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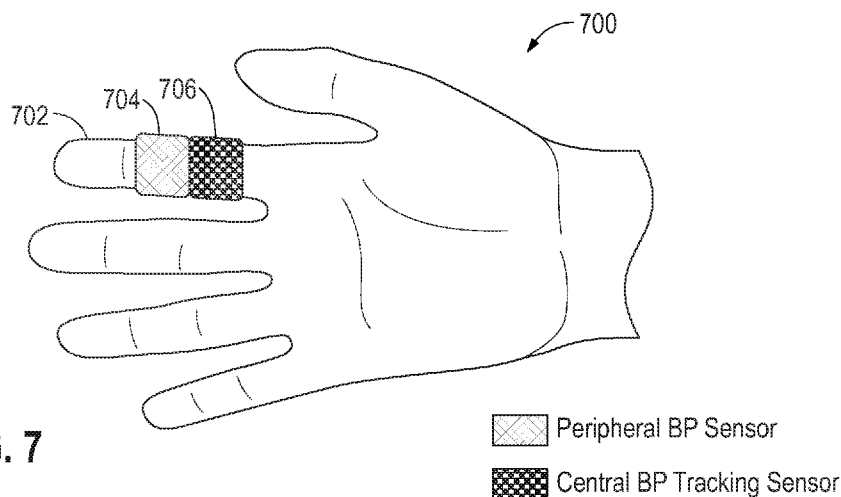


FIG. 7

(57) Abstract: Disclosed is a device to measure the blood pressure of a patient. The device may comprise: a peripheral blood pressure sensor positioned at a peripheral location of the patient to measure local blood pressure values; a central blood pressure sensor positioned at a peripheral location of the patient to measure central blood pressure estimate values; and control circuitry coupled to the peripheral blood pressure sensor and the central blood pressure sensor. The control circuitry may be configured to correct the measured local blood pressure values based upon the measured central blood pressure estimate values.



**DEVICE TO MEASURE THE BLOOD PRESSURE OF A PATIENT****BACKGROUND****CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims the benefit of U.S. Provisional Patent Application No. 62/808,217 filed February 20<sup>th</sup>, 2019, which is incorporated by reference herein in its entirety.

**Field**

[0002] Embodiments of the invention relate generally to non-invasive blood pressure measurement. More particularly, embodiments of the invention relate to a device to measure the blood pressure of a patient utilizing a peripheral blood pressure sensor and a central blood pressure sensor without the use of a heart reference sensor.

**Relevant Background**

[0003] Volume clamping is a technique for non-invasively measuring blood pressure in which pressure is applied to a patient's finger in such a manner that arterial pressure may be balanced by a time varying pressure to maintain a constant arterial volume. In a properly fitted and calibrated system, the applied time varying pressure is equal to the arterial blood pressure in the finger. The applied time varying pressure may be measured to provide a reading of the patient's arterial blood pressure.

[0004] This may be accomplished by a finger cuff that is arranged or wrapped around a finger of a patient. The finger cuff may include an infrared light source, an infrared sensor, and an inflatable bladder. The infrared light may be sent through the finger in which a finger artery is present. The infrared sensor picks up the infrared light and the amount of infrared light registered by the sensor may be inversely proportional to the artery diameter and indicative of the pressure in the artery.

[0005] In the finger cuff implementation, by inflating the bladder in the finger cuff, a pressure is exerted on the finger artery. If the pressure is high enough, it will compress the artery and the amount of light registered by the sensor will increase. The amount of pressure necessary in the inflatable bladder to compress the artery is dependent on the blood pressure. By controlling the pressure of the inflatable bladder such that the diameter of the finger artery is kept constant, the blood pressure may be monitored in very precise detail as the pressure in the inflatable bladder is directly linked to the blood pressure. In a typical present-day finger

cuff implementation, a volume clamp system is used with the finger cuff. The volume clamp system typically includes a pressure generating system and a regulating system that includes: a pump, a valve, and a pressure sensor in a closed loop feedback system that is used in the measurement of the arterial volume. To accurately measure blood pressure, the feedback loop provides sufficient pressure generating and releasing capabilities to match the pressure oscillations of the patient's blood pressure.

[0006] Although finger cuff based blood pressure monitoring systems work well in providing an accurate direct blood pressure measurement from a peripheral location, height differences between the patient's hand and heart offset the pressure measured at the finger, as compared to the patient's central pressure at the aorta near the heart, due to hydrostatic pressure differences. In many existing finger cuff device systems, this height difference between the hand and the heart is measured using a physical heart reference sensor (HRS) that consists of a flexible oil column and a pressure sensor. One end of the oil column terminates at the patient's heart, the other end at the patient's finger, where the pressure sensor measures the pressure of the oil column created by the height differences between the two ends of the column, and thereby the height difference between the patient's heart and finger. The measured finger pressure is then adjusted to compensate for the finger to heart height difference.

[0007] Unfortunately, this requires the use of an additional HRS device that increases the costs of the finger cuff system, as well as, extra time and procedures that are required to be utilized by the health care professional in using the finger cuff system to perform blood pressure measurement of the patient.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0008] FIG. 1 is a diagram of an example of a blood pressure measurement system.

[0009] FIG. 2 is a block diagram of a device to measure the blood pressure of a patient including a peripheral blood pressure sensor and a central blood pressure sensor, according to an optional example.

[0010] FIG. 3 is a graph of brachial blood pressure with and without heart level correction versus time.

[0011] FIG. 4 is graph illustrating a comparison of finger cuff blood pressure measurements by volume clamps and central blood pressure correlated signal measurements obtained by a pulse oximeter from the same hand as the patient raises and lowers their hand.

[0012] FIG. 5 is graph illustrating a device measuring peripheral blood pressure (BP) measurement values and central blood pressure (BP) correlated signal values and making corrections based thereon, according to an optional example.

[0013] FIG. 6 is a flow diagram illustrating an example of a virtual heart reference sensor (VHRS) algorithm, according an optional example.

[0014] FIG. 7 illustrates a finger cuff combined with a photo-plethysmographic (PPG) sensor, according to an optional example.

[0015] FIG. 8 shows graphs illustrating the results of an optional example wherein the flow diagram in FIG. 6 is applied to the finger pressure measured by a volume clamp system wherein the peripheral BP values are measured directly in the finger cuff and the central BP sensor uses the finger pressure waveform for determining the central BP correlated estimate values.

[0016] FIG. 9 illustrates a finger cuff combined with a PPG sensor on a different finger, according to an optional example.

[0017] FIG. 10 illustrates an invasive blood pressure transducer sensor combined with a PPG sensor, according to an optional example.

[0018] FIG. 11 illustrates an invasive blood pressure transducer sensor and a central blood pressure sensor, according to an optional example.

[0019] FIG. 12 illustrates an arm or wrist cuff blood pressure sensor and a central blood pressure sensor, according to an optional example.

[0020] FIG. 13 illustrates a tonometer and a central blood pressure sensor, according to an optional example.

[0021] FIG. 14 illustrates a state-machine for determining and compensating for motion in a finger cuff implementation, according to an optional example.

### **DETAILED DESCRIPTION**

[0022] With reference to FIG. 1, which illustrates an example of a blood pressure measurement system according to an optional example, in which a blood pressure measurement system 102 that includes a finger cuff 104 that may be attached to a patient's finger and a blood pressure measurement controller 120, which may be attached to the patient's body (e.g., a patient's wrist or hand) is shown.

[0023] In one optional example, the blood pressure measurement system 102 may further be connected to a patient monitoring device 130, and, in one optional example, a pump 134. Further, finger cuff 104 may include a bladder (not shown) and an LED-PD pair (not shown), which are conventional for finger cuffs.

[0024] In one optional example, the blood pressure measurement system 102 may include a pressure measurement controller 120 that includes: a small internal pump, a small internal valve, a pressure sensor, and control circuitry. In one optional example, the control circuitry may be configured to: control the pneumatic pressure applied by the internal pump to the bladder of the finger cuff 104 to replicate the patient's blood pressure based upon measuring the pleth signal received from the LED-PD pair of the finger cuff 104. Further, the control circuitry may be configured to: control the opening of the internal valve to release pneumatic pressure from the bladder; or the internal valve may simply be an orifice that is not controlled. Additionally, the control circuitry may be configured to: measure the patient's blood pressure by monitoring the pressure of the bladder based upon the input from a pressure sensor, which should be the same as patient's blood pressure, and may display the patient's blood pressure on the patient monitoring device 130.

[0025] In one optional example, a conventional pressure generating and regulating system may be utilized, in which, a pump 134 is located remotely from the body of the patient. In one optional example, the blood pressure measurement controller 120 receives pneumatic pressure from remote pump 134 through tube 136 and passes on the pneumatic pressure through tube 123 to the bladder of finger cuff 104. Blood pressure measurement device controller 120 may also control the pneumatic pressure (e.g., utilizing a controllable valve) applied to the finger cuff 104 as well as other functions. In this example, the pneumatic pressure applied by the pump 134 to the bladder of finger cuff 104 to replicate the patient's blood pressure based upon measuring the pleth signal received from the LED-PD pair of the finger cuff 104 (e.g., to keep the pleth signal constant) and measuring the patient's blood pressure by monitoring the pressure of the bladder may be controlled by the blood pressure measurement controller 120 and/or a remote computing device and/or the pump 134 and/or the patient monitoring device 130 to implement the volume clamping method. In one optional example, a blood pressure measurement controller 120 is not used at all and there is simply a connection from tube 136 from a remote pump 134 including a remote pressure regulatory system to finger cuff 104, and all processing for the pressure generating and regulatory system, data processing, and display is performed by a remote computing device.

[0026] Continuing with this optional example, as shown in FIG. 1, a patient's hand may be placed on the face 110 of an arm rest 112 for measuring a patient's blood pressure with the blood pressure measurement system 102. The blood pressure measurement controller 120 of the blood pressure measurement system 102 may be coupled to a bladder of the finger cuff 104 in order to provide pneumatic pressure to the bladder for use in blood

pressure measurement. Blood pressure measurement controller 120 may be coupled to the patient monitoring device 130 through a power/data cable 132. Also, in one optional example, as previously described, in a remote implementation, blood pressure measurement controller 120 may be coupled to a remote pump 134 through tube 136 to receive pneumatic pressure for the bladder of the finger cuff 104. The patient monitoring device 130 may be any type of medical electronic device that may read, collect, process, display, etc., physiological readings/data of a patient including blood pressure, as well as any other suitable physiological patient readings. Accordingly, power/data cable 132 may transmit data to and from patient monitoring device 130 and also may provide power from the patient monitoring device 130 to the blood pressure measurement controller 120 and finger cuff 104.

[0027] As can be seen in FIG. 1, in one optional example, the finger cuff 104 may be attached to a patient's finger and the blood pressure measurement controller 120 may be attached on the patient's hand or wrist with an attachment bracelet 121 that wraps around the patient's wrist or hand. The attachment bracelet 121 may be metal, plastic, Velcro, etc. It should be appreciated that this is just one optional example of attaching a blood pressure measurement controller 120 and that any suitable way of attaching a blood pressure measurement controller to a patient's body or in close proximity to a patient's body may be utilized and that, in some optional examples, a blood pressure measurement controller 120 may not be used at all. It should further be appreciated that the finger cuff 104 may be connected to a blood pressure measurement controller described herein, or a pressure generating and regulating system of any other kind, such as a pressure generating and regulating system that is located remotely from the body of the patient. It should be appreciated that any kind of pressure generating and regulating system can be used, including but not limited to the blood pressure measurement controller, and may be described simply as a pressure generating and regulating system that may be used with a finger cuff 104 including an LED-PD pair and a bladder to implement the volume clamping method.

[0028] It should be noted that the previously described blood pressure measurement system 102 that includes a finger cuff 104 does not include a heart reference sensor (HRS). In many existing finger cuff device systems, the height difference between the hand and the heart is measured using a physical heart reference sensor (HRS) that consists of a flexible oil column and a pressure sensor. One end of the oil column terminates at the patient's heart, the other end at the patient's finger, where the pressure sensor measures the pressure of the oil column created by the height differences between the two ends of the column, and thereby the height difference between the patient's heart and finger. The measured finger pressure is

then adjusted to compensate for the finger to heart height difference. As will be described in more detail hereafter, various optional examples eliminate the need for an HRS device.

