display **120** are a second set of MAP values of the patient that represents MAP values determined for the same time period as the first set of MAP values, the first set being the MAP values determined by processing circuitry **110** and used to determine an autoregulation status of a patient. The processing circuitry **110** may determine the second set of MAP values to display using one or more techniques described herein. In some examples, processing circuitry **110** may be configured to receive the second set of MAP

values from MPM device **150** or processing circuitry **110** may be configured to determine the second set of MAP values based on the first physiological signal received from sensing circuitry **130**. If processing circuitry **110** determines the second set of MAP values based on the first physiological signal, then processing circuitry **110** may be configured to use the same algorithm or a different algorithm for determining both the first set and the second set of MAP values. Accordingly, processing circuitry **110** may be configured to use the same set of MAP values for determining an autoregulation status and for presenting via display **120**.

**[0066]** Processing circuitry **110** may be configured to determine the second set of MAP values to mimic determination of MAP values by MPM device **150**, where the second set of MAP values may be different than the first set of MAP values for determining autoregulation status, even if the first and second sets of MAP values represent MAP values for the same, overlapping (e.g., entirely overlapping) time periods. In some examples, processing circuitry **110** may receive the second set of MAP values from MPM device **150**. Processing circuitry **110** may be configured to present the received second set of MAP values via display **120** and, in some examples, may determine the autoregulation status based on the received second set of MAP values. In other examples, however, processing circuitry **110** may present the received second set of MAP values via display **120** and determine the autoregulation status based on the first set of MAP values.

**[0067]** MPM device **150** may be configured to determine physiological parameters of a patient and present the determined physiological parameters via display **170**. For example, processing circuitry **160** may be configured to present determined MAP values and/or oxygen saturation values via display **170**. MPM device **150** may also be configured to present determined values of other physiological parameters such as the patient's heart rate and/or hemoglobin concentration. As described herein, in some examples, MPM device **150** may be configured to present MAP values determined by processing circuitry **110** of regional oximetry device **100**, while in other examples, MPM device **150** may be configured to present MAP values determined by processing circuitry **160**.

**[0068]** Processing circuitry **160** may be configured to determine physiological parameter values of a patient to present on display **170**, where the values may be for the same or different types of physiological parameters monitored and displayed by regional oximetry device **100**. For example, processing circuitry **160** may be configured to present values for physiological parameters such as regional oxygen saturation, pulse rate, respiration rate, respiration effort, body temperature, blood pressure, blood oxygen saturation (e.g., arterial, venous, or both), hemoglobin concentration (e.g., oxygenated, deoxygenated, and/or total), any other suitable physiological parameters, or any combination thereof, whereas processing circuitry **110** may be configured to present values for physiological parameters such as regional oxygen saturation and MAP.

**[0069]** For a given type of physiological parameter, such as MAP, the physiological parameter values presented on display **170** of MPM device **150** may be different than the physiological parameter values presented on display **120** of regional oximetry device **100**. For example, as discussed above, processing circuitry **110** and **160** may be configured to use different algorithms for determining a physiological parameter such as MAP, such that processing circuitry **110** and **160** may present different MAP values via displays **120** and **170** for the same time period. Even if sensing circuitry **130**, **180**, via respective sensing devices **132** and **182**, receive the same physiological signal indicative of MAP, processing circuitry **110** may be configured to determine a first set of MAP values using a first algorithm, and processing circuitry **160** may be configured to determine a second set of MAP values using a second algorithm different from the first algorithm. The techniques described above may help synchronize the MAP values displayed by displays **120**, **170** of devices **100**, **150**, respectively.

**[0070]** In addition to a physiological signal indicating blood pressure, in some examples, processing circuitry **110** may also receive one or more physiological signals indicating other physiological parameters such as oxygen saturation. Processing circuitry **110** may be configured to determine other physiological parameter values based on the additional physiological signals. For example, processing circuitry **110** may be configured to use the determined MAP values and the determined physiological parameter values in order to determine an autoregulation status of the patient. In some examples, processing circuitry **110** determines the autoregulation status of a patient based on a set of MAP values for a time period and a set of oxygen saturation values for the same time period.

**[0071]** A patient state, as indicated by sensed physiological signals, may change relatively rapidly over time. Thus, if processing circuitry **110** determines an autoregulation status of a patient based on physiological signals that do not coincide in time, then the determined autoregulation status may not be accurate. In some examples, processing circuitry **110** may be configured to synchronize (in time) a blood-pressure physiological signal and an oxygen-saturation physiological signal, such that an autoregulation status of a patient is determined based on physiological signals indicative of the same patient state. In some examples, processing circuitry **110** is also configured to synchronize other sets of two or more physiological signals in addition to or instead of blood pressure and oxygen-saturation signals, where each set may include signals such as, but not limited to, blood pressure signals, oxygen saturation signals, blood volume signals, hemoglobin-related signals, and/or other physiological signals. Processing circuitry **110** may be configured to determine a relative time delay between the MAP values and the oxygen saturation values and use the relative time delay to determine the autoregulation status. Processing circuitry **110** may be configured to shift the set of MAP values and/or the set of $rSO_2$ values before determining the autoregulation status of the patient.

**[0072]** The relative time delay may be caused by the hardware and/or software of regional oximetry device **100**. For example, regional oximetry device **100** may use different circuitry for receiving the first physiological signal and the second physiological signal, which may result in different delays in the communication of the physiological signals from the patient to processing circuitry **110**. In addition to or instead of the time delay caused by the circuitry, the relative time delay may result from processing the physiological signals, the MAP values, and the $rSO_2$ values. In some examples, processing circuitry **110** may be configured to use sampling windows with different time durations for each

physiological signal, and the different time durations may cause a relative time delay between the MAP values and the oxygen saturation values.

**[0073]** Memory **112** and memory **162** may be configured to store measurements of physiological parameters, MAP values, $rSO_2$ values, COx values, and value(s) of an LLA and/or a ULA, for example. Memory **112** and **162** may also be configured to store data such as threshold levels for physiological parameters and threshold levels for signal quality metrics. In some examples, memory **112** and **162** may store program instructions, which may include one or more program modules, which are executable by processing circuitry **110** and **160**. When executed by processing circuitry **110** and **160**, such program instructions may cause processing circuitry **110** and **160** to provide the functionality ascribed to it herein. The program instructions may be embodied in software, firmware, and/or RAMware. Memory **112** and **162** may include any volatile, non-volatile, magnetic, optical, or electrical media, such as a random access memory (RAM), read-only memory (ROM), non-volatile RAM (NVRAM), electrically-erasable programmable ROM (EEPROM), flash memory, or any other digital media.

**[0074]** Communication interface **140** may enable device **100** to exchange information with device **150** and/or other external devices. Communication interface **140** may include any suitable hardware, software, or both, which may allow device **100** to communicate external devices such as electronic circuitry, a device, a network, a server or other workstations, a display, or any combination thereof. Communication interface **140** may include one or more receivers, transmitters, transceivers, antennas, plug-in connectors, ports, communications buses, communications protocols, device identification protocols, any other suitable hardware or software, or any combination thereof. Communication interface **140** may be configured to enable wired communication (e.g., using USB, RS-232, Ethernet, coaxial, or other standards), wireless communication (e.g., using Wi-fi, infrared, WiMax, Bluetooth, universal serial bus (USB), or other standards), or both. For example, communication interface **140** may be configured using a USB protocol (e.g., USB 2.0, USB 3.0), and may be configured to couple to other devices (e.g., remote memory devices storing templates) using a four-pin USB standard Type-A connector (e.g., plug and/or socket) and cable. In some examples, communication interface **140** may include an internal bus such as, for example, one or more slots for insertion of expansion cards.

**[0075]** FIG. **2** is a conceptual block diagram illustrating an example regional oximetry device **200** configured to monitor the autoregulation status of a patient. As shown, regional oximetry device **200** includes blood pressure sensor **232**, oxygen saturation sensor **234** (e.g., a regional oxygen saturation sensor), controller **214**, and output device **222**. Regional oximetry device **200** is an example of regional oximetry device **100** shown in FIG. **1**, and blood pressure sensor **232** and oxygen saturation sensor **234** are examples of sensing devices **132** shown in FIG. **1**. In some examples, regional oximetry device **200** may or may not include blood pressure sensor **232**. Regional oximetry device **400**, depicted in FIG. **4**, is an example of a regional oximetry device without a blood pressure sensor.

**[0076]** Blood pressure sensor **232** may be any sensor or device configured to obtain the patient's blood pressure (e.g., arterial blood pressure). For example, blood pressure sensor **232** may include a blood pressure cuff for non-invasively monitoring blood pressure or an arterial line for invasively monitoring blood pressure. In certain examples, blood pressure sensor **232** may include one or more pulse oximetry sensors. In some such cases, the patient's blood pressure may be derived by processing time delays between two or more characteristic points within a single plethysmography (PPG) signal obtained from a single pulse oximetry sensor.

**[0077]** Additional example details of deriving blood pressure based on a comparison of time delays between certain components of a single PPG signal obtained from a single pulse oximetry sensor are described in commonly owned U.S. Patent Application Publication No. 2009/0326386 filed Sep. 30, 2008, and entitled "Systems and Methods for Non-Invasive Blood Pressure Monitoring," the entire content of which is incorporated herein by reference. In other cases, the patient's blood pressure may be continuously, non-invasively monitored via multiple pulse oximetry sensors placed at multiple locations on the patient's body. As described in U.S. Pat. No. 6,599,251, entitled "Continuous Non-invasive Blood Pressure Monitoring Method and Apparatus," the entire content of which is incorporated herein by reference, multiple PPG signals may be obtained from the multiple pulse oximetry sensors, and the PPG signals may be compared against one another to estimate the patient's blood pressure. Regardless of its form, blood pressure sensor **232** may be configured to generate a blood pressure signal indicative of the patient's blood pressure (e.g., arterial blood pressure) over time. As discussed in more detail below, blood pressure sensor **232** may provide the blood pressure signal to controller **214** or to any other suitable processing device to enable evaluation of the patient's autoregulation status.

**[0078]** In some examples, oxygen saturation sensor **234** is a regional oxygen saturation sensor configured to generate an oxygen saturation signal indicative of blood oxygen saturation within the venous, arterial, and/or capillary systems within a region of the patient. For example, oxygen saturation sensor **234** may be configured to be placed on the patient's forehead and may be used to determine the oxygen saturation of the patient's blood within the venous, arterial, and/or capillary systems of a region underlying the patient's forehead (e.g., in the cerebral cortex).

