US 20200107989A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2020/0107989 A1**

Adedipe et al. (43) **Pub. Date: Apr. 9, 2020**

(54) **SYSTEM AND METHOD OF NONINVASIVE BLOOD FLOW MEASUREMENT DURING CARDIOPULMONARY RESUSCITATION USING SIGNAL GATING**

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(21) Appl. No.: **16/597,656**

(22) Filed: **Oct. 9, 2019**

Related U.S. Application Data

(60) Provisional application No. 62/743,435, filed on Oct. 9, 2018.

Publication Classification

(51) **Int. Cl.**

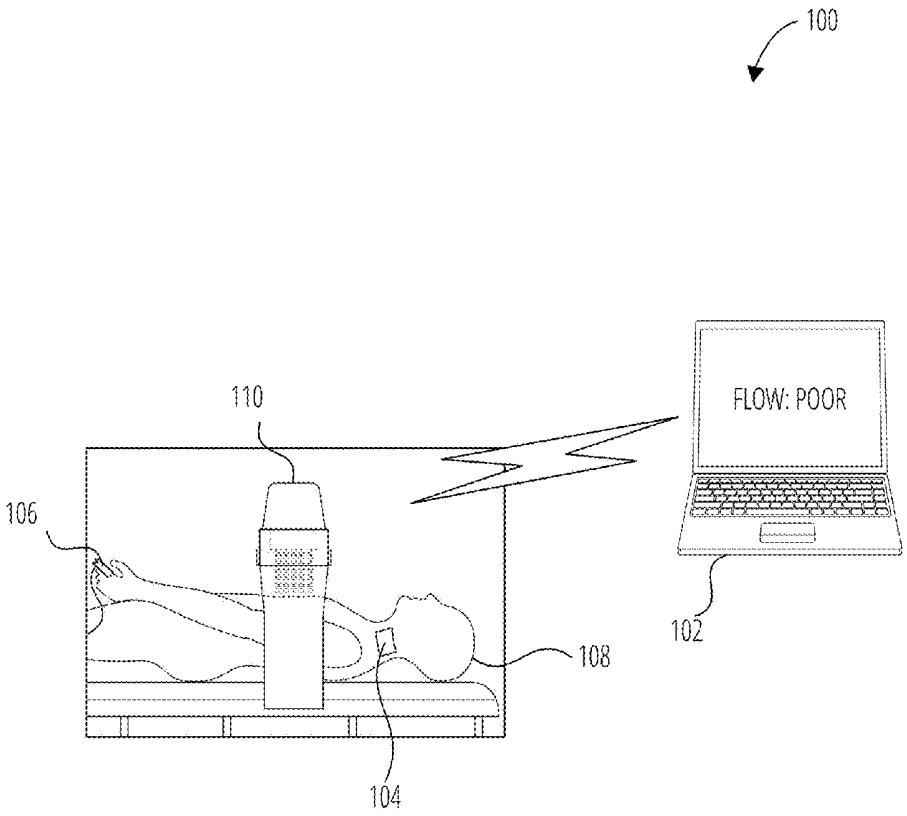
A61H 31/00	(2006.01)
A61B 8/08	(2006.01)
A61B 8/06	(2006.01)
A61B 8/00	(2006.01)
A61B 5/026	(2006.01)
A61B 5/08	(2006.01)
A61B 5/00	(2006.01)
A61B 5/0295	(2006.01)

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

CPC ***A61H 31/006*** (2013.01); ***A61B 8/5215*** (2013.01); ***A61B 8/06*** (2013.01); ***A61B 8/4272*** (2013.01); ***A61B 5/0261*** (2013.01); *A61H 2201/501* (2013.01); ***A61B 5/7271*** (2013.01); ***A61B 5/0295*** (2013.01); *A61H 2230/255* (2013.01); *A61H 2230/405* (2013.01); ***A61B 5/082*** (2013.01)

(57) **ABSTRACT**

In some embodiments, a blood flow sensor device such as a non-invasive cardiac arrest monitor (NICAM) that uses ultrasound to detect blood flow is used to monitor blood flow during cardiopulmonary resuscitation. One or more gating signal generation devices transmit gating signals to a blood flow monitoring computing device. The blood flow monitoring computing device uses the gating signals to determine time periods during which blood flow information generated by the blood flow sensor device is most likely to be accurate. The blood flow monitoring computing device measures blood flow during the time periods. In some embodiments, the blood flow monitoring computing device presents the measured blood flow to a user. In some embodiments, the blood flow monitoring computing device transmits a command to a chest compression device based on the measured blood flow.