[0029] With additional reference to FIG. 2, FIG. 2 is a block diagram of a device 200 to measure the blood pressure of a patient according to one optional example. Device 200 may include peripheral blood pressure sensor 201 and central blood pressure sensor 211. The peripheral blood pressure sensor 201 may be positioned at a peripheral location of the patient to measure directly local blood pressure values. The central blood pressure sensor 211 may also be positioned at a peripheral location of the patient to measure central blood pressure estimate values. Control circuitry 230 may be coupled to the peripheral blood pressure sensor 201 and the central blood pressure sensor 211 to calculate peripheral blood pressure (BP) measurement values 232 and central blood pressure (BP) measurement estimate values 234. As will be described in more detail hereafter, the control circuitry 230 may be configured to correct measured local BP values based upon processing of the peripheral BP measurement values 232 and based upon the central BP measurement estimate values 234. Further, as will be described in more detail hereafter, the peripheral blood pressure sensor 201 and/or the central blood pressure sensor 211 may be positioned at peripheral locations on a patient's finger, wrist, arm, or other peripheral locations. Moreover, as will be described in more detail hereafter, the peripheral blood pressure sensor 201 may be: a finger cuff, an invasive blood pressure transducer sensor, an arm or wrist cuff blood pressure sensor, or other types of peripheral blood pressure sensors; and the central blood pressure sensor 211 may be a plethysmographic sensor, such as, a photoplethysmographic (PPG) sensor, a pulse oximeter, etc. These are just various examples, and other examples will be described in more detail hereafter.

[0030] As one optional example, as shown in FIG. 2, the peripheral blood pressure sensor 201 may be a finger cuff that includes an enclosing portion 210, an inflatable bladder 212 and an LED-PD pair 214. The enclosing portion 210 may encircle or enclose a patient's finger and includes the inflatable bladder 212 and the LED-PD pair 214. The inflatable bladder 212 may be pneumatically connected to a pressure generating and regulating system 220. The LED may be used to illuminate the finger skin and light absorption or reflection may be detected with the PD. The pressure generating and regulating system 220 and control circuitry (e.g., including a processor) 230 may generate, measure, and regulate pneumatic pressure that inflates or deflates the inflatable bladder 212, and may further comprise such elements as a pump, a valve, a pressure sensor, and/or other suitable elements, as previously described. In particular, pressure generating and regulating system 220 in cooperation with

control circuitry 230 may be configured to implement a volume clamp method with the finger cuff 202 by: applying pneumatic pressure to the inflatable bladder 212 of the finger cuff 202 to replicate the patient's blood pressure based upon measuring the pleth signal received from the LED-PD pair 214 of the finger cuff 202 (e.g., to keep the pleth signal constant); and measuring the patient's blood pressure by monitoring the pressure of the inflatable bladder 212 based upon input from a pressure sensor, which should be the same as patient's blood pressure, and may further command the display of the patient's blood pressure on the patient monitoring device. However, it should be appreciated that a finger cuff (including an inflatable bladder 212, LED-PD pair 214, and pressure generating and regulating system 220) is only one optional example of a peripheral blood pressure sensor 201 that may be used and that other types of optional examples of peripheral blood pressure sensors (with or without the finger cuff related elements), such as, invasive blood pressure transducer sensors, arm or wrist cuff blood pressure sensors, etc., or any suitable peripheral blood pressure sensor, may be used, as will be described in more detail hereafter.

[0031] It should be appreciated that various optional examples of different types of peripheral blood pressure sensors and central blood pressures may be used to implement techniques to compensate for heart to hand height differences by monitoring blood pressure and/or flow related signals rather than using a physical sensing apparatus, such as, a heart reference sensor (HRS). As has been described, blood pressure may be measured at a peripheral location of the patient (e.g., a hand, a wrist, an arm, etc.). Height differences between the patient's peripheral location and heart, as has been described, result in hydrostatic pressure offsets between the patient's central blood pressure near the heart and their peripheral location. Because physicians are mostly concerned with a patient's central blood pressure, not the peripheral pressure, the hydrostatic pressures due to height differences between the central and peripheral locations need to be subtracted from the blood pressure values displayed to the physician. As has been described, this has previously been performed by the use of a heart reference sensor (HRS).

[0032] It has been found that waveforms generated by a patient's blood pressure waveform can be obtained at peripheral locations of the patient through a variety of means including: a volume clamp pressure waveform measured at the mid-phalanx, a transmitted plethysmograph acquired at the mid-phalanx as used in the volume clamp system, a transmitted plethysmograph acquired at the distal phalanx capillary bed as used in pulse oximetry, a reflected plethysmograph signal, a pressure signal acquired through a pressure sensor in contact with the subject's skin, or a strain sensor signal acquired through a sensor in

contact with the subject's skin. All of these blood pressure related waveforms may contain features generated by reflections along the patient's central aorta that correlate with the patient's central blood pressure. Continuous monitoring of these features provides a data stream that correlates with, and tracks in time, central blood pressure. Various types of apparatus and methods to obtain data related to central blood pressure measurement estimates based on these correlations will be hereafter described.

[0033] As one optional example, to begin with, a blood pressure waveform may be obtained at the patient's finger by finger cuff 104, utilizing the volume clamp method, as previously described. Therefore, as one optional example, the finger cuff 104 may be the peripheral blood pressure sensor 201. The peripheral blood pressure waveform may be continuously compared with a central blood pressure correlated signal from a central blood pressure sensor 211 in order to distinguish between changes in peripheral blood pressure due to a patient's physiology verses changes due to height changes between the peripheral location of the finger cuff and the patient's heart. A change due to the patient's physiology will appear in both data streams, whereas a change due to the patient raising or lowering their hand will only appear in the peripheral blood pressure waveform - but not in the central blood pressure correlated signal. Thus, peripheral blood pressure changes due to changes in heart to hand height can be distinguished from peripheral blood pressure changes due to physiology and can be removed from the blood pressure values presented to the physician. As will be described, the finger cuff 104 is just one optional example of a type of peripheral blood pressure sensor, and a wide variety of different types of peripheral blood pressure sensors and central blood pressure sensors may be utilized. Thus as an optional example, the peripheral blood pressure sensor 201 may be a finger cuff, as previously described. However, any suitable peripheral blood pressure sensor 201 may be utilized

[0034] As has been described, a device 200 to measure the blood pressure of a patient may be utilized. Device 200 may include a peripheral blood pressure sensor 201 and a central blood pressure sensor 211. The peripheral blood pressure sensor 201 may be positioned at a peripheral location of the patient to measure directly local blood pressure values. The central blood pressure sensor 211 may also be positioned at a peripheral location of the patient to measure central blood pressure estimate values. Control circuitry 230 may be coupled to the peripheral blood pressure sensor 201 and the central blood pressure sensor 211 to calculate peripheral blood pressure (BP) measurement values 232 and central blood pressure (BP) measurement estimate values 234. The control circuitry 230 may be configured to correct measured local BP values based upon processing of the peripheral BP

measurement values 232 and based upon the central BP measurement estimate values 234. Further, as will be described in more detail hereafter, the peripheral blood pressure sensor 201 and/or the central blood pressure sensor 211 may be positioned at peripheral locations on a patient's finger, wrist, arm, or other peripheral location. Moreover, as will be described in more detail hereafter, the peripheral blood pressure sensor 201 may be: a finger cuff, an invasive blood pressure transducer sensor, an arm or wrist cuff blood pressure sensor, or other types of peripheral blood pressure sensors; and the central blood pressure sensor 211 may be a plethysmographic sensor, such as, a photoplethysmographic (PPG) sensor, a pulse oximeter, etc. These are just various optional examples, and other examples will be described in more detail hereafter.

[0035] Further, as will be described in more detail, when the measured local blood pressure values 232 by the peripheral blood pressure sensor 201 change, whereas, the measured central blood pressure estimate values 234 from the central blood pressure sensor 211 remain approximately constant, the change in measured local blood pressure values may be subtracted from the blood pressure value that is displayed. For example, a patient's blood pressure may be displayed on the monitoring device 130. Also, when the measured local blood pressure values 232 by the peripheral blood pressure sensor 201 change in value, and, the measured central blood pressure estimate values 232 from the central blood pressure sensor 211 also change in value in tandem, the change in the measured local blood pressure values may be included in the displayed blood pressure on the patient monitoring device 130.

[0036] As one optional example, as has been described, the peripheral blood pressure sensor 201 may be a finger cuff, connectable to the patient's finger to be used in measuring the patient's blood pressure by a blood pressure measurement system utilizing the volume clamp method. In this optional example implementation, the finger cuff may include an enclosing portion 210 that encloses a patient's finger and the enclosing portion of the finger cuff may include an inflatable bladder 212 and a LED-PD pair 214. In other optional examples, the peripheral blood pressure sensor 201 may be an invasive blood pressure transducer sensor, an arm or wrist cuff blood pressure sensor, or other types of peripheral blood pressure sensors. The central blood pressure sensor 211 may be a plethysmographic sensor, such as, a photoplethysmographic (PPG) sensor, a pulse oximeter, etc. It should be appreciated that the central blood pressure sensor 211 may any type of sensor (optical, electric, mechanical, etc.) that can generate a plethysmogram to obtain data that correlates and/or tracks central blood pressure. Also, as one optional example, the central blood pressure sensor 211 may be a pulse oximeter that utilizes the LED-PD pair of the finger cuff.

These are just various examples, and other optional examples will be described in more detail hereafter. It should be appreciated that the central blood pressure sensor 211 may include any type of pressure sensor that can generate a plethysmogram that may be utilized to obtain central blood pressure estimate values that correlate with and/or track central blood pressure. In this way, the central blood pressure sensor 211, that is located at a peripheral location, may be utilized to obtain values that correlate with and/or track central blood pressure. Therefore, a central blood pressure sensor 211 may obtain central blood pressure estimate values that are correlated with and/or track central blood pressure, but that are not direct blood pressure measurements.

[0037] FIG. 3 is a graph of brachial blood pressure with and without heart level correction versus time. In particular, FIG. 3 illustrates systolic and diastolic blood pressure when a patient's hand is at an elevated position and when the patient's hand is at a lower position relative to the heart. Block 301 illustrates the time area when the hand is lowered by 20 inches. In particular, line 302 illustrates systolic pressure that is not corrected and line 304 illustrates systolic pressure that is corrected. Line 306 illustrates diastolic pressure that is not corrected and line 308 illustrates diastolic pressure that is corrected. As can be seen by these lines, lowering the hand by approximately 20 inches raises systolic pressure by approximately 31 mm Hg and lowering the hand by 20 inches raises diastolic pressure by approximately 31 mm Hg. Because of these differences, a standard finger cuff implementation typically requires a heart reference sensor (HRS) to measure the heart to hand height difference such that the difference in blood pressure can be accounted for.

[0038] As another illustration, with reference FIG. 4, FIG. 4 is graph illustrating a comparison of finger cuff blood pressure measurements 402 by volume clamps and central blood pressure correlated signal measurements 404 obtained by a pulse oximeter from the same hand as the patient raises and lowers their hand. As can be seen in the graph, when the hand is raised, the finger pressure 402 drops but the central pressure correlated signal 404 remains basically constant. Similarly, when the hand is lowered the finger pressure 402 rises but the central pressure correlated signal 404 remains basically constant. Based upon this, it has been determined that central blood pressure correlated signals obtained by a pulse oximeter do not change significantly when a patient's hand is raised up or down, whereas blood pressure measurements from a finger cuff sensor do significantly change, as a patient's hand is raised up or down.