**[0079]** In such cases, oxygen saturation sensor **234** may include emitter **236** and multiple detectors **238**. Emitter **236** may include at least two light emitting diodes (LEDs), each configured to emit at different wavelengths of light, e.g., red or near infrared light. In some examples, light drive circuitry (e.g., within sensor **234** or controller **214**) may provide a light drive signal to drive emitter **236** and to cause emitter **236** to emit light. In some examples, the LEDs of emitter **236** emit light in the range of about 600 nanometers (nm) to about 1000 nm. In a particular example, one LED of emitter **236** is configured to emit light at about 730 nm and the other LED of emitter **236** is configured to emit light at about 810 nm. Other wavelengths of light may also be used in other examples.

**[0080]** One of detectors **238** is positioned relatively "close" (e.g., proximal) to emitter **236** and one of detectors **238** is positioned relatively "far" (e.g., distal) from emitter **236**. Light intensity of multiple wavelengths may be received at both the "close" and the "far" detectors **238**. For example, if two wavelengths are used, the two wavelengths may be contrasted at each location and the resulting signals

may be contrasted to arrive at a regional saturation value that pertains to additional tissue through which the light received at the "far" detector passed (tissue in addition to the tissue through which the light received by the "close" detector passed, e.g., the brain tissue), when it was transmitted through a region of a patient (e.g., a patient's cranium). Surface data from the skin and skull may be subtracted out, to generate a regional oxygen saturation ($rSO_2$) signal for the target tissues over time. Oxygen saturation sensor **234** may provide the regional oxygen saturation signal to controller **214** or to any other suitable processing device to enable evaluation of the patient's autoregulation status.

**[0081]** In operation, blood pressure sensor **232** and oxygen saturation sensor **234** may each be placed on the same or different parts of the patient's body. For example, blood pressure sensor **232** and oxygen saturation sensor **234** may physically separate from each other and separately placed on the patient. As another example, blood pressure sensor **232** and oxygen saturation sensor **234** may in some cases be part of the same sensor or supported by a single sensor housing. For example, blood pressure sensor **232** and oxygen saturation sensor **234** may be part of an integrated oximetry system configured to non-invasively measure blood pressure (e.g., based on time delays in a PPG signal) and regional oxygen saturation. One or both of blood pressure sensor **232** or oxygen saturation sensor **234** may be further configured to measure other parameters, such as hemoglobin, respiratory rate, respiratory effort, heart rate, saturation pattern detection, response to stimulus such as bispectral index (BIS) or electromyography (EMG) response to electrical stimulus, or the like. While an example regional oximetry device **200** is shown in FIG. **2**, the components illustrated in FIG. **2** are not intended to be limiting. Additional or alternative components and/or implementations may be used in other examples.

**[0082]** In some examples, signals generated by sensors **232** and **234** may be offset in time. For example, each of sensors **232** and **234** may have a different delay in receiving, processing, and/or delivering the respective physiological signals to controller **214**. The difference between the delay in controller **214** receiving a first physiological signal from blood pressure sensor **232** and the delay in controller **214** receiving a second physiological signal from oxygen saturation sensor **232** may result in a relative time delay between the determined MAP values and oxygen saturation values of a patient. As one example, at a particular time, sensor **232** may deliver a signal to controller **214** that indicates blood pressure one hundred milliseconds ago. At the same particular time, sensor **234** may deliver a signal to controller **214** that indicates oxygen saturation one second ago. If controller **214** determines an index or measure of cerebral autoregulation, such as a correlation index (e.g., COx index) or another measure, based on the two unsynchronized data sets, then the relative time delay may cause the determination of the COx index by controller **214** to be inaccurate or at least less accurate compared to instances in which there is no relative time delay. The COx index may be inaccurate or less accurate because the two signals may represent patient states at different times, particularly if the patient state is changing relatively quickly over time.

**[0083]** Even if sensors **232** and **234** deliver signals to controller **214** with no relative time delay, inaccuracies may arise if controller **214** uses algorithms for determining mean arterial pressure and oxygen saturation with different-sized sampling windows. For example, controller **214** may be configured to determine mean arterial pressure based on a sampling window of ten seconds and determine oxygen saturation based on a sampling window of five seconds. The different-sized sampling windows may cause the MAP values and the oxygen saturation values to not be matched up exactly in time, which may cause controller **214** to determine COx values and an autoregulation status based on unsynchronized data.

**[0084]** In some examples, regional oximetry device is configured to synchronize (in time) signals received from blood pressure sensor **232** and oxygen saturation sensor **234**. To synchronize the signals received and processed by controller **214**, regional oximetry device **200** may be configured to receive user input indicating a model number of blood pressure sensor **232** or another blood pressure measurement device that is connected to regional oximetry device **200**. In some examples, there may be a separate blood pressure measurement device that receives a signal from blood pressure sensor **232**, determines the MAP values, and delivers the MAP values to controller **214**. For example, regional oximetry device **200** may include an input device such as a keyboard or a touchscreen that allows the user to input the model number of the blood pressure equipment, and controller **214** may determine the time delay associated with the blood pressure equipment. A particular model of blood pressure equipment may be associated with a known time delay in a memory (e.g., memory **212**) of device **200** or another device communicatively coupled to device **200**. Controller **214** may use the determined time delay to synchronize the MAP values with the oxygen saturation value in order to improve the accuracy of the COx index. Controller **214** may determine the COx index, and ultimately the autoregulation status, based on the MAP values, the oxygen saturation values, and the relative time delay between the MAP values and the oxygen saturation values.

**[0085]** In some examples, controller **214** may determine the relative time delay based on the sampling windows for mean arterial pressure and oxygen saturation. If the durations of the sampling windows are ten and five seconds, respectively, for mean arterial pressure and oxygen saturation, then the centers of the sampling windows may be offset by two-and-one-half seconds. Using these example durations, controller **214** may determine a MAP value based on a waveform of the blood pressure signal over the previous ten seconds and determine an $rSO_2$ value based on a waveform of the oxygen saturation signal over the previous five seconds. Controller **214** may determine a relative time delay of two-and-one-half seconds in order to align the centers of the sampling windows. When controller **214** determines an aggregated value from a sampling window, the center of a sampling window is effectively the source of the aggregated value if the sampling and weighting is constant across the sampling window.

**[0086]** In some examples, controller **214** may be configured to determine the relative time delay between the data sets in real-time. Controller **214** may determine the relative time delay by determining a cross-correlation function for the MAP values and the oxygen saturation values.

**[0087]** Controller **214** may then determine the time lag at which the cross-correlation function has a maximum amplitude, which may indicate the relative time delay between the MAP and oxygen saturation values. Controller **214** may use the time lag to synchronize the set of MAP values and the

set of oxygen saturation values. In some examples, controller **214** may synchronize the two sets by adding or subtracting the determined delay from the time (e.g., timestamp) associated with each value in the set. For example, controller **214** may store a multi-dimensional data structure such as an array to memory **212**, where the data structure associates each MAP value with a time of measurement. Controller **214** may adjust (e.g., shift) the associated time by the determined delay in order to synchronize the set of MAP values with the set of oxygen saturation values. When synchronized, the MAP values for a particular time period better correspond in time to the oxygen saturation values observed for the patient for the same time period. Controller **214** may then use the synchronized data sets to determine COx values and the limit(s) of autoregulation.

**[0088]** As noted above, blood pressure sensor **232** may be configured to provide the blood pressure signal to controller **214**, and oxygen saturation sensor **234** may be configured to provide the oxygen saturation signal to controller **214**. In certain examples, controller **214** is an electronic controller having electrical circuitry configured to process the various received signals. For example, controller **214** may be configured to process the blood pressure signal and the oxygen saturation signal to evaluate the patient's cerebral autoregulation status. Although blood pressure sensor **232** and oxygen saturation sensor **234** may be configured to provide their respective signals or data directly to controller **214**, in certain examples, the signals or data obtained by blood pressure sensor **232** and/or oxygen saturation sensor **234** may be provided to one or more intermediate processing devices (e.g., specialized monitor, such as a blood pressure monitor or an oxygen saturation monitor, or the like), which may in turn provide processed signals or data to controller **214**.

**[0089]** Controller **214** may be configured to determine COx values based on the blood pressure signal and the oxygen saturation signal. The COx index may be indicative of vascular reactivity, which is related to cerebral blood vessels' ability to control proper blood flow, via vasoconstriction (a narrowing of the blood vessel) and/or vasodilation (expansion of the blood vessel), for example. Thus, the COx index is also indicative of whether the patient's autoregulation is impaired. Controller **214** may derive the COx index by determining a linear correlation between blood pressure measurements and oxygen saturation measurements. The linear correlation may be based on a Pearson coefficient, for example. The Pearson coefficient may be defined as the covariance of the measured blood pressure (e.g., arterial blood pressure) and oxygen saturation divided by the product of their standard deviations. The result of the linear correlation may be a regression line between oxygen saturation measurements and blood pressure measurements, and the slope of the regression line may be indicative of the patient's autoregulation status. In one example implementation, a regression line with a relatively flat or negative slope (e.g., regional oxygen saturation increases after blood pressure decreases) may suggest that cerebral autoregulation of the patient is working properly, while a regression line with a positive slope (e.g., regional oxygen saturation remains the same or decreases after blood pressure decreases) may suggest that the cerebral autoregulation of the patient is impaired. Controller **214** may be configured to generate a notification in response to determining that the autoregulation status of a patient is impaired. Controller **214** may then be configured to present the notification via display **220**.

**[0090]** Controller **214** may determine a value of the COx index, which may be between −1 and 1, inclusive, where −1 represents total negative correlation, +1 represents total positive correlation, and 0 represents the absence of correlation between the blood pressure measurements and the oxygen saturation measurements. Thus, COx values between −1 and 0 may suggest that cerebral autoregulation of a patient is working properly, while COx values between 0 and 1 may suggest that the cerebral autoregulation of the patient is impaired. In some cases, a predetermined threshold between 0 and 1 may be utilized to determine whether the patient's autoregulation is impaired. For example, in some examples, controller **214** may be configured to determine that the patient's autoregulation is impaired when the COx value is greater than 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, or 0.9. Accordingly, controller **214** may be configured to determine the COx value and/or the patient's autoregulation status based on the linear correlation between the blood pressure measurements and oxygen saturation measurements obtained by the blood pressure sensor **232** and the oxygen saturation sensor **234**, respectively.