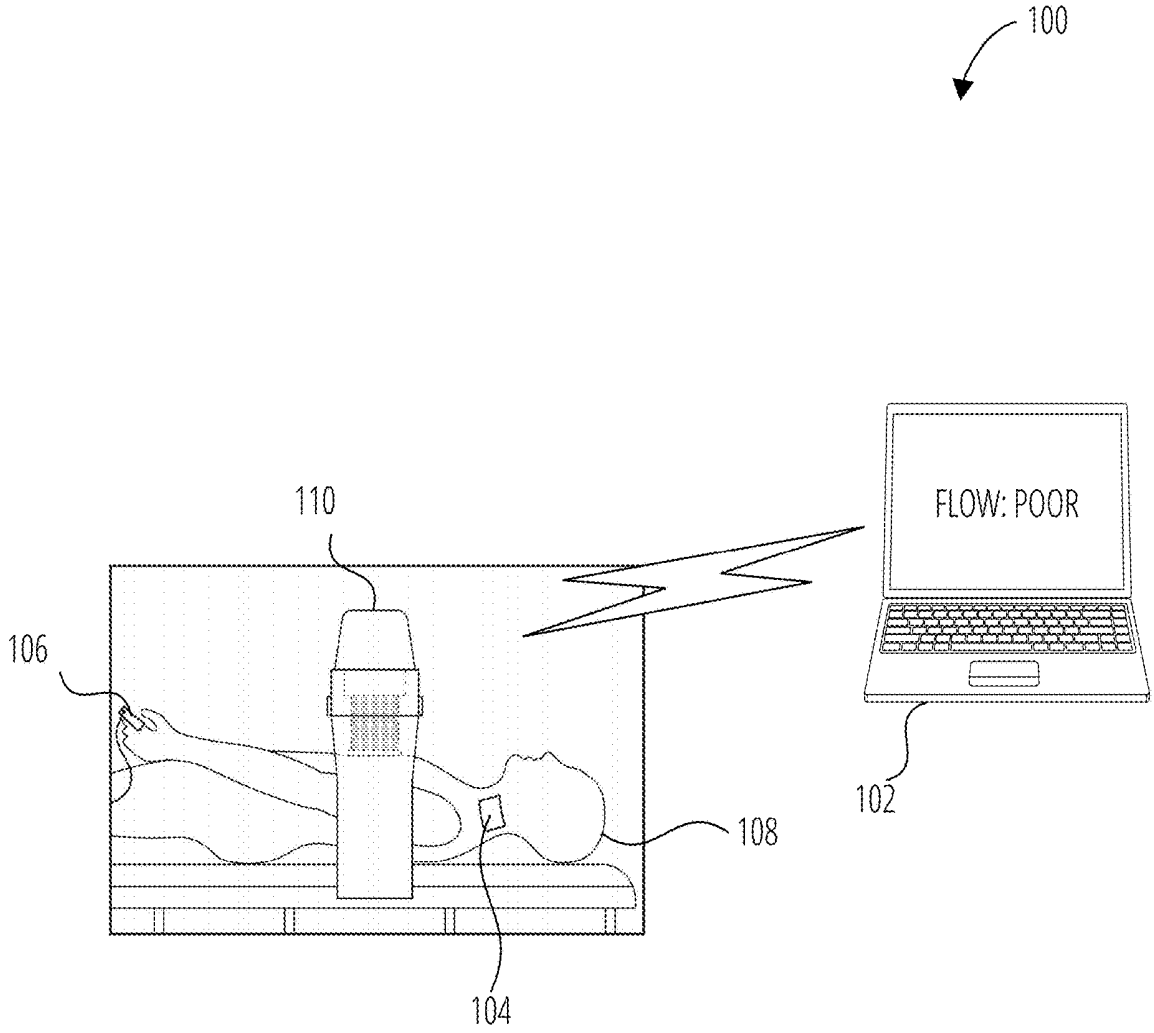


FIG. 1

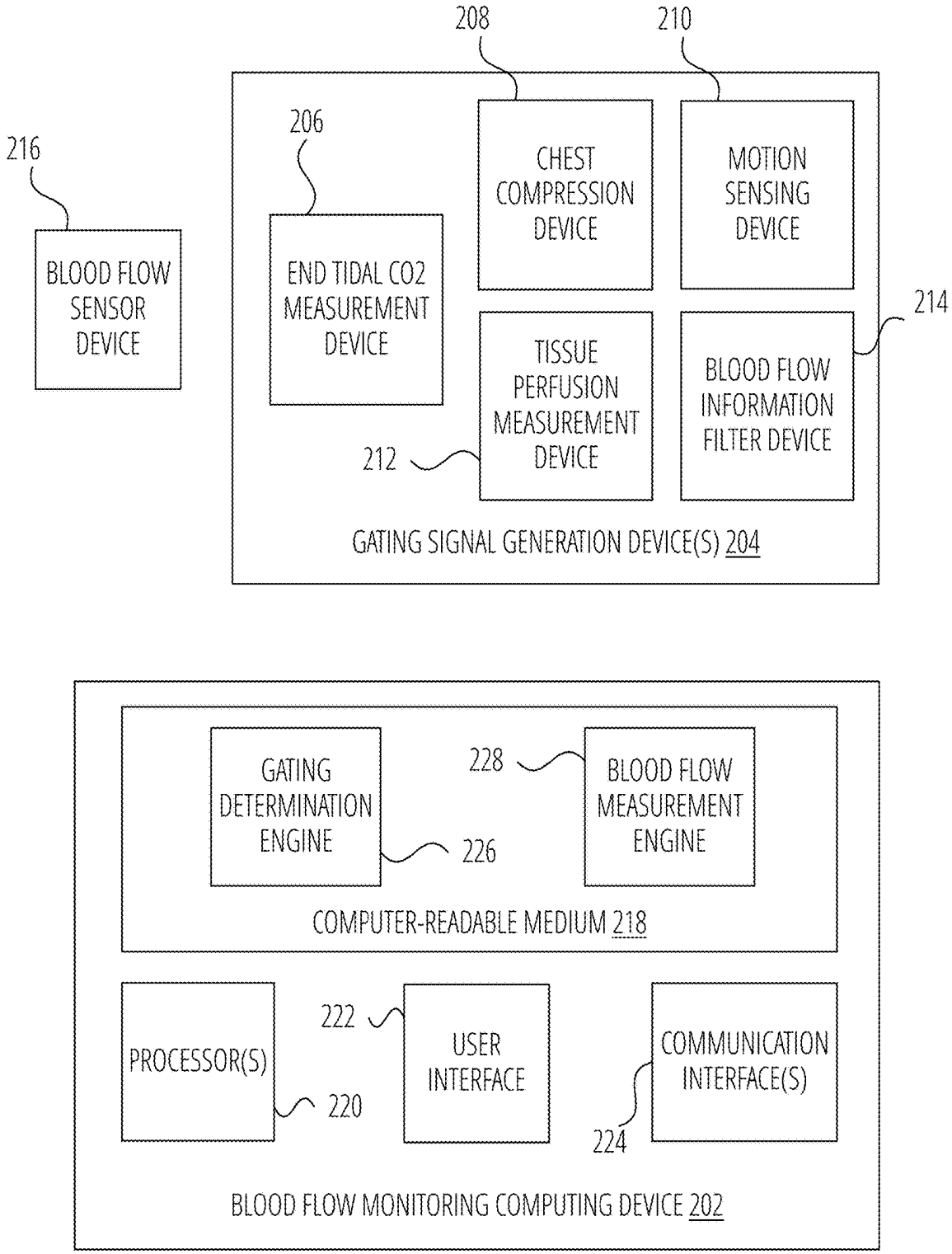

208
210
206
216
CHEST COMPRESSION DEVICE
MOTION SENSING DEVICE
BLOOD FLOW SENSOR DEVICE
END TIDAL CO2 MEASUREMENT DEVICE
214
TISSUE PERFUSION MEASUREMENT DEVICE
BLOOD FLOW INFORMATION FILTER DEVICE
212
GATING SIGNAL GENERATION DEVICE(S) 204
GATING DETERMINATION ENGINE
228
BLOOD FLOW MEASUREMENT ENGINE
226
COMPUTER-READABLE MEDIUM 218
222
PROCESSOR(S)
USER INTERFACE
COMMUNICATION INTERFACE(S)
220
224
BLOOD FLOW MONITORING COMPUTING DEVICE 202