[0039] An illustration of how device 200 may correct measured local peripheral blood pressure (BP) values 232 based upon measured central blood pressure estimate values 234,

will be hereafter described. As has been described, device 200 may include peripheral blood pressure sensor 201 and central blood pressure sensor 211. The peripheral blood pressure sensor 201 may be positioned at a peripheral location of the patient to measure directly local blood pressure values. The central blood pressure sensor 211 may also be positioned at a peripheral location of the patient to measure central blood pressure estimate values. In particular, central blood pressure sensor 211 may obtain central blood pressure estimate values that are correlated with and/or track central blood pressure, but that are not direct blood pressure measurements. Control circuitry 230 may be coupled to the peripheral blood pressure sensor 201 and the central blood pressure sensor 211 to calculate peripheral blood pressure (BP) measurement values 232 and central blood pressure (BP) measurement estimate values 234. As will be described, the control circuitry 230 may be configured to correct measured local BP values based upon processing of the peripheral BP measurement values 232 and based upon the central BP measurement estimate values 234.

[0040] As can be seen in FIG. 5, in one optional example, device 200 may measure peripheral blood pressure (BP) measurement values 502 and central blood pressure (BP) correlated signal values 506. In particular, at points 510, control circuitry 230 can determine that the central BP correlated signal 506 is constant despite a change in the peripheral BP measurement 502 and may therefore determine that the change in peripheral PB measurement 502 is due to hand motion and not physiology and that this change in peripheral PB measurement 502 is subtracted out of the displayed BP value 504 that may be displayed on the display device. Therefore, the measured central blood pressure estimate values from the central blood pressure sensor 211 are determined to remain approximately constant, and the change in the peripheral BP measurement values are subtracted from the displayed BP value 504.

[0041] On the other hand, when the peripheral BP measurement values 502 and central BP correlated signal values 506 are determined by the control circuitry 230 to change together at points 512, this change is determined to be due to patient physiology and is kept in the displayed BP value 504. In this way, when the measured local peripheral PB values from the peripheral blood pressure sensor 201 change in value, and, the measured central BP correlated signal values from the central blood pressure sensor 211 also change in value, in tandem, that change in measured blood pressure values is included in the displayed BP value 504 on the display device.

[0042] Therefore, the peripheral BP measurement 502 is removed from the displayed BP values 504 on the display device when the central BP correlated signal 506 does not

change, and, changes in peripheral BP measurement 502 are kept in the displayed blood pressure value 504 when the central BP correlated signal 506 does change in tandem with the peripheral blood pressure measurement 502.

[0043] As one optional example, in the finger cuff optional example, in which the peripheral blood pressure sensor 201 is a finger cuff, the peripheral blood pressure waveform obtained at the finger by the volume clamp method may also contain the central blood pressure features used to create the central blood pressure correlated signal via the LED-PD pair 214. Thus, in this implementation, the peripheral PB measurement 502 and the central BP correlated signal 506 may both be obtained from the same volume clamp measurement via the finger cuff device such that a secondary central blood pressure sensor 211 (e.g., a pulse oximeter) is not necessary.

[0044] In one optional example, the peripheral blood pressure sensor 201 may include an accelerometer 215 (e.g., see FIG. 2). In this optional example, an accelerometer signal 520 may be measured such that accelerometer signal changes can be detected with hand movements. For example, an accelerometer change 522 may be utilized to detect hand motion. In this way, the peripheral BP measurement change 510 can be confirmed to be due to hand motion and not patient physiology. Therefore, hand motion can be confirmed. On the other hand, at another point 522, without significant accelerometer signal change, it can be confirmed that the peripheral BP measurement change 511 is due to patient physiology and not hand motion.

[0045] As one optional example, the previously described methodology to merge the information related to peripheral blood pressure measurement values 232 from the peripheral blood pressure sensor 201 (e.g., the one that is corrected by hydrostatic pressure bias) and the information related to central blood pressure measurement estimate values 234 from the central blood pressure tracking sensor 211 (e.g., the one that actually tracks trends of central blood pressure, irrespective of the sensor position) may be combined into a virtual heart reference sensor (VHRS) algorithm to be implemented by the control circuitry 230. Therefore, in one optional example, the VHRS algorithm may be implemented by the device 202 that incorporates both a peripheral blood pressure sensor and a central blood pressure sensor. In particular, the VHRS algorithm continuously corrects peripheral BP measurements supported by information provided by the central BP tracking sensor.

[0046] With reference to FIG. 6, FIG. 6 is a flow diagram 600 illustrating an optional example of the VHRS algorithm. At decision block 602, peripheral BP sensor data is obtained from the peripheral BP sensor and the VHRS algorithm at decision 602 determines

whether a baseline change has occurred. If not, the peripheral BP measurements are determined to be reliable. However, if there is a baseline change, VHRS algorithm 600 moves to decision block 604. At decision block 604, central BP trend sensor data from the central BP sensor is obtained and the VHRS algorithm 600 determines whether a baseline change has occurred. If not, the peripheral BP measurements are reliable. However, if at decision block 604, a baseline change from the central BP sensor has been detected, then HRS algorithm 600 moves on to HRS compensation at block 606.

[0047] At HRS compensation block 606, the change in measured local blood pressure values is accounted for (subtracted/added) in the blood pressure values to be displayed such that the change identified by the central BP sensor indicating a real physiological change (e.g., not a hand movement change) is accounted for. Thus, a virtual heart reference sensor (VHRS) is utilized. At block 608, if the HRS compensation is successful then the HRS corrected BP measurements are reliable, whereas if the HRS compensation block was not successful, then the peripheral BP measurements are not reliable.

[0048] It should be noted that the VHRS algorithm of HRS compensation block 606 provides a way to continuously correct peripheral BP measurements by the information provided by the central BP tracking sensor that measures central BP correlated signals. The VHRS algorithm may: 1) continuously analyze the instantaneous values provided by the peripheral BP sensor in order to generate a “trend model” of the data (TM1); and 2) continuously analyze the instantaneous values provided by the central BP sensor in order to generate a “trend model” of the data (TM2). Further, whenever: 1) there is a significant mismatch between models TM1 and TM2; and 2) the reliability of TM2 is determined to be strong enough, then the TM1 data may be corrected on the basis of TM2 data (from the central BP sensor). In particular, the data from the peripheral BP sensor is corrected on the basis of the corrected-TM1 data.

[0049] With additional reference to FIG. 7, in one optional example 700, the peripheral blood pressure sensor 704 may be a finger cuff utilizing the volume clamp method, as previously described, and the central blood pressure sensor 706 may be a photoplethysmographic (PPG) sensor (e.g., a pulse oximeter). In this optional example, both the peripheral blood pressure sensor 704 and the central blood pressure sensor 706 may be mounted to the patient's finger 702. In one optional example, the central blood pressure sensor 706 may be included in the finger cuff itself, and utilize the same electronic components, such that only one finger cuff component is utilized. In particular, in one optional example, the central blood pressure sensor 706 may utilize the same LED-PD pair

components of the finger cuff to create the PPG sensor for determining the central BP correlated estimate values such that only one finger cuff component is utilized. The continuous measured local peripheral direct BP values from the finger cuff 704 may be corrected based upon the central BP correlated estimate values from the central BP sensor 706. As has been described, the correction may include determining that because the central BP correlated estimate values are constant, that changes in the peripheral BP values are due to motion, not physiology, and changes are removed from the peripheral BP values for BP display, or, the central BP correlated estimate values change in value in tandem with the peripheral BP values, and the change in the measured peripheral BP values are physiological (not due to motion) and should be included in displayed blood pressure values. In particular, these peripheral BP and central BP sensors may be used to implement the previously described VHRS algorithm.

[0050] With continued reference to FIG. 7, in one optional example 700, the peripheral blood pressure sensor 704 may be a finger cuff utilizing the volume clamp method, as previously described, and the central blood pressure sensor 706 may utilize data streams, e.g., the blood pressure waveform, acquired by the peripheral blood pressure sensor 704 to estimate a central blood pressure. In this optional example, both the peripheral blood pressure sensor 704 and the central blood pressure sensor 706 may be mounted to the patient's finger 702. In one optional example, the central blood pressure sensor 706 may be included in the finger cuff itself, and utilize the same electronic components, such that only one finger cuff component is utilized. In particular, the central blood pressure sensor 706 may utilize the blood pressure waveform measured by the peripheral blood pressure sensor for determining the central BP correlated estimate values such that only one finger cuff component is utilized. The continuous measured local peripheral direct BP values from the finger cuff 704 may be corrected based upon the central BP correlated estimate values from the central BP sensor 706. As has been described, the correction may include determining that because the central BP correlated estimate values are constant, that changes in the peripheral BP values are due to motion, not physiology, and changes are removed from the peripheral BP values for BP display, or, the central BP correlated estimate values change in value in tandem with the peripheral BP values, and the change in the measured peripheral BP values are physiological (not due to motion) and should be included in displayed blood pressure values. In particular, these peripheral BP and central BP sensors may be used to implement the previously described VHRS algorithm.

[0051] Figure 8 illustrates the results of an optional example wherein the flow diagram of Figure 6 is applied to the finger pressure measured by a volume clamp system wherein the peripheral BP values are measured directly in the finger cuff and the central BP sensor uses the finger pressure waveform for determining the central BP correlated estimate values. Panel 810 shows the finger systolic and diastolic BP values over time while the subject uses both hydrostatic hand raising, 811, and lowering, 812, to change the finger blood pressure and physical maneuvers: cold pressor, 813, and exercise bike, 814, to change the finger BP values. Panel 820 shows the resulting corrections made to the finger pressure as determined by both an oil column sensor (the control system) and by the virtual HRS as described in Figures 6 and 7. The virtual HRS correctly identifies the hand motions and removes them. There are short time periods over which the HRS misidentifies physiological BP changes as peripheral hydrostatic changes but corrects itself as more data arrives from the central BP sensor. Panel 830 shows the correct finger pressure with the hydrostatic BP changes removed by the physiological changes remaining.

[0052] With additional reference to FIG. 9, in one optional example 900, the peripheral blood pressure sensor 904 may be a finger cuff utilizing the volume clamp method mounted to one finger 902, as previously described, and the central blood pressure sensor 906 may be a photo-plethysmographic (PPG) sensor (e.g., a pulse oximeter) mounted to another finger 906. In this optional example 900, the continuous measured local peripheral direct BP values from the finger cuff 904 may be corrected based upon the central BP correlated estimate values from the central BP sensor 908. As has been described, the correction may include determining that because the central BP correlated estimate values are constant, that changes in the peripheral BP values are due to motion, not physiology, and changes are removed from the peripheral BP values for BP display, or, the central BP correlated estimate values change in value in tandem with the peripheral BP values, and the change in the measured peripheral BP values are physiological (not due to motion) and should be included in displayed blood pressure values. Therefore, in this optional example, a central BP sensor 908 is added as an additional component to the volume clamp sensor setup of the finger cuff 904 to aid in implementing the VHRS functionality, previously described. In particular, these peripheral BP and central BP sensors may be used to implement the previously described VHRS algorithm.

[0053] With additional reference to FIG. 10, in one optional example 1000, the peripheral blood pressure sensor 1004 may be an invasive blood pressure transducer sensor to directly measure the patient's blood pressure. The invasive blood pressure transducer sensor

1004 may be properly connected to a patient's artery on the patient's arm or wrist 1002 to perform local direct blood pressure measurement. The central blood pressure sensor 1008 may be a photo-plethysmographic (PPG) sensor (e.g., a pulse oximeter) mounted to a finger 1006. In this optional example 1000, the continuous measured local peripheral direct BP values from the invasive blood pressure transducer sensor 1004 may be improved based upon the central BP correlated estimate values from the central BP sensor 1008. In particular, these peripheral BP and central BP sensors may be used to implement the previously described VHRS algorithm.