**[0091]** In the illustrated example, controller **214** includes processing circuitry **210** and memory **212**, which are examples of processing circuitry **110** and memory **112** shown in FIG. **1**. Controller **214** may also include one or more storage devices, such as memory **212**. Processing circuitry **210** may be used to execute software, such as software for carrying out any of the techniques disclosed herein, such as processing the blood pressure signals and/or oxygen saturation signals, determining relative time delays, determining cross-correlation functions, determining COx values, synchronizing signals and data values, and carrying out appropriate remedial actions, and so forth.

**[0092]** Memory **212** may store a variety of information and may be used for various purposes. For example, memory **212** may store processor-executable instructions (e.g., firmware or software) for processing circuitry **210** to execute, such as instructions for carrying out any of the techniques discloses herein, such as processing blood pressure signals and/or oxygen saturation signals, determining relative time delays, determining cross-correlation functions, determining COx values, synchronizing signals and data values, and/or taking appropriate remedial actions. Memory **212** may store data (e.g., the blood pressure signal, the oxygen saturation signal, the COx, the relative time delay, the time delays for sensors **232** and **234** and other equipment, and the like), instructions (e.g., software or firmware for processing the blood pressure signal and/or the oxygen saturation signal, determining the COx and/or the relative time delay, and/or taking appropriate remedial actions), predetermined thresholds, and any other suitable data.

**[0093]** Regional oximetry device **200** includes output device **222**, which includes display **220**, which is an example of display **120** shown in FIG. **1**. In some examples, controller **214** may be configured to provide signals indicative of the patient's autoregulation status to output device **222**. As discussed in more detail below, controller **214** may be configured to present, via output device **222**, a visual, audible, or somatosensory notification (e.g., an alarm signal) indicative of the patient's autoregulation status. Output

device **222** may include any device configured to receive signals (e.g., the signal indicative of the patient's autoregulation status, the alarm signal, or the like) from controller **214** and visually, audibly, and/or somatosensorily output information indicative of the patient's autoregulation status (e.g., the COx value, the COx signal, an alarm, or the like). For instance, output device **222** can include display **220** configured to provide a visual representation of the patient's autoregulation status and/or the alarm signal as determined by controller **214** (see, e.g., graphical user interface **300** shown in FIG. **3**). Additionally or alternatively, output device **222** may include an audio device configured to provide sounds in accordance with the alarm signal, the patient's autoregulation status, or both. Output device **222** may be any suitable device for conveying such information, including a computer workstation, a server, a desktop, a notebook, a laptop, a handheld computer, a mobile device, or the like. In some examples, controller **214** and output device **222** may be part of the same device or supported within one housing (e.g., a computer or monitor).

**[0094]** FIG. **3** illustrates an example graphical user interface **300** including autoregulation information. Processing circuitry **110** of regional oximetry device **100** (FIG. **1**), processing circuitry **160** of MPM device **150** (FIG. **1**), or processing circuitry of another device may be configured to generate graphical user interface **300** and present it via a respective display, e.g. display **120** or display **170**. Thus, although processing circuitry **110** and display **120** of regional oximetry device **100** are primarily referred to throughout the description of FIG. **3**, in other examples, graphical user interface **300** may be generated by and/or displayed by another device, such as MPM device **150**.

**[0095]** FIG. **3** is an example of a presentation by processing circuitry **110** on display **120** shown in FIG. **1**. Graphical user interface **300** may be configured to display various information related to the COx index. As shown, graphical user interface **300** may include oxygen saturation signal indicator **310**, blood pressure signal indicator **320**, and COx signal indicator **330**. Graphical user interface **300** may include COx value indicator **340** and autoregulation status indicator **350**.

**[0096]** Blood pressure signal indicator **320** may present a set of MAP values determined by processing circuitry **110** of regional oximetry device **100**. In some examples, blood pressure signal indicator **320** may present MAP values as discrete points over time or in a table. Blood pressure signal indicator **320** may also present MAP values as a moving average or waveform of discrete points. Blood pressure signal indicator **320** may present MAP values as a single value (e.g., a number) representing a current MAP value. Oxygen saturation signal indicator **310** and COx signal indicator **330** may also present $rSO_2$ values and COx values, respectively, as discrete points, in a table, as a moving average, as a waveform, and/or as a single value.

**[0097]** In some examples, regional oximetry device **100** may be configured to determine a set of MAP values and communicate the determined set of MAP values to MPM device **150** so that both devices **100** and **150** present the same MAP values (for the same period of time). As discussed above with respect to FIG. **1**, processing circuitry **110** of regional oximetry device **100** may be configured to use the same algorithm or different algorithms for determining the presented set of MAP values in blood pressure signal indicator **320** and for determining a set of MAP values to use in determining COx value indicator **340** and autoregulation status indicator **350**. Additionally or alternatively, regional oximetry device **100** may determine a set of MAP values for display in blood pressure signal indicator **320** using an algorithm to mimic determination of MAP values by MPM device **150**. The algorithm can be, for example, the same algorithm used by processing circuitry **160** of MPM device **150** to determine and display MAP values. In other examples, regional oximetry device **100** may also be configured to present a set of MAP values blood pressure signal indicator **320** that regional oximetry device **100** receives from MPM device **150**.

**[0098]** These techniques for determining a set of MAP values to present via graphical user interface **300** may promote consistency between the MAP values presented as blood pressure signal indicator **320** and the set of MAP values presented by MPM device **150**. These techniques may provide more consistent presentations of MAP values by devices **100** and **150**, as compared to merely delivering the same raw blood pressure signal to both of devices **100** and **150**. A clinician may be able to quickly determine the mean arterial pressure and autoregulation status of a patient if both of displays **120** and **170** are presenting the same MAP values. In this way, graphical user interface **300** may provide an improvement over a graphical user interface that presents MAP values that differ from the MAP values presented by MPM device **150**.

**[0099]** Graphical user interface **300** is not the mere display of different physiological parameter values, but, rather, provides an improved graphical user interface that promotes a higher confidence in monitored physiological parameters of a patient by presenting MAP values that are consistent with MAP values presented by MPM device **150**. Graphical user interface **300** may also speed up a user's determination of the most recent MAP value of a patient by presenting MAP values that are consistent with the MAP values presented by MPM device **150**. Rather than choosing between different MAP values on two devices, a clinician will be presented with two consistent sets of MAP values by devices **100** and **150**.

**[0100]** Although FIG. **3** illustrates a particular graphical user interface **300** with blood pressure signal indicator **320** displayed in addition to other information, in other examples, regional oximetry device **100**, MPM device, **150**, and other devices described herein may generate and present any suitable graphical user interface that includes blood pressure signal indicator **320** or other indications of determined MAP values of a patient.

**[0101]** FIG. **4** is a conceptual block diagram illustrating an example physiological parameter monitoring system **402**. In the example shown in FIG. **4**, system **402** includes sensing device **434** and regional oximetry device **400**, which each generate and process physiological signals of a subject. In some examples, sensing device **434** and regional oximetry device **400** may be part of an oximeter. As shown in FIG. **4**, regional oximetry device **400** includes back-end processing circuitry **414**, user interface **422**, light drive circuitry **430**, front-end processing circuitry **450**, control circuitry **470**, and communication interface **490**. Regional oximetry device **400** may be communicatively coupled to sensing device **434**. Regional oximetry device **400** is an example of regional oximetry device **100** shown in FIG. **1** and regional oximetry device **200** shown in FIG. **2**. In some examples, regional oximetry device **400** may also include a blood pressure

sensor. Regional oximetry device **200**, depicted in FIG. **2**, is an example of a regional oximetry device that includes a blood pressure sensor.

**[0102]** In the example shown in FIG. **4**, sensing device **434** includes light source **436**, detector **438**, and detector **439**. Light source **436** may be configured to emit photonic signals having two or more wavelengths of light (e.g., red and IR) into a subject's tissue. For example, light source **436** may include a red light emitting light source and an IR light emitting light source, (e.g., red and IR light emitting diodes (LEDs)), for emitting light into the tissue of a subject to generate physiological signals. In some examples, the red wavelength may be between about 600 nm and about 700 nm, and the IR wavelength may be between about 800 nm and about 1000 nm. Other wavelengths of light may be used in other examples. Light source **436** may include any number of light sources with any suitable characteristics. In examples in which an array of sensors is used in place of sensing device **434**, each sensing device may be configured to emit a single wavelength. For example, a first sensing device may emit only a red light while a second may emit only an IR light. In some examples, light source **436** may be configured to emit two or more wavelengths of near-infrared light (e.g., wavelengths between 600 nm and 1000 nm) into a subject's tissue. In some examples, light source **436** may be configured to emit four wavelengths of light (e.g., 724 nm, 770 nm, 810 nm, and 850 nm) into a subject's tissue.

**[0103]** As used herein, the term "light" may refer to energy produced by radiative sources and may include one or more of ultrasound, radio, microwave, millimeter wave, infrared, visible, ultraviolet, gamma ray or X-ray electromagnetic radiation. Light may also include any wavelength within the radio, microwave, infrared, visible, ultraviolet, or X-ray spectra, and that any suitable wavelength of electromagnetic radiation may be appropriate for use with the present techniques. Detectors **438** and **439** may be chosen to be specifically sensitive to the chosen targeted energy spectrum of light source **436**.

**[0104]** In some examples, detectors **438** and **439** may be configured to detect the intensity of multiple wavelengths of near-infrared light. In some examples, detectors **438** and **439** may be configured to detect the intensity of light at the red and IR wavelengths. In some examples, an array of detectors may be used and each detector in the array may be configured to detect an intensity of a single wavelength. In operation, light may enter detector **438** after passing through the subject's tissue, including skin, bone, and other shallow tissue (e.g., non-cerebral tissue and shallow cerebral tissue). Light may enter detector **439** after passing through the subject's tissue, including skin, bone, other shallow tissue (e.g., non-cerebral tissue and shallow cerebral tissue), and deep tissue (e.g., deep cerebral tissue). Detectors **438** and **439** may convert the intensity of the received light into an electrical signal. The light intensity may be directly related to the absorbance and/or reflectance of light in the tissue. That is, when more light at a certain wavelength is absorbed or reflected, less light of that wavelength is received from the tissue by detectors **438** and **439**.

**[0105]** After converting the received light to an electrical signal, detectors **438** and **439** may send the detection signals to regional oximetry device **400**, where the detection signals may be processed and physiological parameters may be determined (e.g., based on the absorption of the red and IR wavelengths in the subject's tissue at both detectors). In some examples, one or more of the detection signals may be preprocessed by sensing device **434** before being transmitted to regional oximetry device **400**. Additional example details of determining oxygen saturation based on light signals may be found in commonly owned U.S. Pat. No. 9,861,317, which issued on Jan. 9, 2018, and is entitled "Methods and Systems for Determining Regional Blood Oxygen Saturation," the entire content of which is incorporated herein by reference.