FIG. 2

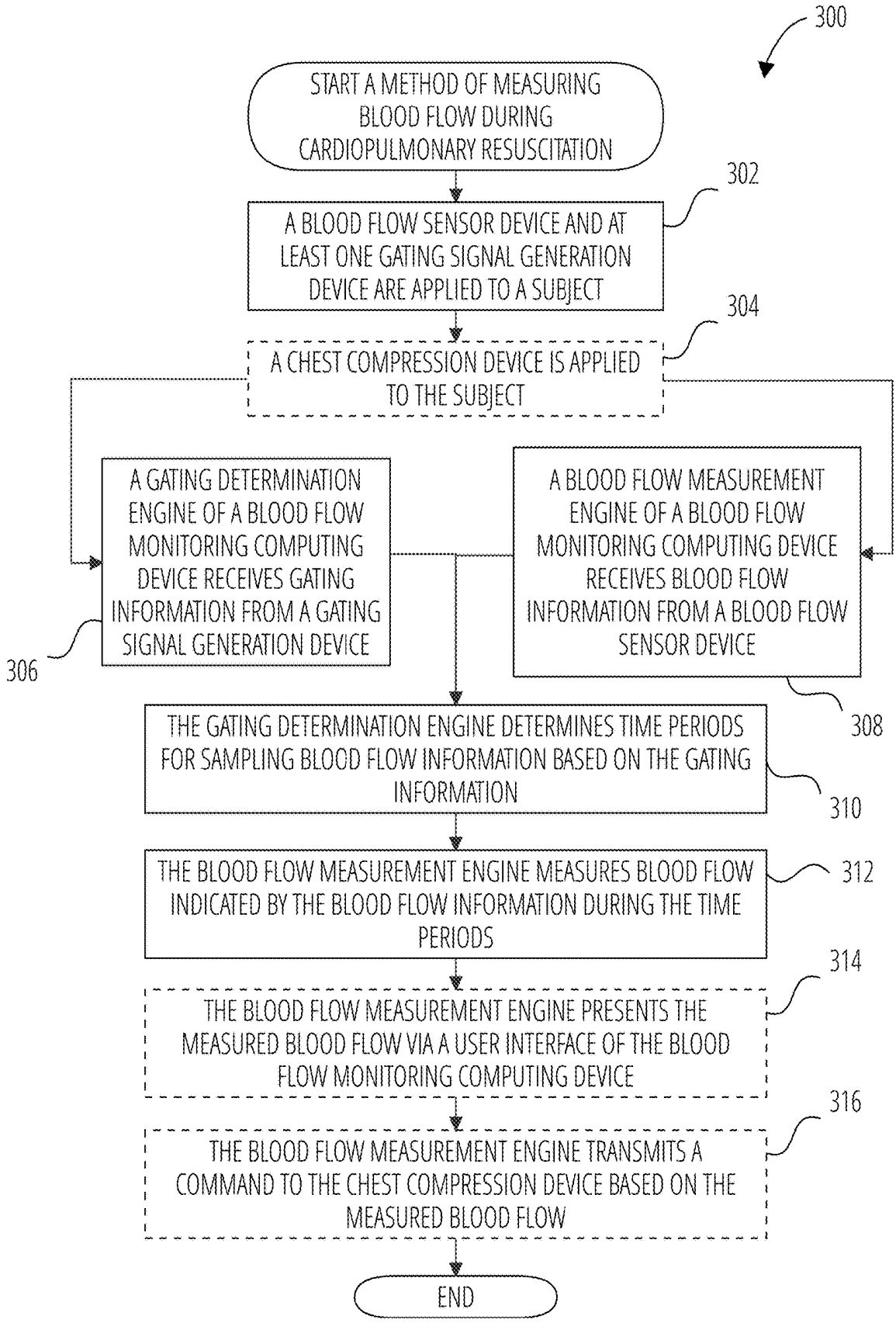

300
START A METHOD OF MEASURING BLOOD FLOW DURING CARDIOPULMONARY RESUSCITATION
302
A BLOOD FLOW SENSOR DEVICE AND AT LEAST ONE GATING SIGNAL GENERATION DEVICE ARE APPLIED TO A SUBJECT
304
A CHEST COMPRESSION DEVICE IS APPLIED TO THE SUBJECT
A GATING DETERMINATION ENGINE OF A BLOOD FLOW MONITORING COMPUTING DEVICE RECEIVES GATING INFORMATION FROM A GATING SIGNAL GENERATION DEVICE
306
A BLOOD FLOW MEASUREMENT ENGINE OF A BLOOD FLOW MONITORING COMPUTING DEVICE RECEIVES BLOOD FLOW INFORMATION FROM A BLOOD FLOW SENSOR DEVICE
308
THE GATING DETERMINATION ENGINE DETERMINES TIME PERIODS FOR SAMPLING BLOOD FLOW INFORMATION BASED ON THE GATING INFORMATION
310
THE BLOOD FLOW MEASUREMENT ENGINE MEASURES BLOOD FLOW INDICATED BY THE BLOOD FLOW INFORMATION DURING THE TIME PERIODS
312
314
THE BLOOD FLOW MEASUREMENT ENGINE PRESENTS THE MEASURED BLOOD FLOW VIA A USER INTERFACE OF THE BLOOD FLOW MONITORING COMPUTING DEVICE
316
THE BLOOD FLOW MEASUREMENT ENGINE TRANSMITS A COMMAND TO THE CHEST COMPRESSION DEVICE BASED ON THE MEASURED BLOOD FLOW
END