[0054] With additional reference to FIG. 11, in one optional example 1100, the peripheral blood pressure sensor 1104 may be an invasive blood pressure transducer sensor to directly measure the patient's blood pressure. The invasive blood pressure transducer sensor 1104 may be properly connected to a patient's artery on the patient's arm or wrist 1102 to perform local direct blood pressure measurement. Further, the central blood pressure sensor 1106 may be connected with the invasive blood pressure transducer sensor 1104 on the patient's arm or wrist 1102. As an optional example, the sensors may be connected together to form one device. In this optional example 1100, the invasive blood pressure transducer sensor 1104 performs direct continuous peripheral BP measurements, and the arterial line signals from the invasive blood pressure transducer sensor 1104 may be used as inputs to the central blood pressure sensor 1106 that utilizes them to determine central BP correlated estimate values, as previously described, to implement the VHRS algorithm, to improve the accuracy of the peripheral direct BP measurements from the invasive blood pressure transducer sensor. In particular, these peripheral BP and central BP sensors may be used to implement the previously described VHRS algorithm.

[0055] With additional reference to FIG. 12, in one optional example 1200, the peripheral blood pressure sensor 1204 may be an arm or wrist cuff blood pressure sensor to directly measure the patient's blood pressure. The arm or wrist cuff blood pressure sensor 1204 may be properly fitted to the patient's arm or wrist 1202 (e.g., wrapped around) to perform local direct blood pressure measurement. Further, the central blood pressure sensor 1206 may be connected with/included in the arm or wrist cuff blood pressure sensor 1204. In this optional example 1200, the arm or wrist cuff blood pressure sensor 1204 performs direct continuous peripheral BP measurements, and the blood pressure signals acquired from the arm or wrist cuff blood pressure sensor 1204 may be used as inputs via pressure sensors to the central blood pressure sensor 1206 that utilizes them to determine central BP correlated estimate values, as previously described, to implement the VHRS algorithm, to improve the

accuracy of the peripheral direct BP measurements from the arm or wrist cuff blood pressure sensor. In particular, these peripheral BP and central BP sensors may be used to implement the previously described VHRS algorithm.

[0056] With additional reference to FIG. 13, in one optional example 1300, the peripheral blood pressure sensor 1304 may be a non-invasive pressure sensor attached to the patient's skin, such as, a tonometer, to directly measure the patient's blood pressure. The tonometer 1304 may be placed near a patient's artery (e.g., on patient's arm or wrist 1304) to perform local direct blood pressure measurement. Further, a central blood pressure sensor 1306 may be connected with the tonometer 1304 on the patient's arm or wrist 1302. As an example, the sensors may be connected together to form one device. In the optional example 1300, the tonometer 1304 performs direct continuous peripheral BP measurements, and the signals from tonometer 1304 may be used as inputs to the central blood pressure sensor 1306 that utilizes them to determine central BP correlated estimate values, as previously described, to implement the VHRS algorithm, to improve the accuracy of the peripheral direct BP measurements from the tonometer 1304. In particular, these peripheral BP and central BP sensors may be used to implement the previously described VHRS algorithm.

[0057] With additional reference to FIG. 14 another optional example, in a state-machine form, of determining and compensating for motion in a finger cuff implementation will be described. Reference can also be made to previously described FIG. 5 which provides a graph illustration. In this example implementation 1400, there is a static state 1402 and a motion state 1404. There are two inputs, as previously described, peripheral blood pressure (BP) measurement values and central blood pressure (BP) correlated signal tracking values. In this example, the peripheral BP values may be Finger Pressure (FP) values from a finger cuff (e.g., finger systolic and/or diastolic values, beat-to-beat) and central BP correlated tracking signal values (e.g., based on pulse oximeter PPG readings beat-to-beat (e.g., systolic and/or diastolic)). In the static state 1402, new FP values and new central BP tracking values are compared via a comparison function to previous FP values and central BP tracking values. The comparison function will be hereafter described. If the comparisons are Similar, the previous FP=the current FP, the static state 1402 is maintained, if not, and the comparisons are Different, then the motion state 1404 is entered.

[0058] As to the compare function, the inputs are a buffer of the most recent FP values and central BP tracking values. The buffers may be filtered (e.g., 5 beat rolling average). Derivatives may be calculated and compared, and a determination made as to

whether the derivatives are Similar or Different. The output is then Similar (True) or Different (False).

[0059] If entry into the motion state occurs due to Different determination,  $P_0$  is set to the previous FP values. In the motion state 1404, when new FP values and new central BP tracking values are obtained and buffered, the compare function is called. If the compare function results in Different, then the motion state 1404 is maintained and further comparisons are made. If the compare function results in Similar, then  $P_F$  is set to the current FP values from the buffer and the hydrostatic offset (HSO) value is updated and the static state 1402 is returned to. In particular, the HSO value is set to  $HSO = HSO - (P_0 - P_F)$ . The HSO is equivalent to the HRS pressure and is a DC offset that is subtracted from the finger pressure waveform.

[0060] As has been described, with additional previous reference to FIG. 2, a device 200 to measure the blood pressure of a patient may be utilized. Device 200 may include a peripheral blood pressure sensor 201 and a central blood pressure sensor 211. The peripheral blood pressure sensor 201 may be positioned at a peripheral location of the patient to measure directly local blood pressure values. The central blood pressure sensor 211 may also be positioned at a peripheral location or another suitable location of the patient to measure central blood pressure estimate values. Control circuitry 230 may be coupled to the peripheral blood pressure sensor 201 and the central blood pressure sensor 211 to calculate peripheral blood pressure (BP) measurement values 232 and central blood pressure (BP) measurement estimate values 234. The control circuitry 230 may be configured to correct measured local BP values based upon processing of the peripheral BP measurement values 232 and based upon the central BP measurement estimate values 234. As has been described, as optional examples, the peripheral blood pressure sensor 201 may be: a finger cuff, an invasive blood pressure transducer sensor, an arm or wrist cuff blood pressure sensor, or any other type of suitable peripheral blood pressure sensor. Further, as optional examples, the central blood pressure sensor may be a plethysmographic sensor, such as, a photoplethysmographic (PPG) sensor, a pulse oximeter, or any other type of suitable central blood pressure sensor. It should be appreciated that any of the previously described optional examples of previously described peripheral blood pressure sensors and central blood pressure sensor may be utilized together to achieve the previously described functions. Moreover, it should be appreciated that these are just optional examples of peripheral and central blood pressure sensors and that any suitable peripheral or central blood pressure sensor may be utilized. For example, the central blood pressure sensor may be any type of

sensor (optical, electric, mechanical, etc.) that obtains data that correlates and/or tracks central blood pressure and the peripheral blood pressure sensor may be any type of sensor (optical, electric, mechanical, etc.) to measure local blood pressure values.

[0061] It should be appreciated that Figure 2 illustrates a non-limiting example of a control circuitry 230 implementation. As an example, control circuitry may comprise a processor, a memory, and an input/output connected with a bus. Under the control of the processor, data may be received from an external source through the input/output interface and stored in the memory, and/or may be transmitted from the memory to an external destination through the input/output interface. The processor may process, add, remove, change, or otherwise manipulate data stored in the memory. Further, code may be stored in the memory. The code, when executed by the processor, may cause the processor to perform operations relating to data manipulation and/or transmission and/or any other possible operations.

[0062] It should be appreciated that aspects of the invention previously described may be implemented in conjunction with the execution of instructions by control circuitry, processors, circuitry, controllers, etc. As an example, control circuitry may operate under the control of a program, algorithm, routine, or the execution of instructions to execute methods or processes in accordance with embodiments of the invention previously described. For example, such a program may be implemented in firmware or software (e.g. stored in memory and/or other locations) and may be implemented by control circuitry, processors, and/or other circuitry, these terms being utilized interchangeably. Further, it should be appreciated that the terms processor, microprocessor, circuitry, control circuitry, circuit board, controller, microcontroller, etc., refer to any type of logic or circuitry capable of executing logic, commands, instructions, software, firmware, functionality, etc., which may be utilized to execute embodiments of the invention.

[0063] The various illustrative blocks, processors, modules, and circuitry described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose processor, a specialized processor, circuitry, a microcontroller, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A processor may be a microprocessor or any conventional processor, controller, microcontroller, circuitry, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a

DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[0064] The steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module/firmware executed by a processor, or any combination thereof. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor.

[0065] The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

[0066] The disclosure also includes the following clauses:

1. A device to measure the blood pressure of a patient, the device comprising:  
a peripheral blood pressure sensor positioned at a peripheral location of the patient to measure local blood pressure values;  
a central blood pressure sensor positioned at a peripheral location of the patient to measure central blood pressure estimate values; and  
control circuitry coupled to the peripheral blood pressure sensor and the central blood pressure sensor, the control circuitry configured to correct the measured local blood pressure values based upon the measured central blood pressure estimate values.

2. The device of claim 1, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change, whereas, the measured central blood pressure estimate values from the central blood pressure sensor remain approximately constant, the change in the measured local blood pressure values is subtracted from a displayed blood pressure value.

3. The device of any of the claims 1-2, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change in value, and, the measured central blood pressure estimate values from the central blood pressure sensor also change in value in tandem, the change in the measured local blood pressure values is included in the displayed blood pressure value.

4. The device of any of the claims 1-3, wherein the peripheral blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

5. The device of any of the claims 1-4, wherein the central blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

6. The device of any of the claims 1-5, wherein the peripheral blood pressure sensor comprises a finger cuff connectable to the patient's finger to be used in measuring the patient's blood pressure by a blood pressure measurement system utilizing the volume clamp method, the finger cuff including an enclosing portion that encloses the patient's finger, the enclosing portion including a bladder and a light emitting diode (LED) and photodiode (PD) pair.

7. The device of any of the claims 1-5, wherein the peripheral blood pressure sensor comprises an invasive blood pressure transducer sensor.

8. The device of any of the claims 1-5, wherein the peripheral blood pressure sensor comprises an arm or wrist cuff blood pressure sensor.

9. The device of any of the claims 1-8, wherein the central blood pressure sensor comprises a photoplethysmographic (PPG) sensor.

10. The device of any of the claims 1-9, wherein the central blood pressure sensor uses a waveform acquired by the peripheral blood pressure sensor as an input.

11. A method to measure the blood pressure of a patient, the method comprising:  
measuring local blood pressure values by a peripheral blood pressure sensor positioned at a peripheral location of the patient;

measuring central blood pressure estimate values by a central blood pressure sensor positioned at a peripheral location of the patient; and

correcting the measured local blood pressure values based upon the measured central blood pressure estimate values.

12. The method of claim 11, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change, whereas, the measured central blood pressure estimate values from the central blood pressure sensor remain approximately constant, the change in the measured local blood pressure values is subtracted from a displayed blood pressure value.

13. The method of any of the claims 11-12, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change in value, and, the measured central blood pressure estimate values from the central blood pressure sensor also change in value in tandem, the change in the measured local blood pressure values is included in the displayed blood pressure value.

14. The method of any of the claims 11-13, wherein the peripheral blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

15. The method of any of the claims 11-14, wherein the central blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

16. The method of any of the claims 11-15, wherein the peripheral blood pressure sensor comprises a finger cuff connectable to the patient's finger to be used in measuring the patient's blood pressure by a blood pressure measurement system utilizing the volume clamp method, the finger cuff including an enclosing portion that encloses the patient's finger, the enclosing portion including a bladder and a light emitting diode (LED) and photodiode (PD) pair.

17. The method of any of the claims 11-15, wherein the peripheral blood pressure sensor comprises an invasive blood pressure transducer sensor.

18. The method of any of the claims 11-15, wherein the peripheral blood pressure sensor comprises an arm or wrist cuff blood pressure sensor.

19. The method of any of the claims 11-18, wherein the central blood pressure sensor comprises a photoplethysmographic (PPG) sensor.

20. The method of any of the claims 11-19, wherein the central blood pressure sensor uses a waveform acquired by the peripheral blood pressure sensor as an input.

21. A device to measure the blood pressure of a patient, the device comprising:  
a peripheral blood pressure sensor positioned at a peripheral location of the patient to measure local blood pressure values;  
a central photoplethysmographic (PPG) sensor positioned at a peripheral location of the patient to measure central blood pressure estimate values; and  
control circuitry coupled to the peripheral blood pressure sensor and the central PPG sensor, the control circuitry configured to correct the measured local blood pressure values based upon the measured central blood pressure estimate values.