**[0106]** Control circuitry **470** may be coupled to light drive circuitry **430**, front-end processing circuitry **450**, and back-end processing circuitry **414**, and may be configured to control the operation of these components. In some examples, control circuitry **470** may be configured to provide timing control signals to coordinate their operation. For example, light drive circuitry **430** may generate one or more light drive signals, which may be used to turn on and off light source **436**, based on the timing control signals provided by control circuitry **470**. Front-end processing circuitry **450** may use the timing control signals to operate synchronously with light drive circuitry **430**. For example, front-end processing circuitry **450** may synchronize the operation of an analog-to-digital converter and a demultiplexer with the light drive signal based on the timing control signals. In addition, the back-end processing circuitry **414** may use the timing control signals to coordinate its operation with front-end processing circuitry **450**.

**[0107]** Light drive circuitry **430**, as discussed above, may be configured to generate a light drive signal that is provided to light source **436** of sensing device **434**. The light drive signal may, for example, control the intensity of light source **436** and the timing of when light source **436** is turned on and off. In some examples, light drive circuitry **430** provides one or more light drive signals to light source **436**. Where light source **436** is configured to emit two or more wavelengths of light, the light drive signal may be configured to control the operation of each wavelength of light. The light drive signal may comprise a single signal or may comprise multiple signals (e.g., one signal for each wavelength of light).

**[0108]** Front-end processing circuitry **450** may perform any suitable analog conditioning of the detector signals. The conditioning performed may include any type of filtering (e.g., low pass, high pass, band pass, notch, or any other suitable filtering), amplifying, performing an operation on the received signal (e.g., taking a derivative, averaging), performing any other suitable signal conditioning (e.g., converting a current signal to a voltage signal), or any combination thereof. The conditioned analog signals may be processed by an analog-to-digital converter of circuitry **450**, which may convert the conditioned analog signals into digital signals. Front-end processing circuitry **450** may operate on the analog or digital form of the detector signals to separate out different components of the signals. Front-end processing circuitry **450** may also perform any suitable digital conditioning of the detector signals, such as low pass, high pass, band pass, notch, averaging, or any other suitable filtering, amplifying, performing an operation on the signal, performing any other suitable digital conditioning, or any combination thereof. Front-end processing circuitry **450** may decrease the number of samples in the digital detector signals. In some examples, front-end processing circuitry **450** may also remove dark or ambient contributions to the received signal.

**[0109]** Back-end processing circuitry **414** may include processing circuitry **410** and memory **412**. Processing circuitry **410** may include an assembly of analog or digital electronic components and may be configured to execute software, which may include an operating system and one or more applications, as part of performing the functions described herein. Processing circuitry **410** may receive and further process physiological signals received from front-end processing circuitry **450**. For example, processing circuitry **410** may determine one or more physiological parameter values based on the received physiological signals. For example, processing circuitry **410** may compute one or more of regional oxygen saturation, blood oxygen saturation (e.g., arterial, venous, or both), pulse rate, respiration rate, respiration effort, blood pressure, hemoglobin concentration (e.g., oxygenated, deoxygenated, and/or total), any other suitable physiological parameters, or any combination thereof. Processing circuitry **410** may perform any suitable signal processing of a signal, such as any suitable band-pass filtering, adaptive filtering, closed-loop filtering, any other suitable filtering, and/or any combination thereof. Processing circuitry **410** may also receive input signals from additional sources not shown. For example, processing circuitry **410** may receive an input signal containing information about treatments provided to the subject from user interface **422**. Additional input signals may be used by processing circuitry **410** in any of the determinations or operations it performs in accordance with back-end processing circuitry **414** or regional oximetry device **400**.

**[0110]** Memory **412** may include any suitable computer-readable media capable of storing information that can be interpreted by processing circuitry **410**. In some examples, memory **412** may store reference absorption curves, reference sets, determined values, such as blood oxygen saturation, pulse rate, blood pressure, fiducial point locations or characteristics, initialization parameters, any other determined values, or any combination thereof, in a memory device for later retrieval. Back-end processing circuitry **414** may be communicatively coupled with user interface **422** and communication interface **490**.

**[0111]** User interface **422** may include user input **424**, display **420**, and speaker **426**. User interface **422** may include, for example, any suitable device such as one or more medical devices (e.g., a medical monitor that displays various physiological parameters, a medical alarm, or any other suitable medical device that either displays physiological parameters or uses the output of back-end processing **414** as an input), one or more display devices (e.g., monitor, personal digital assistant (PDA), mobile phone, tablet computer, clinician workstation, any other suitable display device, or any combination thereof), one or more audio devices, one or more memory devices, one or more printing devices, any other suitable output device, or any combination thereof.

**[0112]** User input **424** may include any type of user input device such as a keyboard, a mouse, a touch screen, buttons, switches, a microphone, a joy stick, a touch pad, or any other suitable input device or combination of input devices. User input **424** may also receive inputs to select a model number of sensing device **434**, blood pressure sensor **232** (FIG. **2**), or blood pressure processing equipment. In some examples, processing circuitry **410** may associate each model number of sensing device and processing equipment with a known time delay in memory **412**, and use the known time delay of sensing device to determine a set of MAP values for determining COx values and an autoregulation status.

**[0113]** In some examples, the subject may be a medical patient and display **420** may exhibit a list of values which may generally apply to the subject, such as, for example, an oxygen saturation signal indicator, a blood pressure signal indicator, a COx signal indicator, a COx value indicator, and/or an autoregulation status indicator. Display **420** may also be configured to present additional physiological parameter information. Graphical user interface **300** is an example of an interface that can be presented via display **420** of FIG. **4**. Additionally, display **420** may display, for example, one or more estimates of a subject's regional oxygen saturation generated by regional oximetry device **400** (referred to as an "$rSO_2$" measurement). Speaker **426** within user interface **422** may provide an audible sound that may be used in various examples, such as for example, sounding an audible alarm in the event that a patient's physiological parameters are not within a predefined normal range.

**[0114]** Communication interface **490** may enable regional oximetry device **400** to exchange information with external devices. Communication interface **490** may include any suitable hardware, software, or both, which may allow regional oximetry device **400** to communicate with electronic circuitry, a device, a network, a server or other workstations, a display, or any combination thereof. For example, regional oximetry device **400** may communicate MAP values to MPM device **150** (FIG. **1**) via communication interface **490** or regional oximetry device **400** may receive MAP values from MPM device **150** via communication interface **490**.

**[0115]** The components of physiological monitoring system **402** that are shown and described as separate components are shown and described as such for illustrative purposes only. In some examples the functionality of some of the components may be combined in a single component. For example, the functionality of front end processing circuitry **450** and back-end processing circuitry **414** may be combined in a single processor system. Additionally, in some examples the functionality of some of the components of regional oximetry device **400** shown and described herein may be divided over multiple components. For example, some or all of the functionality of control circuitry **470** may be performed in front end processing circuitry **450**, in back-end processing circuitry **414**, or both. In other examples, the functionality of one or more of the components may be performed in a different order or may not be required. In some examples, all of the components of physiological monitoring system **402** can be realized in processor circuitry.

**[0116]** FIG. **5** is a perspective-view diagram illustrating an example physiological parameter monitoring system **502**. Physiological parameter monitoring system **502** is an example of the system shown in FIG. **1**, which includes regional oximetry device **100** and MPM device **150**. Physiological monitoring system **502** may include sensing device **434** and regional oximetry device **500**, where regional oximetry device **500** is an example of regional oximetry device **100** shown in FIG. **1**. In some examples, sensing device **434** may be part of an oximeter and may include one or more light sources **436** for emitting light at one or more wavelengths into a subject's tissue. Physiological monitoring system **502** may also include one or more additional

sensor units (not shown) that may, for example, take the form of any of the examples described herein with reference to sensing device **434**. An additional sensor unit may be the same type of sensor unit as sensing device **434**, or a different sensor unit type than sensing device **434** (e.g., a photoacoustic sensor). Multiple sensor units may be capable of being positioned at two different locations on a subject's body.

**[0117]** In some examples, sensing device **434** may be electrically connected to regional oximetry device **500** as shown via a wired connection (as shown) or via a wireless connection. Sensing device **434** may be powered by an internal power source, e.g., a battery (not shown), or may draw power from regional oximetry device **500**.

**[0118]** Regional oximetry device **500** may be configured to determine physiological parameter values of a patient based at least in part on data relating to light emission and acoustic detection received from one or more sensor units such as sensing device **434**. For example, regional oximetry device **500** may be configured to determine regional oxygen saturation, pulse rate, respiration rate, respiration effort, blood pressure, blood oxygen saturation (e.g., arterial, venous, or both), hemoglobin concentration (e.g., oxygenated, deoxygenated, and/or total), any other suitable physiological parameters, or any combination thereof. In some examples, determinations may be performed on the sensor units or an intermediate device and the result of the determinations may be passed to regional oximetry device **500**.

**[0119]** Regional oximetry device **500** may include display **520** configured to display the physiological parameters or other information about the system. In the example shown in FIG. **5**, regional oximetry device **500** may also include a speaker **526** to provide an audible sound that may be used in various other examples, such as for example, sounding an audible alarm in the event that a subject's physiological parameters are not within a predefined normal range. In some examples, physiological monitoring system **502** may include a stand-alone monitor in communication with the regional oximetry device **500** via a cable or a wireless network link.

**[0120]** In some examples, sensing device **434** may be communicatively coupled to regional oximetry device **500** via a cable **546** at port **548**. Cable **546** may include electronic conductors (e.g., wires for transmitting electronic signals from detectors **438** and **439**), optical fibers (e.g., multi-mode or single-mode fibers for transmitting emitted light from light source **436**), any other suitable components, any suitable insulation or sheathing, or any combination thereof. In some examples, a wireless transmission device (not shown) or the like may be used instead of or in addition to cable **546**. Regional oximetry device **500** may include a sensor interface configured to receive physiological signals from sensing device **434**, provide signals and power to sensing device **434**, or otherwise communicate with sensing device **434**. The sensor interface may include any suitable hardware, software, or both, which may allow communication between regional oximetry device **500** and sensing device **434**.

**[0121]** In some examples, physiological monitoring system **502** may include calibration device **580**. In some examples, calibration device **580** may include a manual input device (not shown) used by an operator to manually input reference signal measurements obtained from some other source (e.g., an external invasive or non-invasive physiological measurement system). Calibration device **580**, which may have any suitable power source (e.g., regional oximetry device **500**, a battery, or a conventional power source such as a wall outlet), may include any suitable calibration device. Calibration device **580** may be communicatively coupled to regional oximetry device **500** via communicative coupling **582**, and/or may communicate wirelessly (not shown). In some examples, calibration device **580** is completely integrated within regional oximetry device **500**.

**[0122]** MPM device **150** may include any suitable display device **170**, such as, but not limited to, a cathode ray tube display, a flat panel display (as shown) such as a liquid crystal display (LCD) or a plasma display, or may include any other type of monitor now known or later developed. MPM device **150** may be configured to determine physiological parameters and to present, via display **170**, information from regional oximetry device **500** and from other medical monitoring devices or systems (not shown). For example, MPM device **150** may be configured to display an estimate of a subject's blood oxygen saturation and hemoglobin concentration generated by regional oximetry device **500**. MPM device **150** may include a speaker **572**.

**[0123]** Regional oximetry device **500** may be communicatively coupled to MPM device **150** via a cable **540** or **541** that is coupled to a sensor input port or a digital communications port, respectively and/or may communicate wirelessly (not shown). In addition, regional oximetry device **500** and/or MPM device **150** may be coupled to a network to enable the sharing of information with servers or other workstations (not shown).

**[0124]** Devices **500** and **150** may be configured to communicate MAP values with each other (one way or both ways) via cables **540** and/or **541**. For example, regional oximetry device **500** may be configured to determine a set of MAP values to present via display **520**. Regional oximetry device **500** may communicate the set of MAP values to MPM device **150** so that devices **500** and **150** present the same MAP values via the respective displays **520** and **170**. Communication of MAP values between devices **500**, **150** may improve the operation of devices **500** and **150** by increasing the consistency between the MAP values presented via displays **520** and **170**. Consistency between the presented MAP values may increase the confidence that a user has in the data presented via displays **520** and **170**.

**[0125]** Regional oximetry devices (e.g., devices **100**, **200**, **400**, and/or **500**) and MPM device **150** may determine MAP values using any suitable technique. The regional oximetry device and/or MPM device **150** may be configured to determine MAP values based on a blood pressure signal received from a blood pressure sensor, such as sensing device **132** and/or **182** (FIG. **1**). The blood pressure signal may include a waveform (See FIGS. **6**A and **6**B) that includes systolic peaks and diastolic peaks (or troughs).

**[0126]** FIGS. **6**A and **6**B illustrate example blood-pressure waveforms. Regional oximetry device **100** (e.g., processing circuitry **110**) shown in FIG. **1** may determine a MAP value based on systolic peaks **600** and diastolic peaks **610**. In accordance with a first algorithm, regional oximetry device **100** may determine an average of the amplitudes of one or more of systolic peaks **600** and one or more of diastolic peaks **610**, as shown in Equation (1). In accordance with a second algorithm, regional oximetry device **100** may determine a weighted average as shown in Equation (2), using a weighting of k equals two in favor of diastolic peaks **610**, for

example. A value of k that is greater than one, means that a weighting of diastolic peaks **610** is greater than a weighting of systolic peaks **600**. FIG. **6**A depicts average amplitude **620** as an example of a MAP value determined using the second algorithm.

$$MAP \text{ value} = \frac{1}{2N}[\sum_{i=1}^{N}(BP_{systolic_i} + BP_{diastolic_i}) \quad (1)$$

$$MAP \text{ value} = \frac{1}{N(k+1)}\sum_{i=1}^{N} BP_{systolic_i} + \frac{k}{N(k+1)}\sum_{i=1}^{N} BP_{diastolic_i} \quad (2)$$

$$MAP \text{ value} = \frac{1}{N}\sum_{i=1}^{N} BP_i \quad (3)$$

**[0127]** In accordance with a third algorithm, regional oximetry device **100** may determine a MAP value using the centroid of the waveform. Regional oximetry device **100** may determine the centroid by sampling the blood pressure waveform at a relatively high rate (e.g., one hundred times the frequency of the waveform) and averaging all of the sampled amplitudes, as shown in Equation (3). FIG. **6**B shows an example of determining a MAP value using centroid **650**, which may include sampling along the blood pressure waveform between diastolic peak **660** and diastolic peak **662**. For example, FIG. **6**B depicts six sampling points **670** between the times of diastolic peak **660** and diastolic peak **662**. In accordance with the third algorithm, regional oximetry device **100** may determine an average of an ensemble pulse waveform by averaging all of the sampled amplitudes.

**[0128]** Regional oximetry device **100** may be configured to use one or more of the algorithms described above to determine a first set of MAP values for determining an autoregulation status of a patient. Additionally or alternatively, regional oximetry device **100** may be configured to use one or more of the algorithms to determine a second set of set of MAP values for presenting via display **120**. In some examples, regional oximetry device **100** may be configured to use one or more of the algorithms to mimic the determination of a set of MAP values by MPM device **150**. These algorithms may be used to determine MAP values for transmitting to MPM device **150** (see FIG. **7**) and/or for determining an autoregulation status of a patient (see FIG. **8**).

**[0129]** FIG. **7** is a flow diagram illustrating example techniques for presenting coherent MAP values, in accordance with some examples of this disclosure. Although FIG. **7** are described with respect to processing circuitry **110** of regional oximetry device **100** (FIG. **1**), in other examples, processing circuitry **160**, **210**, **410**, **414**, and/or **450**, alone or in combination with processing circuitry **110**, may perform any part of the techniques of FIG. **7**.

**[0130]** In the example techniques of FIG. **7**, processing circuitry **110** receives a first physiological signal of a patient (**700**). Processing circuitry **110** may receive the first physiological signal directly from a sensing device, or from another processing device (e.g., processing circuitry **160** of MPM device **150**). The first physiological signal may be, for example, a blood pressure signal received from sensing device **132** and sensing circuitry **130**. Sensing device **132** may include a blood pressure cuff and/or a pulse oximetry sensor configured to receive a PPG signal.

**[0131]** Processing circuitry **110** determines a first set of mean arterial pressure (MAP) values of the patient for a time period based on the first physiological signal using a first algorithm (**702**). The first algorithm can be any suitable algorithm for calculating MAP values from a blood pressure signal, such as, but not limited to, Equations (1), (2), and/or (3) described with respect to FIGS. **6**A and **6**B above. In some examples, processing circuitry **110** may use an algorithm that is specifically tailored to patients undergoing a cardiovascular medical procedure or to neo-natal patients.

**[0132]** Processing circuitry **110** determines an autoregulation status of the patient based on the first set of MAP values (**704**). Processing circuitry **110** may be configured to determine the autoregulation status by determining a set of COx values based on the first set of MAP values and a set of oxygen saturation values. Processing circuitry **110** may receive the set of oxygen saturation values for the time period from, for example, sensing device **132** and sensing circuitry **130** (e.g., oxygen saturation sensor **234** shown in FIG. **2**). In some examples, processing circuitry **110** determines a lower limit of autoregulation and an upper limit of autoregulation in terms of MAP in order to determine whether the most current MAP value determined for the patient is between or outside of the limits of autoregulation. In particular, processing circuitry **110** may be configured to determine an autoregulation status based on whether one or more MAP values are less than a lower limit of autoregulation.

**[0133]** Processing circuitry **110** presents, via display **120**, a second set of MAP values of the patient for the time period, wherein the second set of mean arterial pressure values are determined using a second algorithm (**706**). In some examples, the second algorithm may be the same as the first algorithm, such that processing circuitry **110** determines only one set of MAP values for presentation and determination of autoregulation status. In other examples, however, the first and second algorithms for determining MAP values are different, such that processing circuitry **110** determines the autoregulation status of the patient (**704**) based on a first set of MAP values that differs from the second set of MAP values that processing circuitry **110** presents to a user via display **120**.

**[0134]** Processing circuitry **110** determines the second set of MAP values using any suitable technique. In some examples, processing circuitry **110** receives the second set of MAP values from another device, such as MPM device **150**. In other examples, processing circuitry **110** is configured to determine two distinct sets of MAP values for the time period, the first set for determination of autoregulation status and the second set for presentation. In some of these examples, processing circuitry **110** does not present the first set of MAP values via display **120** and only presents the second set of MAP values via display **120**. Processing circuitry **110** may determine the second set of MAP values to mimic the determination of MAP values by MPM device **150** (or another patient monitoring device) or processing circuitry **110** may determine the second set of MAP values and transmit the second set of MAP values to MPM device **150** for presentation via display **170**. Additionally or alternatively, processing circuitry **110** may also be configured to receive the first set of MAP values and/or the second set of

MAP values from another device, e.g., MPM device **150** as described with respect to, for example, FIGS. **9**A, **9**B, **12**A, and **12**B.

**[0135]** FIGS. **8**A-**12**B are flow diagrams of several possible examples for coordinating the MAP values that are presented by regional oximetry device **100** and by MPM device **150**. The examples of FIGS. **8**A-**12**B show example techniques for improving the consistency between the MAP values that are presented by the two devices, thereby improving the operation of one of the particular devices and/or the system including devices **100**, **150**. The examples of FIGS. **8**A-**12**B may also be modified to include delivering and presenting consistent sets of values on both displays for other physiological parameters, such as blood volume saturation, hemoglobin volume index, and the like.

**[0136]** FIGS. **8**A and **8**B are a flow diagram and a conceptual block diagram, respectively, illustrating an example technique performed by regional oximetry device **100** to determine and display MAP to mimic the MAP determined by an MPM device **150**, as well as a corresponding example technique performed by MPM device **150**. In the example shown in FIG. **8**A, both devices **100** and **150** may receive one or more raw blood pressure signals from patient **890**, from which MAP values may be determined (**810**, **812**). Devices **100** and **150** may receive the raw blood pressure signals from any suitable device, such as, for example, one or both of sensing devices **132** and **182**. In some examples, one of sensing devices **132** or **182** may be configured to deliver the same blood pressure signal to both of devices **100** and **150**. Additionally or alternatively, sensing device **132** may provide a first blood pressure signal to processing circuitry **110** of regional oximetry device **100**, and sensing device **182** may provide a second blood pressure signal to processing circuitry **160** of MPM device **150**.