22. The device of claim 21, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change, whereas, the measured central blood pressure estimate values from the central PPG sensor remain approximately constant, the change in the measured local blood pressure values is subtracted from a displayed blood pressure value.

23. The device of any of the claims 21-22, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change in value, and, the measured central blood pressure estimate values from the central PPG sensor also change in value in tandem, the change in the measured local blood pressure values is included in the displayed blood pressure value.

24. The device of any of the claims 21-23, wherein the peripheral blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

25. The device of any of the claims 21-24, wherein the central blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

26. The device of claim of any of the claims 21-25, wherein the peripheral blood pressure sensor comprises a finger cuff connectable to the patient's finger to be used in measuring the patient's blood pressure by a blood pressure measurement system utilizing the volume clamp method, the finger cuff including an enclosing portion that encloses the patient's finger, the enclosing portion including a bladder and a light emitting diode (LED) and photodiode (PD) pair.

27. The device of any of the claims 21-25, wherein the peripheral blood pressure sensor comprises an invasive blood pressure transducer sensor.

28. The device of any of the claims 21-25, wherein the peripheral blood pressure sensor comprises an arm or wrist cuff blood pressure sensor.

**WHAT IS CLAIMED IS:**

1. A device to measure the blood pressure of a patient, the device comprising:  
a peripheral blood pressure sensor positioned at a peripheral location of the patient to measure local blood pressure values;  
a central blood pressure sensor positioned at a peripheral location of the patient to measure central blood pressure estimate values; and  
control circuitry coupled to the peripheral blood pressure sensor and the central blood pressure sensor, the control circuitry configured to correct the measured local blood pressure values based upon the measured central blood pressure estimate values.

2. The device of claim 1, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change, whereas, the measured central blood pressure estimate values from the central blood pressure sensor remain approximately constant, the change in the measured local blood pressure values is subtracted from a displayed blood pressure value.

3. The device of any of the claims 1-2, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change in value, and, the measured central blood pressure estimate values from the central blood pressure sensor also change in value in tandem, the change in the measured local blood pressure values is included in the displayed blood pressure value.

4. The device of any of the claims 1-3, wherein the peripheral blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

5. The device of any of the claims 1-4, wherein the central blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

6. The device of any of the claims 1-5, wherein the peripheral blood pressure sensor comprises a finger cuff connectable to the patient's finger to be used in measuring the patient's blood pressure by a blood pressure measurement system utilizing the volume clamp method, the finger cuff including an enclosing portion that encloses the patient's finger, the

enclosing portion including a bladder and a light emitting diode (LED) and photodiode (PD) pair.

7. The device of any of the claims 1-5, wherein the peripheral blood pressure sensor comprises an invasive blood pressure transducer sensor.

8. The device of any of the claims 1-5, wherein the peripheral blood pressure sensor comprises an arm or wrist cuff blood pressure sensor.

9. The device of any of the claims 1-8, wherein the central blood pressure sensor comprises a photoplethysmographic (PPG) sensor.

10. The device of any of the claims 1-9, wherein the central blood pressure sensor uses a waveform acquired by the peripheral blood pressure sensor as an input.

11. A method to measure the blood pressure of a patient, the method comprising:  
measuring local blood pressure values by a peripheral blood pressure sensor positioned at a peripheral location of the patient;  
measuring central blood pressure estimate values by a central blood pressure sensor positioned at a peripheral location of the patient; and  
correcting the measured local blood pressure values based upon the measured central blood pressure estimate values.

12. The method of claim 11, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change, whereas, the measured central blood pressure estimate values from the central blood pressure sensor remain approximately constant, the change in the measured local blood pressure values is subtracted from a displayed blood pressure value.

13. The method of any of the claims 11-12, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change in value, and, the measured central blood pressure estimate values from the central blood pressure sensor also change in value in tandem, the change in the measured local blood pressure values is included in the displayed blood pressure value.

14. The method of any of the claims 11-13, wherein the peripheral blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

15. The method of any of the claims 11-14, wherein the central blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

16. The method of any of the claims 11-15, wherein the peripheral blood pressure sensor comprises a finger cuff connectable to the patient's finger to be used in measuring the patient's blood pressure by a blood pressure measurement system utilizing the volume clamp method, the finger cuff including an enclosing portion that encloses the patient's finger, the enclosing portion including a bladder and a light emitting diode (LED) and photodiode (PD) pair.

17. The method of any of the claims 11-15, wherein the peripheral blood pressure sensor comprises an invasive blood pressure transducer sensor.

18. The method of any of the claims 11-15, wherein the peripheral blood pressure sensor comprises an arm or wrist cuff blood pressure sensor.

19. The method of any of the claims 11-18, wherein the central blood pressure sensor comprises a photoplethysmographic (PPG) sensor.

20. The method of any of the claims 11-19, wherein the central blood pressure sensor uses a waveform acquired by the peripheral blood pressure sensor as an input.

21. A device to measure the blood pressure of a patient, the device comprising:  
a peripheral blood pressure sensor positioned at a peripheral location of the patient to measure local blood pressure values;  
a central photoplethysmographic (PPG) sensor positioned at a peripheral location of the patient to measure central blood pressure estimate values; and  
control circuitry coupled to the peripheral blood pressure sensor and the central PPG sensor, the control circuitry configured to correct the measured local blood pressure values based upon the measured central blood pressure estimate values.

22. The device of claim 21, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change, whereas, the measured central blood pressure estimate values from the central PPG sensor remain approximately constant, the change in the measured local blood pressure values is subtracted from a displayed blood pressure value.

23. The device of any of the claims 21-22, wherein, when the measured local blood pressure values by the peripheral blood pressure sensor change in value, and, the measured central blood pressure estimate values from the central PPG sensor also change in value in tandem, the change in the measured local blood pressure values is included in the displayed blood pressure value.

24. The device of any of the claims 21-23, wherein the peripheral blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

25. The device of any of the claims 21-24, wherein the central blood pressure sensor is positioned on at least one of a finger, a wrist, or an arm of the patient.

26. The device of claim of any of the claims 21-25, wherein the peripheral blood pressure sensor comprises a finger cuff connectable to the patient's finger to be used in measuring the patient's blood pressure by a blood pressure measurement system utilizing the volume clamp method, the finger cuff including an enclosing portion that encloses the patient's finger, the enclosing portion including a bladder and a light emitting diode (LED) and photodiode (PD) pair.

27. The device of any of the claims 21-25, wherein the peripheral blood pressure sensor comprises an invasive blood pressure transducer sensor.

28. The device of any of the claims 21-25, wherein the peripheral blood pressure sensor comprises an arm or wrist cuff blood pressure sensor.