**[0137]** In the example shown in FIGS. **8**A and **8**B, each of devices **100** and **150** use different algorithms to determine MAP values to present via respective displays **120**, **170**. Processing circuitry **110** of regional oximetry device **100** may determine a first set of MAP values ($MAP_O$) using a first algorithm (**820**) and may determine a measure of CA based on the first set of MAP values (**822**), e.g., as described with respect to FIG. **7**. Regional oximetry device **100** may present the measure of CA via display **120** (**824**). In some examples, processing circuitry **110** presents the measure of CA as the autoregulation status of patient **890**, indicated by red or green color, or a COx value, and/or as the lower limit of autoregulation or the upper limit of autoregulation, as expressed in units of MAP, such as mmHg (millimeters of mercury) or kilopascals (kPa).

**[0138]** Processing circuitry **110** may also determine a second set of MAP values ($MPM_M$) using a second algorithm (**830**) and present the second set of MAP values via display **120** (**832**). In the example shown in FIGS. **8**A and **8**B, the second algorithm is different from the first algorithm and results in a different set of MAP values, even though the MAP values are determined using the same underlying blood pressure signal (**810**) for the same time period. Using the second algorithm, processing circuitry **110** may mimic the determination of MAP by MPM device **150**. Processing circuitry **110** may be configured to use a default algorithm to mimic the determination of MAP by MPM device **150**, or a user may input (via a user interface of regional oximetry device **100**) the model number of MPM device **150**, and processing circuitry **110** **100** may select the second algorithm to mimic the algorithm used by MPM device **150** based on the received model number. Processing circuitry **110** may determine the first and second sets of MAP values at the same time or at different times. For example, processing circuitry **110** may determine the first and second sets of MAP values in series (e.g., one after the other) or in parallel (e.g., with two or more processors or threads operating in parallel).

**[0139]** As shown in FIG. **8**A, during the same time as or at a different time as the determination of the first and second sets of MAP values (**820**, **830**) by processing circuitry **110**, processing circuitry **160** of MPM device **150** may receive a raw blood pressure signal (**812**) and determine a third set of MAP values ($MPM_{MPM}$) based on the raw blood pressure signal (**860**). Processing circuitry **160** may present the third set of MAP values via display **170** (**862**). The third set of MAP values may be the same as or similar to the second set of MAP values because processing circuitry **110** and **160** may use the same or similar algorithms for determining the second and third sets of MAP values. Regional oximetry device **100** may use a second algorithm that is different from the first algorithm in order to improve the consistency between the MAP values presented by devices **100** and **150**.

**[0140]** In some examples, processing circuitry **110** is configured to determine a signal quality metric (Q) based on a difference between the first set of MAP values ($MAP_O$) and the second set of MAP values ($MAP_M$), as shown in Equation (4). In Equation (4), Q is equal to a difference between an average of N number of $MAP_O$ values and an average of K number of $MAP_M$ values.

$$Q = \frac{1}{N}\sum_{i=1}^{N} MAP_{O_i} - \frac{1}{K}\sum_{i=1}^{K} MAP_{M_i} \tag{4}$$

**[0141]** A high value of the signal quality metric may indicate that the first set of MAP values is diverging from the second set of MAP values, possibly due to issues (e.g., noise or an improper interface between a blood pressure measuring device and patient **890**) with the received blood pressure signal. A high value of the signal quality metric may also indicate a delay between the blood pressure signal and the oxygen saturation signal, an artifact in the blood pressure signal (as discussed above), e.g., due to movement of a sensing device or the patient, and/or flushing of the arterial line. If processing circuitry **110** determines that the signal quality metric is greater than or equal to a threshold level, then regional oximetry device **100** may generate the notification (e.g., an alert) via display **120** or another user interface mechanism. The threshold level may be, for example, five, ten, or fifteen mmHg. In some examples, processing circuitry **110** presents the notification via display **120** as a color (e.g., red) or a textual description of the signal quality metric value exceeding the threshold level. Regional oximetry device **100** may also refrain from outputting the measure of CA, which may include the autoregulation status, in response to determining that the signal quality metric is greater than or equal to the threshold level.

**[0142]** FIGS. **9**A and **9**B are a flow diagram and a conceptual block diagram, respectively, illustrating an example technique performed by regional oximetry device **100** to receive and display MAP values determined by an MPM device **150**, as well as a corresponding example technique

performed by MPM device **150**. In the example of FIGS. **9**A and **9**B, both of processing circuitry **110** and **160** are configured to present the same set of MAP values ($MAP_{MPM}$). Processing circuitry **160** receives a raw blood pressure signal (**812**), determines the set of MAP values (**860**), and communicates the set to regional oximetry device **100** (**963**).

**[0143]** Processing circuitry **110** and **160** may be configured to receive the same blood pressure signal from one of sensing devices **132** and **182**, or processing circuitry **110** and **160** may be configured to receive different blood pressure signals from sensing devices **132** and **182**. Processing circuitry **110** may also determine a first set of MAP values ($MAP_O$) using a first algorithm (**820**). The first algorithm may be specifically tailored to the unique pulse morphologies that occur in particular patient groups, such as cardiovascular-surgery patients and neo-natal subjects. In the example shown in FIGS. **9**A and **9**B, the second algorithm is different from the first algorithm and results in a different set of MAP values, even though processing circuitry **110** and **160** may determine the sets of MAP values using the same underlying blood pressure signal for the same time period. Processing circuitry **110** may determine a measure of CA and present the measure of CA based on the first set of MAP values (**822**, **824**).

**[0144]** In the example shown in FIGS. **9**A and **9**B, processing circuitry **110** is configured to present the set of $MAP_{MPM}$ values received from MPM device **150** (**961**, **962**) and determine another set of MAP values ($MAP_O$) for determination the measure of CA (**820**). Processing circuitry **110** may present the set of MAP values of $MAP_{MPM}$ instead of or in addition to the set of $MAP_O$ values determined using the first algorithm in order to present MAP values that are consistent with those presented by processing circuitry **160** of MPM device **150** (**862**). However, because processing circuitry **110** uses the set of $MAP_O$ values (determined using an algorithm that is specifically tailored for cardiovascular medical procedures, neo-natal monitoring, or another patient population) to determine the CA status of the patient, processing circuitry **110** may determine a more accurate CA status of patient compared to if the set of $MAP_{MPM}$ values received from MPM device **150** was used to determine the CA status. In this way, the function of processing circuitry **110** may be improved, and processing circuitry **110** may be configured to present an improved graphical user interface that includes $MAP_{MPM}$ values received from MPM device **150**. The graphical user interface may be improved because, for example, the MAP values presented via display **120** of regional oximetry device **100** match or substantially match (within a particular range, such as 5% of MAP values) the MAP values presented by display **170** of MPM device **150**, thereby improving clinician confidence in the displayed MAP values.

**[0145]** FIGS. **10**A and **10**B are a flow diagram and a conceptual block diagrams illustrating an example technique performed by regional oximetry device **100** to determine, display, and communicate MAP values to an MPM device **150**. In the example of FIG. **10**A, processing circuitry **110** is configured to receive a blood pressure signal from patient **890** via sensing device **132** (**810**) and determine a first set of MAP values using a first algorithm (**820**) based on the raw blood pressure signal. Processing circuitry **110** may also be configured to determine a second set of MAP values ($MAP_M$) using a second algorithm (**830**) based on the raw blood pressure signal. In the example shown in FIGS. **8**A and **8**B, the second algorithm is different from the first algorithm and results in a different set of MAP values, even though the sets of MAP values are determined using the same underlying blood pressure signal for the same time period. Processing circuitry **110** may communicate (e.g., transmit) the second set of MAP values to MPM device **150** for presentation on display **170** (**1060**).

**[0146]** In the example of FIGS. **10**A and **10**B, processing circuitry **110** and **160** may present the same set of MAP values because the MAP values presented by MPM device **150** are received from regional oximetry device **100**. As with the previous examples, the coherence between the MAP values displayed by regional oximetry device **100** and MPM device **150** may result in an improved graphical user interface, thereby improving clinician confidence in the displayed MAP values.

**[0147]** FIGS. **11**A and **11**B are a flow diagram and a conceptual block diagram illustrating an example technique performed by regional oximetry device **100** to determine, display, and communicate MAP values to an MPM device **150** using one algorithm. In the example of FIG. **11**A, processing circuitry **110** receives a blood pressure signal from patient **890** via sensing device **132** (**810**) and determines a set of MAP values ($MAP_O$) (**820**) and uses the set of MAP values for three purposes. First, processing circuitry **110** determines and presents a measure of CA (**822**, **824**). Second, processing circuitry **110** presents the determined set of MAP values (**1132**). Third, processing circuitry **110** communicates the set of MAP values to MPM device **150** for presentation by MPM device **150** (**1160**).

**[0148]** FIGS. **12**A and **12**B are a flow diagram and a conceptual block diagram illustrating an example technique performed by regional oximetry device **100** to receive and display MAP values determined by an MPM device **150**. In the example of FIG. **12**A, processing circuitry **160** receives a raw blood pressure signal from sensing device **182** and determines a set of MAP values ($MAP_{MPM}$). In the example of FIG. **12**A, processing circuitry **110** and **160** may use the set of MAP values for three purposes. First, processing circuitry **160** presents the set of MAP values via a display. Second, processing circuitry **160** communicates the set of MAP values to regional oximetry device **100**, and processing circuitry **110** of regional oximetry device **100** receives the set of MAP values (**1221**) and presents the received set of MAP values via a display (**962**). Third, processing circuitry **110** also uses the received set of MAP values to determine and present a measure of CA (**1232**).

**[0149]** In order to determine a measure of CA, processing circuitry **110** may determine a first set of MAP values. Processing circuitry **110** may also determine a set of oxygen saturation values based on a NIRS signal received from sensing devices **132**. Processing circuitry **110** may then be configured to determine a set of COx values based on the first set of MAP values and the set of oxygen saturation values. Processing circuitry **110** may determine the measure of CA (e.g., the most recent COx value, a limit of autoregulation, or an autoregulation status) based on the set of COx values.

**[0150]** In some examples, to improve the accuracy of the measure of CA, processing circuitry **110** may be configured to synchronize, in time, the first set of MAP values and the set of oxygen saturation values. Processing circuitry **110** may then be configured to determine the measure of CA

based on the synchronized set of MAP values and the synchronized set of oxygen saturation values. Using the synchronized data sets may result in a more accurate determination of the measure of CA because the MAP values and oxygen saturation values may be indicative of the same patient state, rather than patient states at different times from each other. Thus, processing circuitry **110** may present more accurate information about the autoregulation status of a patient to a clinician, allowing the clinician to take appropriate actions.

**[0151]** FIG. **13** is a flow diagram illustrating an example technique for synchronizing MAP values and oxygen saturation values. Although FIG. **13** refers to processing circuitry **210** of FIG. **2**, in other examples, processing circuitry **110**, **160**, **410**, **414**, and/or **450**, alone or in combination with processing circuitry **210**, may perform any part of the technique of FIG. **13**. In the example technique of FIG. **13**, processing circuitry **210** receives a first physiological signal of a patient and a second physiological signal of the patient (**1300**). For example, blood pressure sensor **232** may generate a first signal indicating a blood pressure of the patient, and oxygen saturation sensor **234** may generate a signal indicating an oxygen saturation of the patient. Sensors **232** and **234** may deliver the physiological signals directly to processing circuitry **210**, and/or one or both of sensors **232** and **234** may perform pre-processing on the physiological signals.

**[0152]** Processing circuitry **210** determines a set of MAP values of the patient based on the first physiological signal (**1302**). Processing circuitry **210** may determine the set of MAP values using any suitable algorithm, such as, but not limited to, Equations (1), (2), and/or (3) described with respect to FIGS. **6**A and **6**B above. Processing circuitry **210** also determines a set of oxygen saturation values of the patient based on the second physiological signal (**1304**). Processing circuitry **210** may determine the set of oxygen saturation values using any suitable technique, such as one or more of the techniques described with respect to FIG. **4**. The set of MAP values and the set of oxygen saturation values may not necessarily be synchronized in time.

**[0153]** Processing circuitry **210** determines a relative time delay between the set of oxygen saturation values and the set of MAP values (**1306**). In some examples, processing circuitry **210** may determine the relative time delay based on a force applied to both of sensors **232** and **234**. For example, processing circuitry **210**, via output device **222**, may direct a user to flick or tap (e.g., with a finger) the probes of both of sensors **232** and **234** at the same time. Processing circuitry **210** may detect the spike in each of the signals received from sensors **232** and **234** and determine the time lag between the spike in each signal, where the time lag may be equal to the time delay. The time lag may be zero if there is no relative time delay between the two signals. Processing circuitry **210** may cause output device **222** to direct the user to perform this test several times to determine an average of time delays for each test. Another testing technique may include inputting dummy signals into sensors **232** and **234** and having processing circuitry **210** measure the relative time delay in receiving the dummy signals.

**[0154]** These tests may provide the relative time delay for processing circuitry **210** receiving the signals (e.g., an upstream delay). In addition to or instead of the techniques described above, processing circuitry **210** may determine an additional relative time delay (e.g., a downstream delay) based on the processing of the signals to produce a set of MAP values and a set of oxygen saturation values. For example, if processing circuitry **210** uses sampling windows (e.g., analysis windows) with different characteristics such as different durations, the different characteristics may cause an additional relative time delay between the set of MAP values and the set of oxygen saturation values.

**[0155]** Processing circuitry **210** determines an autoregulation status of the patient based on the set of MAP values, the set of oxygen saturation values, and the relative time delay between the first physiological signal and the second physiological signal (**1308**). Processing circuitry **210** may be configured to synchronize the data sets using the relative time delay by, for example, adding or subtracting the determined delay from the time (e.g., timestamp) associated with each value in the set. For example, processing circuitry **210** may store a multi-dimensional data structure such as an array to memory **212**, where the data structure associates each MAP value with a time of measurement. Processing circuitry **110** may adjust (e.g., shift) the associated time by the determined delay in order to synchronize the set of MAP values with the set of oxygen saturation values. Processing circuitry **210** may then determine a set of COx values based on the synchronized set of MAP values and the synchronized set of oxygen saturation values (**1308**). For example, processing circuitry **210** may determine the limits of autoregulation based on the set of COx values and then determine the autoregulation status based on whether the current MAP value is between or outside of the limits of autoregulation.

**[0156]** By determining the relative time delay and using the relative time delay to determine the autoregulation status, processing circuitry **210** may improve the accuracy of the determination of the autoregulation status, as compared to another regional oximetry device that uses unsynchronized data. For example, another regional oximetry device that uses unsynchronized data may determine incorrect limits of autoregulation and then incorrectly determine that the patient has intact autoregulation or impaired autoregulation. Thus, by using the relative time delay to determine the autoregulation status, processing circuitry **210** may reduce the likelihood of an incorrect determination of the autoregulation status.

**[0157]** In some examples, processing circuitry **210** presents, via display **220**, an indication of the determined autoregulation status of the patient (**1310**). In some examples, the indication of the autoregulation status may include a color, such as green for intact autoregulation and red for impaired autoregulation. In addition to or instead of the color or other nontextual indication of autoregulation status, the indication of the autoregulation status may also include an indication of the determined limits of autoregulation, the most recent MAP value, the most recent COx value, the COx threshold for the intact region of autoregulation, and so on.

**[0158]** Regional oximetry device **200** and processing circuitry **210** may be configured to determine the relative time delay and synchronize the data sets relatively quickly, as compared to other regional oximetry devices. For example, processing circuitry **210** may determine the relative time delay based on benchtop testing including inputting dummy signals or flicking both of sensors **232** and **234**. Processing circuitry **210** may quickly determine a cross-correlation function and the matching time lag over which the cross-correlation function has a maximum amplitude. Processing

circuitry **210** may use the durations of the sampling windows, which may be stored to memory **212**, to determine the relative time delay. In contrast, another regional oximetry device may use a correlation window over a long period of time, such as five or ten minutes, to reduce the effects of noise or delays, without synchronizing the signals in the manner described in some examples herein.

**[0159]** The relative time delay (e.g., upstream and downstream) between the MAP values and the oxygen saturation values may change over time. Thus, in some examples, processing circuitry **210** may be configured to periodically re-determine the relative time delay during the operation of regional oximetry device **200**. For example, processing circuitry **210** may re-determine the relative time delay at regular intervals and/or in response to detection of a detection of a particular event. In some examples, the event is a signal quality metric less than or equal to a threshold value or a signal quality metric that decreases by a certain amount over time. In another example, the event is a change in (e.g., made by processing circuitry **210**) to the duration of a sampling window for a physiological signal. In this example, processing circuitry **210** may re-determine the downstream relative time delay.

**[0160]** In some examples, processing circuitry **210** may re-determine the cross-correlation function at regular intervals in order to re-determine the time lag at which the cross-correlation function has a maximum amplitude. In some examples, processing circuitry **210** may change the relative time delay only in response to determining the change in the sampling window is greater than or equal to a threshold level or if in response to determining the change in the time lag of the cross-correlation function is greater than or equal to a threshold level.

**[0161]** FIG. **14** is a flow diagram illustrating an example regional oximetry device **100** including processing circuitry **110** configured to synchronize regional oxygen saturation ($rSO_2$) and MAP signals. Processing circuitry **110** may be configured to receive the raw NIRS signal from one of sensing devices **132** (**1410**) and determine a set of oxygen saturation values based on the raw NIRS signal **1110** (**1420**). MPM device **150** may be configured to receive a raw blood pressure signal from one of sensing devices **182** and determine a set of MAP values based on the raw blood pressure signal. Processing circuitry **110** may receive the set of MAP values from MPM device **150** (**1440**). In some examples, processing circuitry **110** may receive a blood pressure signal and determine the set of MAP values without receiving a set of MAP values from MPM device **150**.

**[0162]** Processing circuitry **110** may determine a reporting delay and the analysis window characteristics for the set of oxygen saturation values (**1450**). The reporting delay may be based on the hardware for sensing and delivering the NIRS signal to processing circuitry **110**. The analysis window characteristics may be based on the determination of the set of oxygen saturation values by processing circuitry **110** (**1420**). Processing circuitry **110** may determine a reporting delay and the analysis window characteristics for the set of MAP values (**1460**). The reporting delay may be based on the hardware for sensing and delivering the blood pressure signal to MPM device **150**. The reporting delay for the set of MAP values may also be based on the communication interface between processing circuitry **110** and MPM device **150**. The analysis window characteristics may be based on the determination of the set of oxygen saturation values by MPM device **150** (**1440**).

**[0163]** FIG. **14** depicts two types of time delays in the process of determining an autoregulation status. The first type of time delay occurs in receiving of the raw blood pressure and NIRS signals by sensing devices **132** and **182** and the delivery of the raw signals by sensing devices **132** and **182** to processing circuitry **110**. The first type of time delay may be referred to as an upstream delay. The second type of time delay occurs in processing the delivered signals by processing circuitry **110**. The second type of time delay may result from the durations of the sampling windows or other characteristics of the algorithms used by processing circuitry **110** to determine the set of MAP values and the set of oxygen saturation values. The second type of time delay may be referred to as a downstream delay.

**[0164]** Processing circuitry **110** may synchronize the set of MAP values and the set of oxygen saturation values (**1470**). Regional oximetry device **100** may determine the relative time delay by subtracting the total delay for the set of MAP values from the total delay for the set of oxygen saturation values. The total delay for each set of values may be the reporting delay plus the sampling window delay (e.g., the first type of time delay plus the second type of time delay). Processing circuitry **110** may shift one set of values by the relative time delay so that the sets are synchronized in time. Processing circuitry **110** may be configured to determine a CA status based on the synchronized sets of values (**1480**). Processing circuitry **110** may then be configured to present the CA status via display **120** (**1490**).

**[0165]** The disclosure contemplates computer-readable storage media comprising instructions to cause a processor to perform any of the functions and techniques described herein. The computer-readable storage media may take the example form of any volatile, non-volatile, magnetic, optical, or electrical media, such as a RAM, ROM, NVRAM, EEPROM, or flash memory. The computer-readable storage media may be referred to as non-transitory. A programmer, such as patient programmer or clinician programmer, or other computing device may also contain a more portable removable memory type to enable easy data transfer or offline data analysis.

**[0166]** The techniques described in this disclosure, including those attributed to devices **100**, **150**, **200**, **400**, and **500**, processing circuitry **110**, **160**, **210**, **410**, **414**, and **450**, memories **112**, **162**, **212**, and **412**, controller **214**, control circuitry **470**, displays **120**, **170**, **220**, **420**, and **520**, sensing circuitries **130** and **180**, sensing devices **132**, **182**, and **434**, and sensors **232** and **234**, and/or communication interfaces **140** and **490**, and various constituent components, may be implemented, at least in part, in hardware, software, firmware or any combination thereof. For example, various aspects of the techniques may be implemented within one or more processors, including one or more microprocessors, DSPs, ASICs, FPGAs, or any other equivalent integrated or discrete logic circuitry, as well as any combinations of such components, embodied in programmers, such as physician or patient programmers, stimulators, remote servers, or other devices. The term "processor" or "processing circuitry" may generally refer to any of the foregoing logic circuitry, alone or in combination with other logic circuitry, or any other equivalent circuitry.