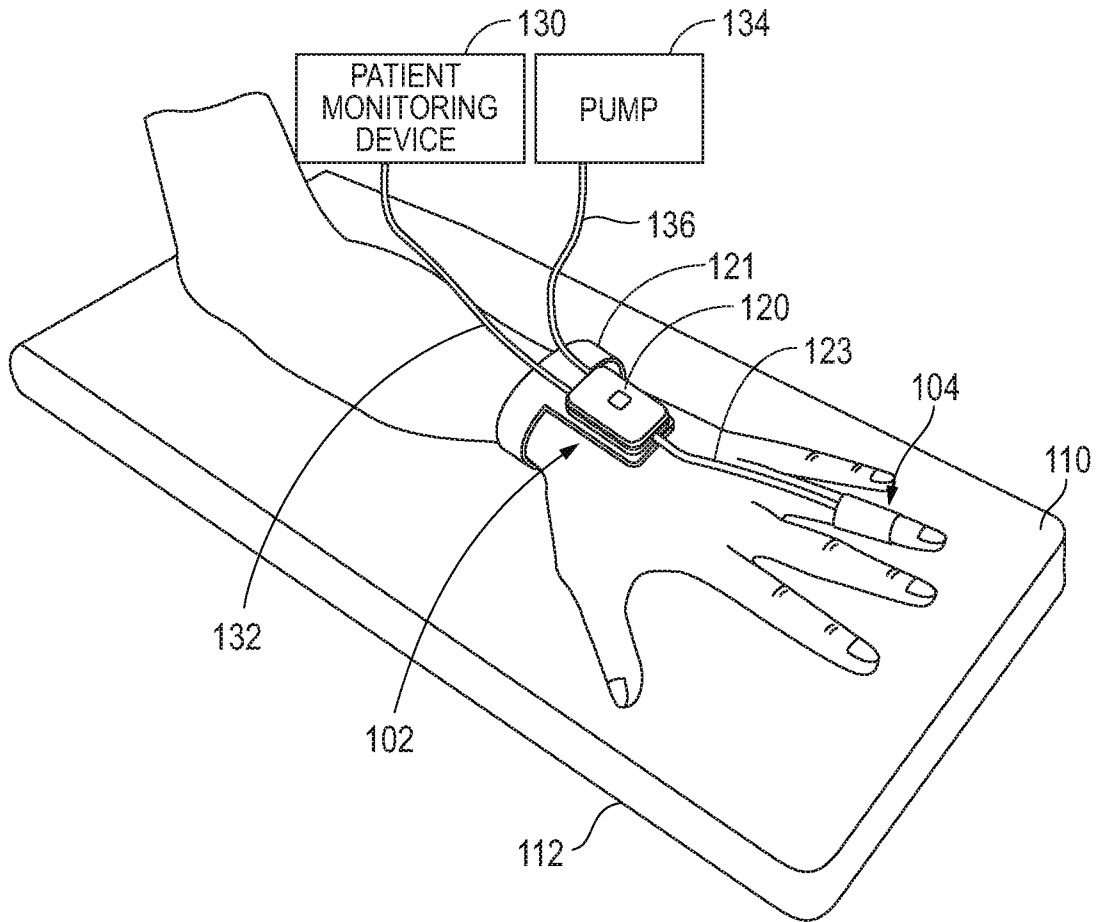


FIG. 1

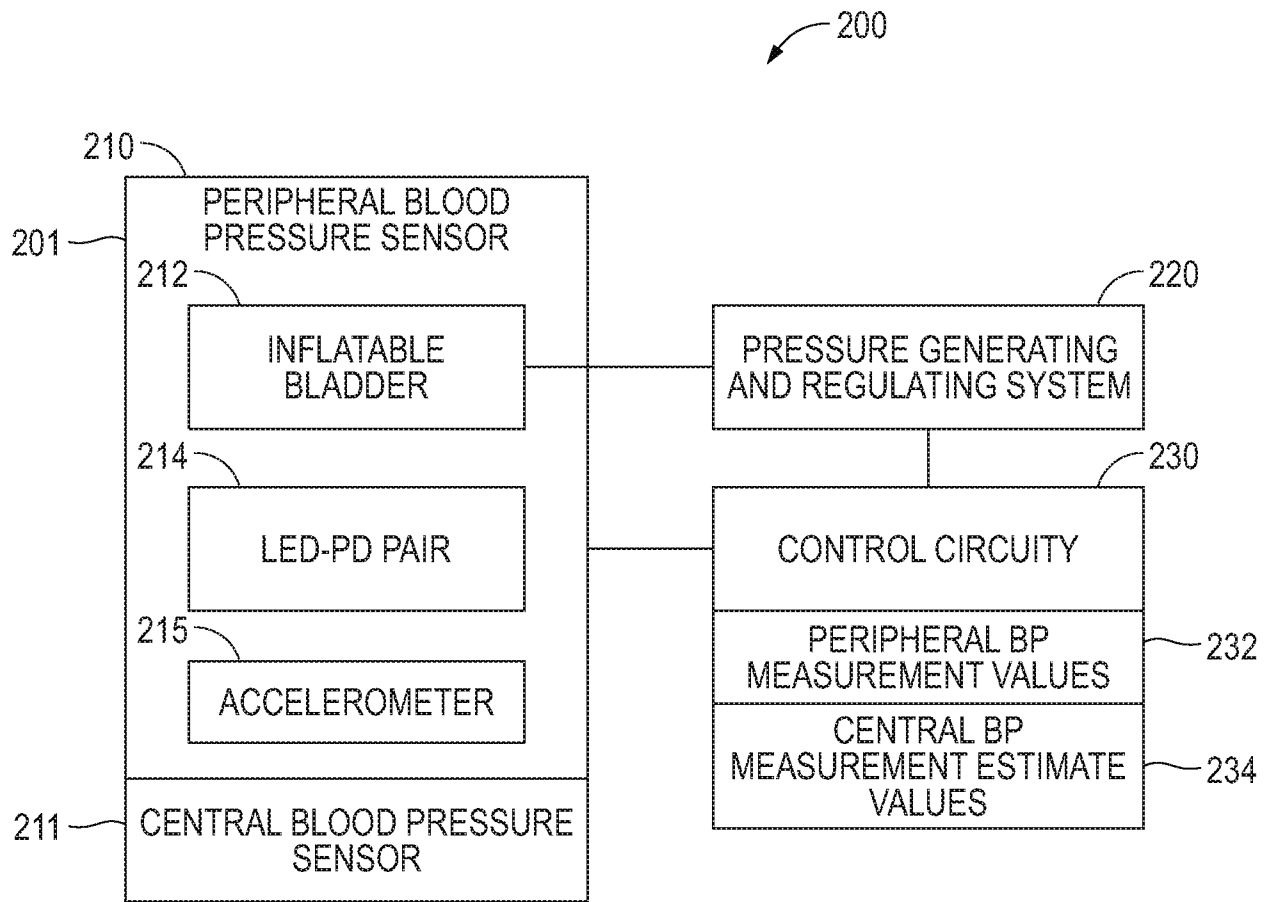


FIG. 2

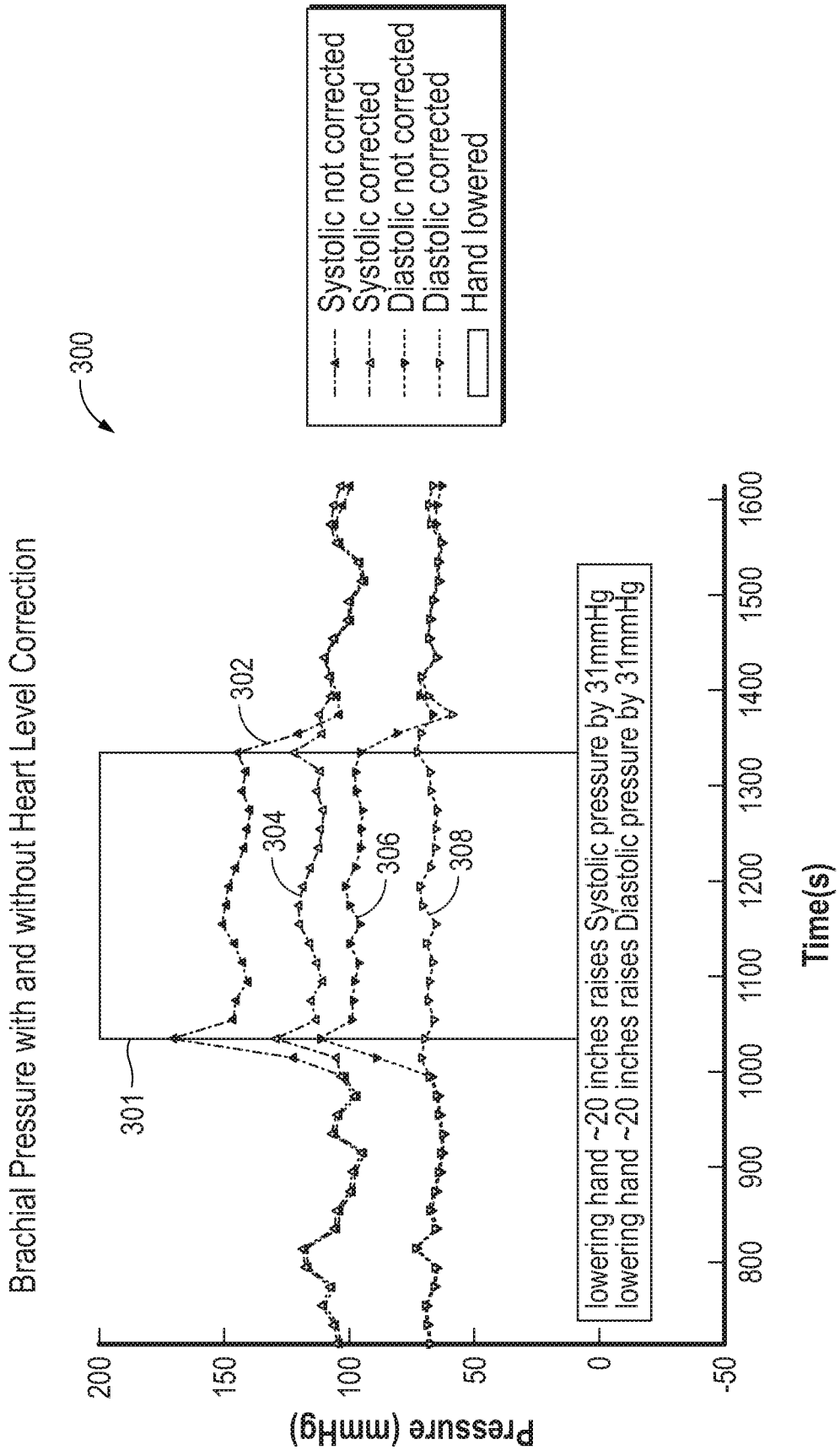


FIG. 3