**[0167]** As used herein, the term "circuitry" refers to an ASIC, an electronic circuit, a processor (shared, dedicated, or group) and memory that execute one or more software or firmware programs, a combinational logic circuit, or other suitable components that provide the described functionality. The term "processing circuitry" refers one or more processors distributed across one or more devices. For example, "processing circuitry" can include a single processor or multiple processors on a device. "Processing circuitry" can also include processors on multiple devices, wherein the operations described herein may be distributed across the processors and devices.

**[0168]** Such hardware, software, firmware may be implemented within the same device or within separate devices to support the various operations and functions described in this disclosure. For example, any of the techniques or processes described herein may be performed within one device or at least partially distributed amongst two or more devices, such as between devices **100** and **150**, processing circuitry **110** and **160**, memories **112** and **162**, sensing circuitries **130** and **180**, and/or communication interface **140**. In addition, any of the described units, modules or components may be implemented together or separately as discrete but interoperable logic devices. Depiction of different features as modules or units is intended to highlight different functional aspects and does not necessarily imply that such modules or units must be realized by separate hardware or software components. Rather, functionality associated with one or more modules or units may be performed by separate hardware or software components, or integrated within common or separate hardware or software components.

**[0169]** The techniques described in this disclosure may also be embodied or encoded in an article of manufacture including a non-transitory computer-readable storage medium encoded with instructions. Instructions embedded or encoded in an article of manufacture including a non-transitory computer-readable storage medium encoded, may cause one or more programmable processors, or other processors, to implement one or more of the techniques described herein, such as when instructions included or encoded in the non-transitory computer-readable storage medium are executed by the one or more processors. Example non-transitory computer-readable storage media may include RAM, ROM, programmable ROM (PROM), erasable programmable ROM (EPROM), electronically erasable programmable ROM (EEPROM), flash memory, a hard disk, a compact disc ROM (CD-ROM), a floppy disk, a cassette, magnetic media, optical media, or any other computer readable storage devices or tangible computer readable media.

**[0170]** In some examples, a computer-readable storage medium comprises non-transitory medium. The term "non-transitory" may indicate that the storage medium is not embodied in a carrier wave or a propagated signal. In certain examples, a non-transitory storage medium may store data that can, over time, change (e.g., in RAM or cache). Elements of devices and circuitry described herein, including, but not limited to, devices **100**, **150**, **200**, **400**, and **500**, processing circuitry **110**, **160**, **210**, **410**, **414**, and **450**, and/or sensing circuitries **130** and **180** may be programmed with various forms of software. The one or more processors may be implemented at least in part as, or include, one or more executable applications, application modules, libraries, classes, methods, objects, routines, subroutines, firmware, and/or embedded code, for example.

**[0171]** Various examples of the disclosure have been described. Any combination of the described systems, operations, or functions is contemplated. These and other examples are within the scope of the following claims.

What is claimed is:

**1**. A device comprising:

a display; and

processing circuitry configured to:

receive a physiological signal indicative of a physiological parameter of a patient;

determine a first set of mean arterial pressure values of the patient for a time period based on the physiological signal using a first algorithm;

determine an autoregulation status of the patient based on the first set of mean arterial pressure values; and

present, via the display, a second set of mean arterial pressure values of the patient for the time period, wherein the second set of mean arterial pressure values are determined using a second algorithm different from the first algorithm.

**2**. The device of claim **1**, wherein the processing circuitry is further configured to:

determine the second set of mean arterial pressure values based on the physiological signal using the second algorithm; and

communicate the second set of mean arterial pressure values to a multi-parametric monitor device.

**3**. The device of claim **1**, wherein the processing circuitry is further configured to determine the second set of mean arterial pressure values based on the physiological signal using the second algorithm to mimic determination of mean arterial pressure for the time period by a multi-parametric monitor device.

**4**. The device of claim **3**,

wherein the processing circuitry is configured to determine the second set of values for mean arterial pressure using the second algorithm to mimic determination of mean arterial pressure by at least determining a weighted average of a systolic peak of the physiological signal and a diastolic peak of the physiological signal, and

wherein a weighting of the diastolic peak of the physiological signal is greater than or equal to a weighting of the systolic peak of the physiological signal.

**5**. The device of claim **1**, wherein the processing circuitry is further configured to receive the second set of mean arterial pressure values from a multi-parametric monitor device.

**6**. The device of claim **1**, wherein the physiological parameter of the patient comprises a first physiological parameter, and wherein the processing circuitry is further configured to:

receive a second physiological signal of the patient, the second physiological signal being indicative of a second physiological parameter different from the first physiological parameter;

determine a set of oxygen saturation values of the patient based on the second physiological signal; and

determine a relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values,

wherein the processing circuitry is configured to determine the autoregulation status of the patient based on the first set of mean arterial pressure values, the set of oxygen saturation values, and the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values.

**7**. The device of claim **6**,

wherein the processing circuitry is configured to determine the first set of mean arterial pressure values based on a sampling window for the first set of mean arterial pressure values,

wherein the processing circuitry is configured to determine the set of oxygen saturation values based on a sampling window for the set of oxygen saturation values, and

wherein the processing circuitry is configured to determine the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values based on a duration of the sampling window for the first set of mean arterial pressure values and a duration of the sampling window for the set of oxygen saturation values.

**8**. The device of claim **6**, wherein the processing circuitry is configured to determine the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values by at least:

determining a cross-correlation function for the first physiological signal and the second physiological signal; and

determining a time lag at which the cross-correlation function has a maximum amplitude.

**9**. The device of claim **6**,

wherein the processing circuitry is further configured to synchronize the first set of mean arterial pressure values and the set of oxygen saturation values based on the relative time delay, and

wherein the processing circuitry is configured to determine the autoregulation status of the patient based on the synchronized first set of mean arterial pressure values and the synchronized set of oxygen saturation values.

**10**. The device of claim **1**, wherein the processing circuitry is further configured to:

determine that the autoregulation status is impaired based on the first set of mean arterial pressure values and a set of oxygen saturation values of the patient, and

generate a notification in response to determining that the autoregulation status is impaired.

**11**. The device of claim **1**, wherein the processing circuitry is further configured to:

determine a signal quality metric based on the difference between the first set of mean arterial pressure values and the second set of mean arterial pressure values,

determine that the signal quality metric is greater than or equal to a threshold level,

generate a notification in response to determining that the signal quality metric is greater than or equal to the threshold level,

output the autoregulation status before determining that the signal quality metric is greater than or equal to the threshold level, and

refrain from further outputting the autoregulation status in response to determining that the signal quality metric is greater than or equal to the threshold level.

**12**. A method comprising:

receiving, by processing circuitry, a physiological signal indicative of a physiological parameter of a patient;

determining, by the processing circuitry, a first set of mean arterial pressure values of the patient for a time period based on the physiological signal using a first algorithm;

determining, by the processing circuitry, an autoregulation status of the patient based on the first set of mean arterial pressure values; and

presenting, via a display, a second set of mean arterial pressure values of the patient for the time period, wherein the second set of mean arterial pressure values are determined using a second algorithm different from the first algorithm.

**13**. The method of claim **12**, further comprising:

determining the second set of mean arterial pressure values based on the physiological signal using the second algorithm; and

communicating the second set of mean arterial pressure values to a multi-parametric monitor device.

**14**. The method of claim **12**, further comprising receiving the second set of mean arterial pressure values from a multi-parametric monitor device.

**15**. The method of claim **12**, further comprising:

receiving, from the sensing circuitry, a second physiological signal of the patient, the second physiological signal being indicative of a second physiological parameter different from the first physiological parameter;

determining a set of oxygen saturation values of the patient based on the second physiological signal; and

determining a relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values,

wherein determining the autoregulation status of the patient is based on the first set of mean arterial pressure values, the set of oxygen saturation values, and the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values.

**16**. The method of claim **15**,

wherein determining the first set of mean arterial pressure values is further based on a sampling window for the first set of mean arterial pressure values,

wherein determining the set of oxygen saturation values is further based on a sampling window for the set of oxygen saturation values,

wherein determining the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values comprises determining the relative time delay based on a duration of the sampling window for the first physiological signal and a duration of the sampling window for the second physiological signal.

**17**. The method of claim **15**, wherein determining the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values comprises:

determining a cross-correlation function for the first physiological signal and the second physiological signal; and

determining a time lag at which the cross-correlation function has a maximum amplitude.

**18**. A device comprising:

a display; and

processing circuitry configured to:

receive a first physiological signal indicative of a physiological parameter of a patient;

determine a first set of mean arterial pressure values of the patient for a time period based on the first physiological signal;

transmit the first set of mean arterial pressure values to a multi-parametric monitor device;

determine an autoregulation status of the patient based on the first set of mean arterial pressure values; and

present, via the display, the first set of mean arterial pressure values of the patient for the time period.

**19**. The device of claim **18**, wherein the physiological parameter of the patient comprises a first physiological parameter, and wherein the processing circuitry is further configured to:

receive a second physiological signal of the patient, the second physiological signal being indicative of a second physiological parameter different from the first physiological parameter;

determine a set of oxygen saturation values of the patient based on the second physiological signal; and

determine a relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values,

wherein the processing circuitry is configured to determine the autoregulation status of the patient based on the first set of mean arterial pressure values, the set of oxygen saturation values, and the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values.

**20**. The device of claim **18**,

wherein the processing circuitry is configured to determine the first set of mean arterial pressure values based on a sampling window for the first set of mean arterial pressure values,

wherein the processing circuitry is configured to determine the set of oxygen saturation values based on a sampling window for the set of oxygen saturation values, and

wherein the processing circuitry is configured to determine the relative time delay between the first set of mean arterial pressure values and the set of oxygen saturation values based on a duration of the sampling window for the first set of mean arterial pressure values and a duration of the sampling window for the set of oxygen saturation values.

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| 申请(专利权)人(译) | COVIDIEN LP | | |
| 当前申请(专利权)人(译) | COVIDIEN LP | | |
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摘要(译)

在一些示例中，一种设备包括显示和处理电路，其被配置为接收指示患者的生理参数的生理信号。处理电路还被配置为使用第一算法基于生理信号确定患者在一段时间内的第一组平均动脉压值。在一些示例中，处理电路还被配置为基于第一组平均动脉压值确定患者的自动调节状态。在一些示例中，处理电路被配置为经由显示器在该时间段内呈现患者的第二组平均动脉压值，其中使用不同于该时间段的第二算法确定第二组平均动脉压值。第一种算法。