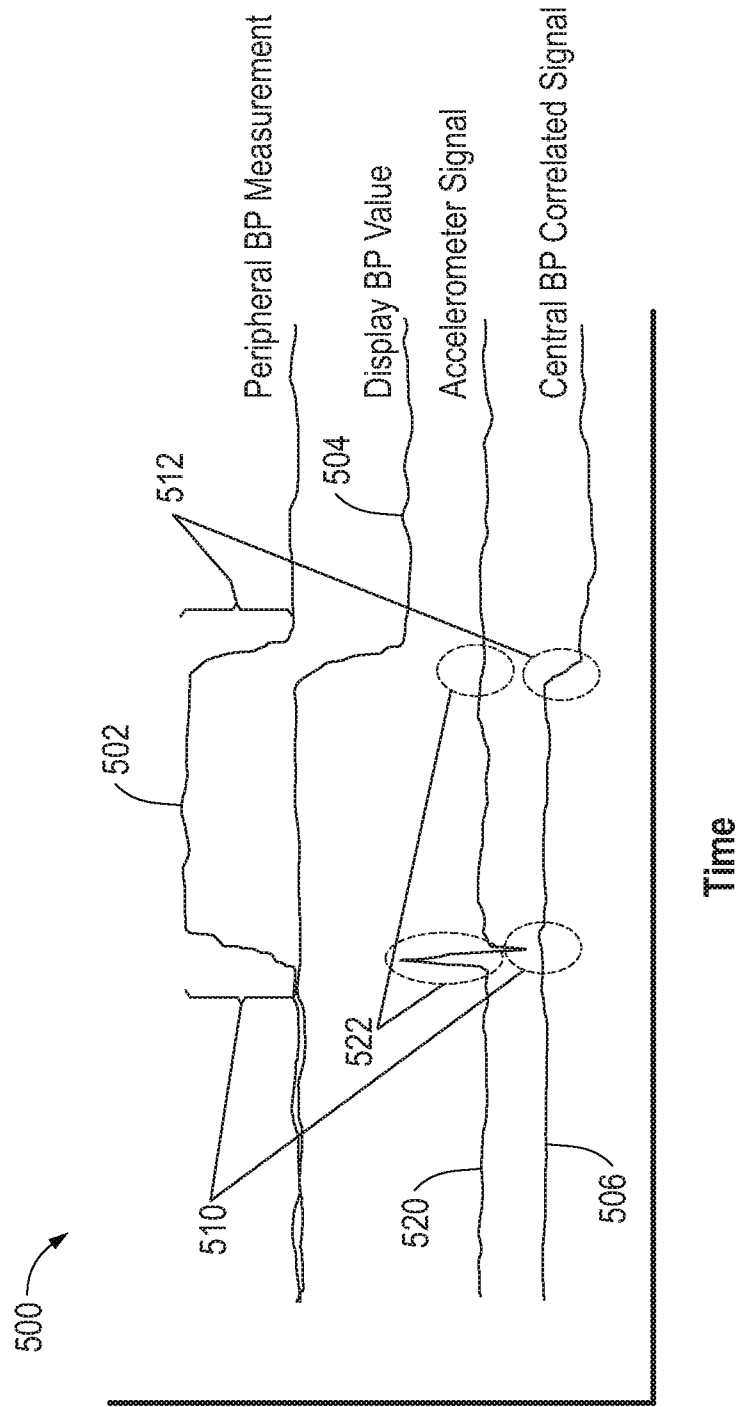


FIG. 5

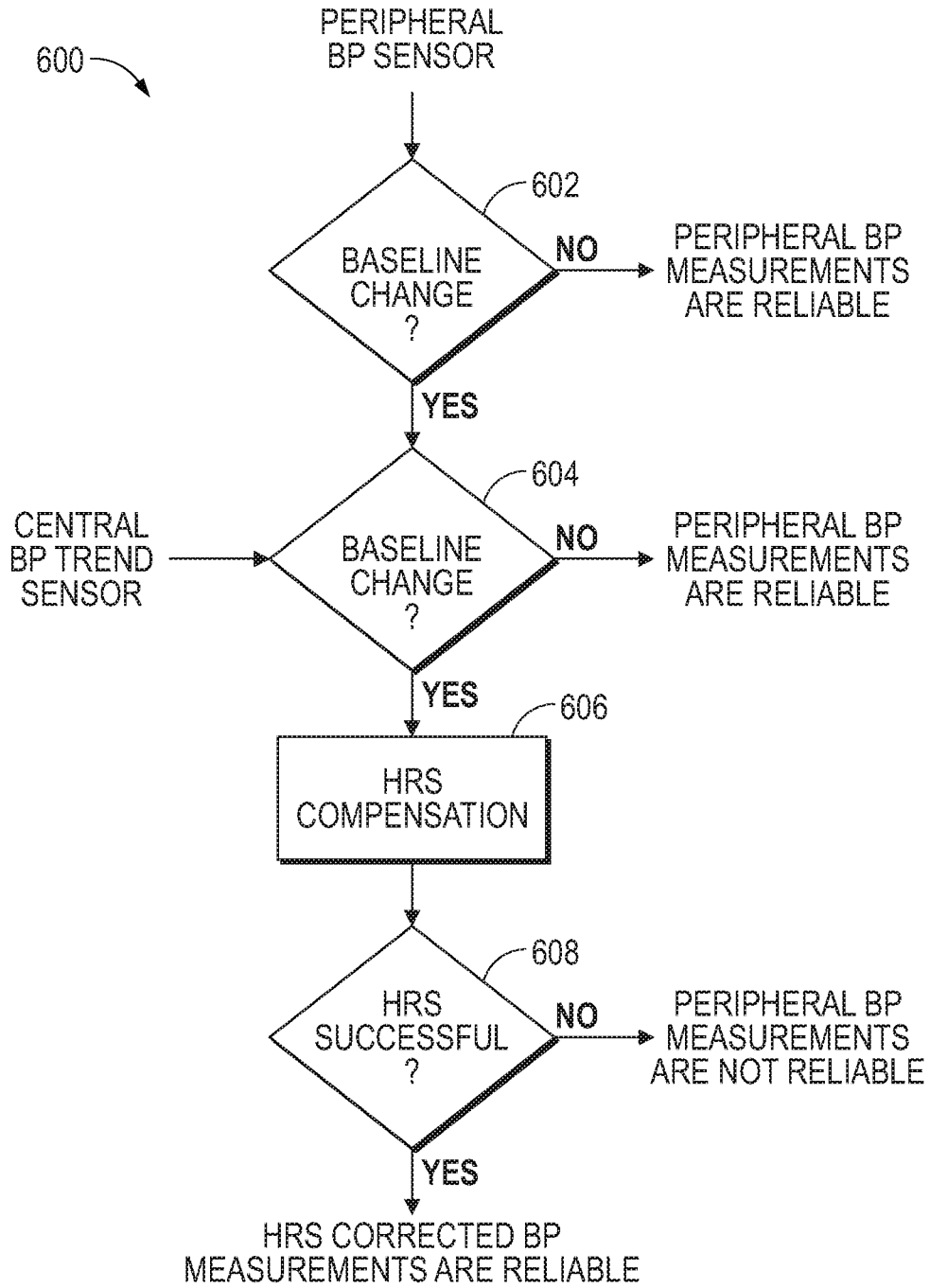
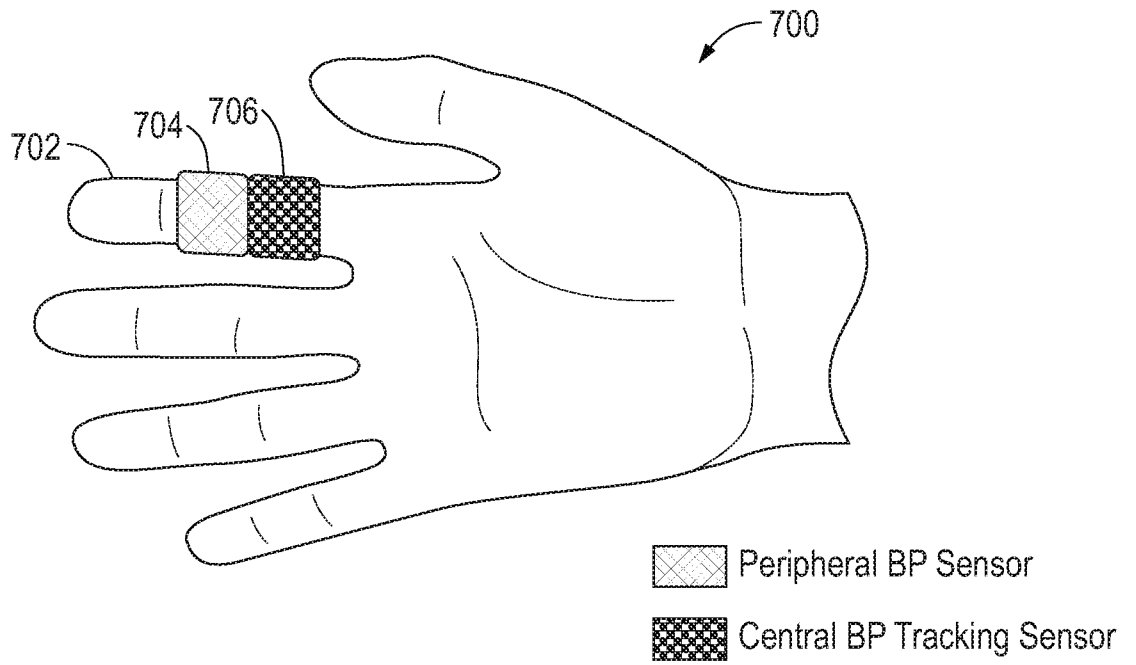
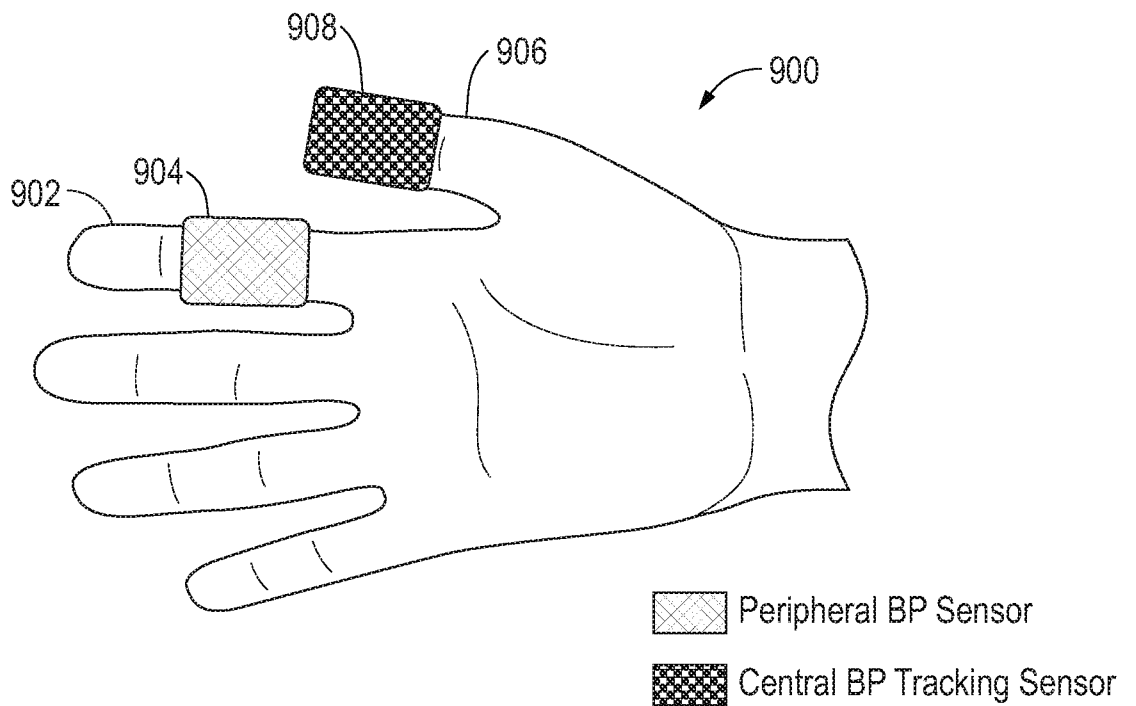


FIG. 6



**FIG. 7**



**FIG. 9**

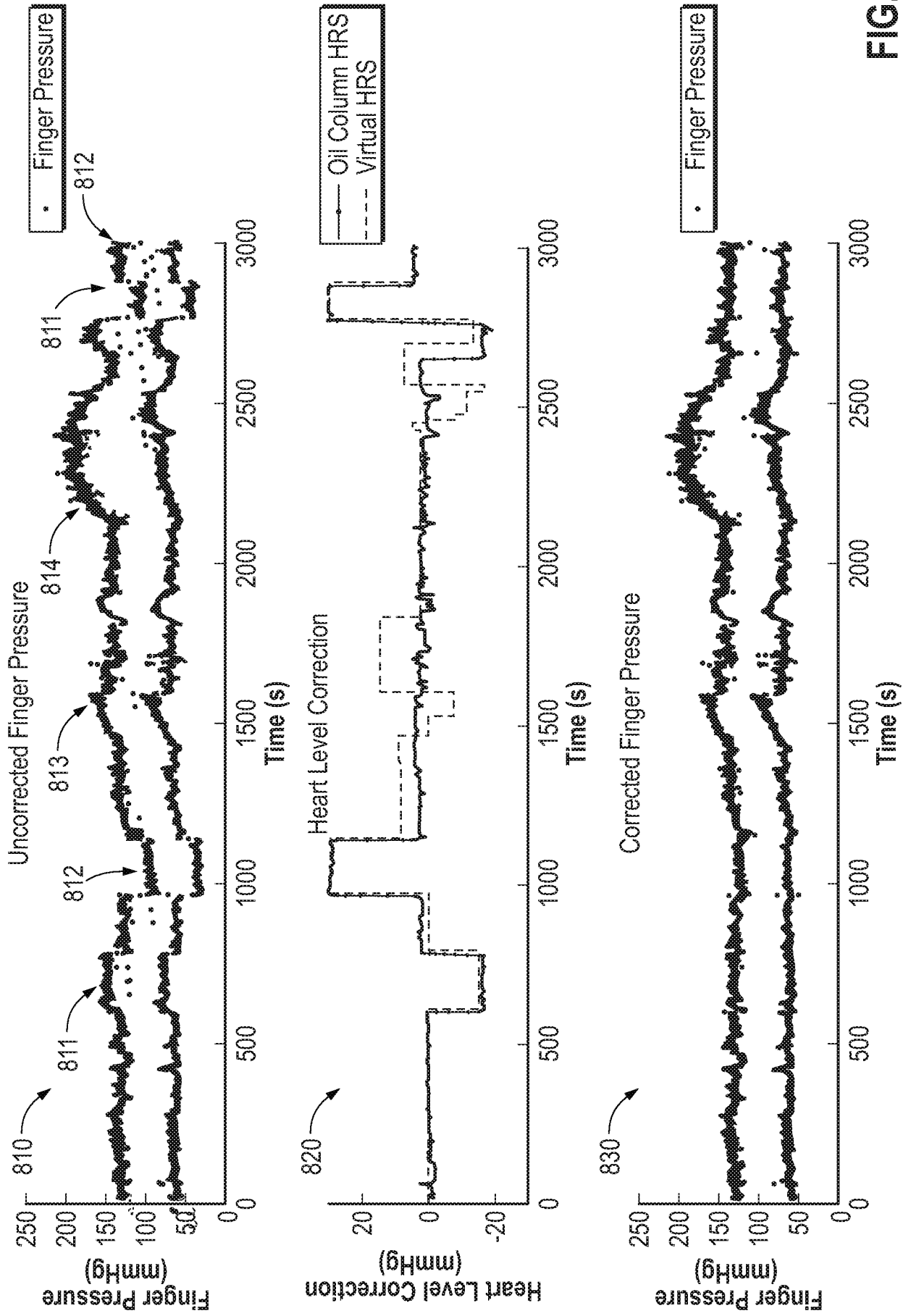


FIG. 8

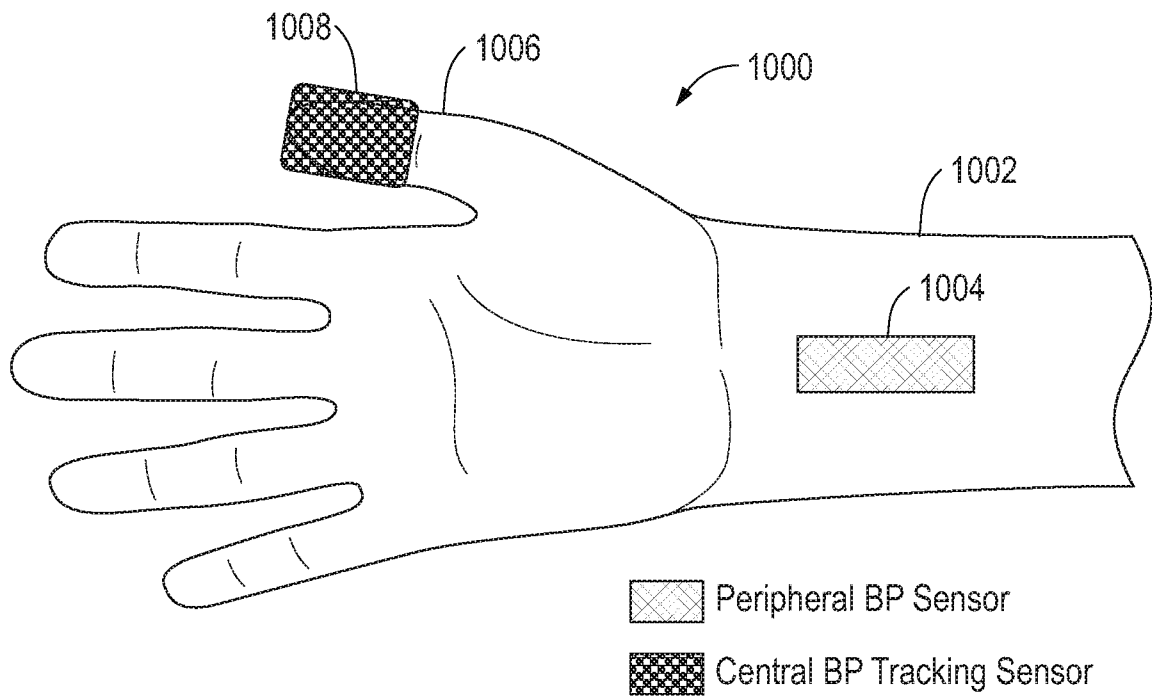


FIG. 10

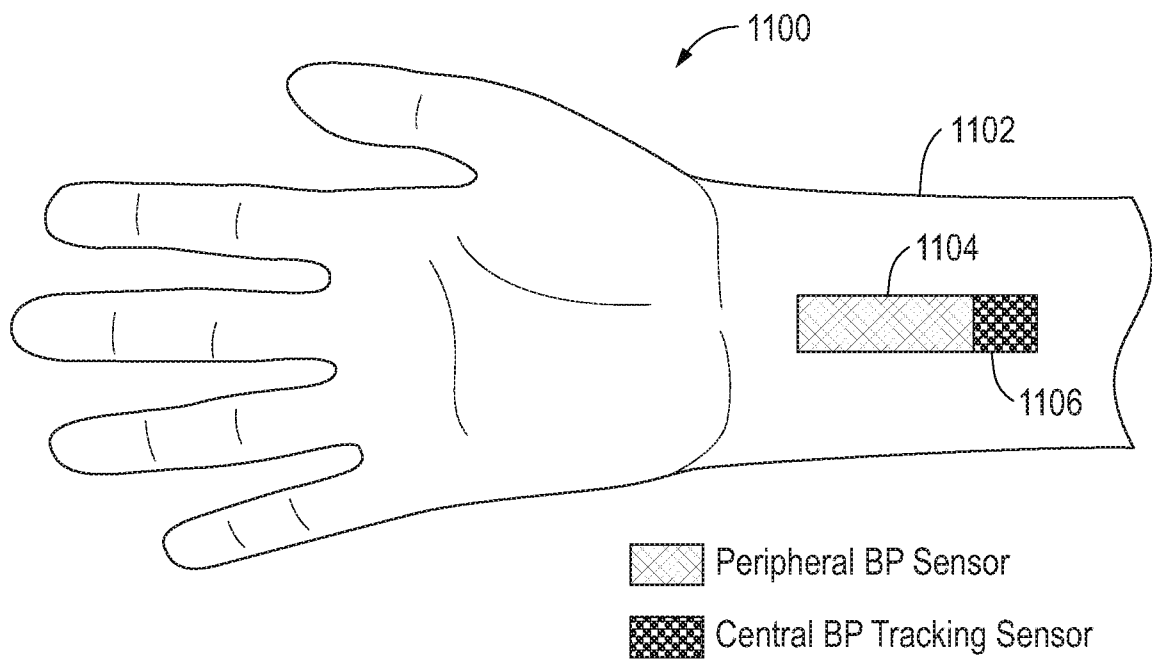


FIG. 11

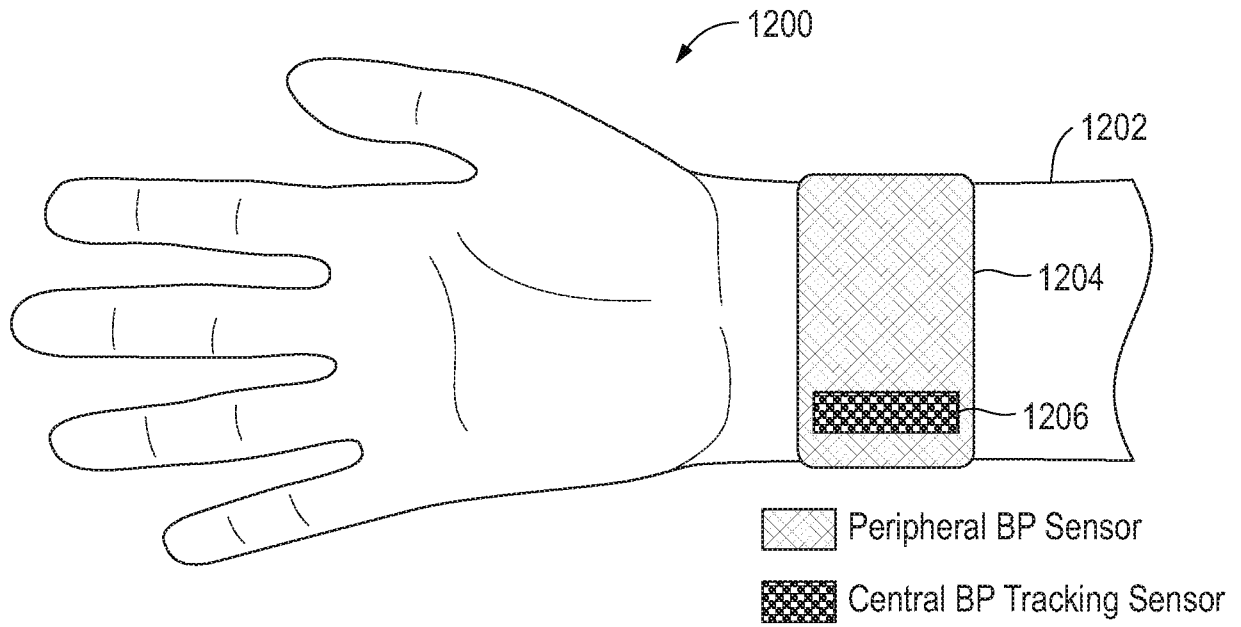


FIG. 12

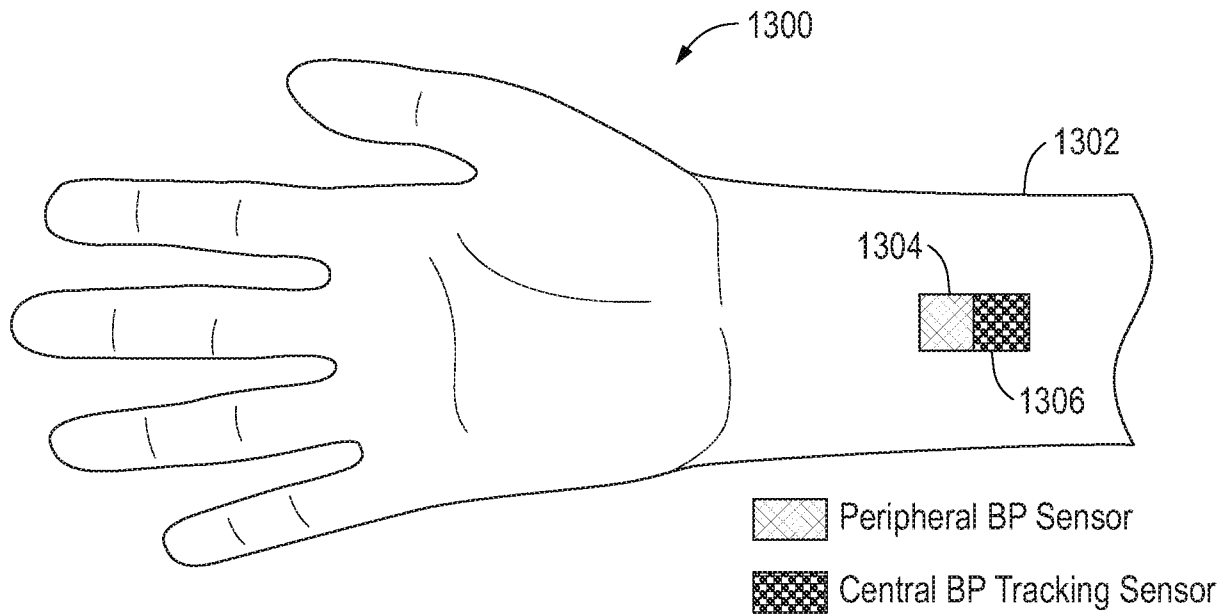


FIG. 13

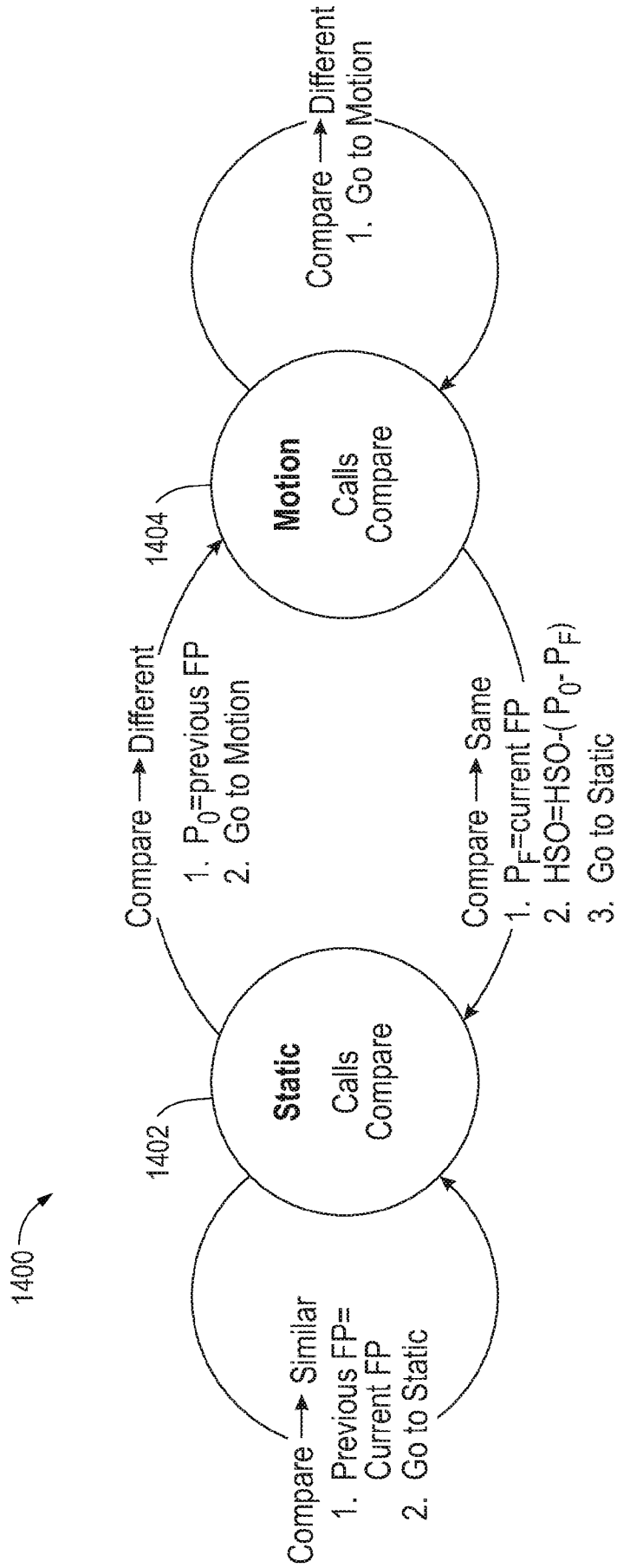


FIG. 14

# INTERNATIONAL SEARCH REPORT

International application No PCT/US2020/016711
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<b>A. CLASSIFICATION OF SUBJECT MATTER</b> INV. A61B5/024      A61B5/022      A61B5/00      A61B5/145      A61B5/1495 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols) A61B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2018/069261 A1 (KONINKLIJKE PHILIPS NV [NL]) 19 April 2018 (2018-04-19) figures 4, 5 page 16, paragraphs 3, last -----	1-28
X	ALBERTO P AVOLIO ET AL: "TOPICAL REVIEW; Arterial blood pressure measurement and pulse wave analysis-their role in enhancing cardiovascular assessment", PHYSIOLOGICAL MEASUREMENT, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, GB, vol. 31, no. 1, 1 January 2010 (2010-01-01), pages R1-R47, XP020169079, ISSN: 0967-3334 page 21, paragraph 5.3.3 -----	1,4-11, 14-21, 24-28
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input checked="" type="checkbox"/> See patent family annex.		
* Special categories of cited documents :		
"A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
Date of the actual completion of the international search	Date of mailing of the international search report	
21 April 2020	06/05/2020	
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer  Almeida, Mariana	

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No  
PCT/US2020/016711

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		EP 3522778 A1	14-08-2019
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		US 2019274558 A1	12-09-2019
		WO 2018069261 A1	19-04-2018
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