FIG. 3

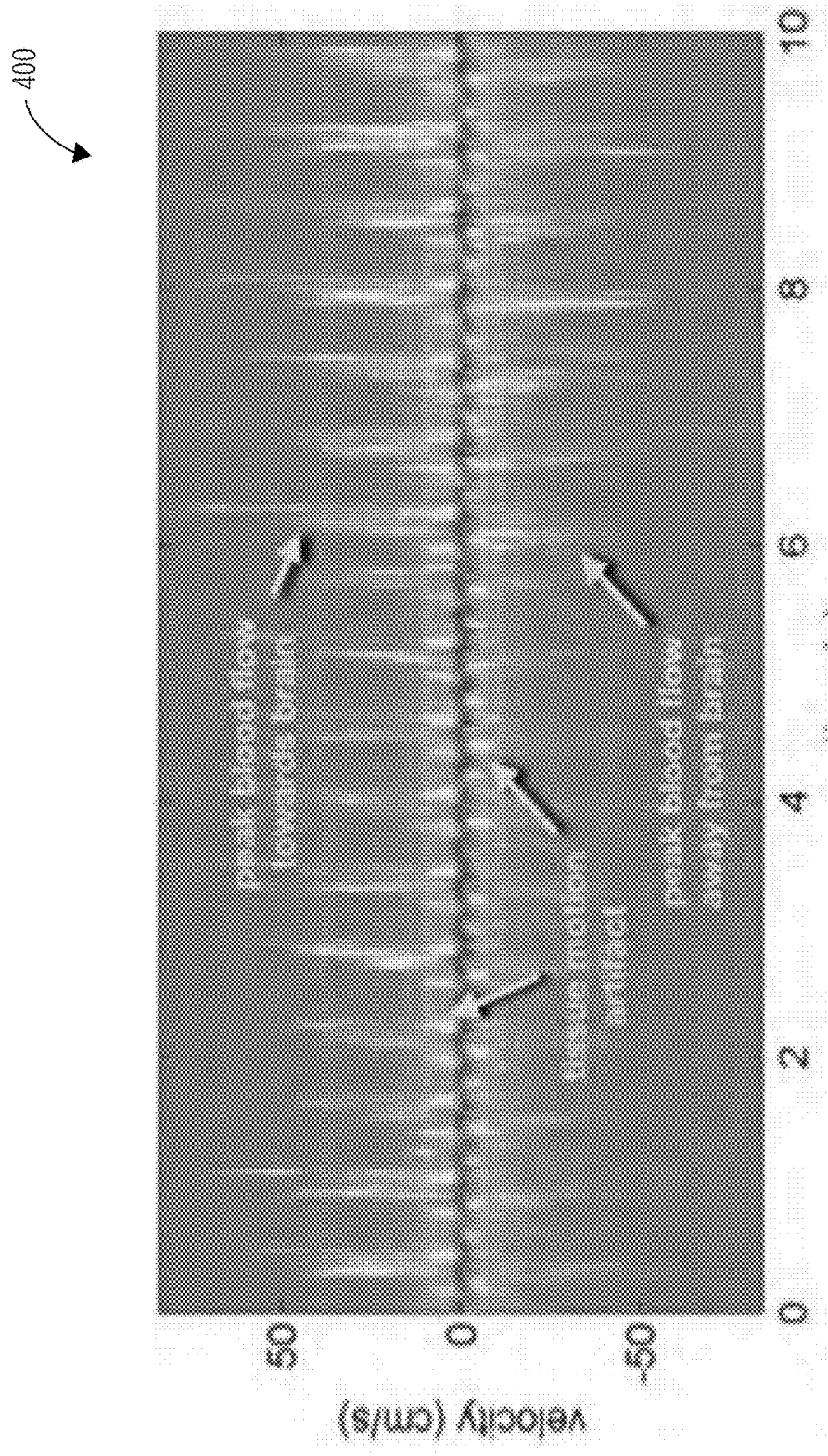

400
velocity (cm/s)
50
0
-50
0
2
4
6
8
10
time (s)
peak blood flow
peak blood flow
end diastolic flow
end diastolic flow

FIG. 4

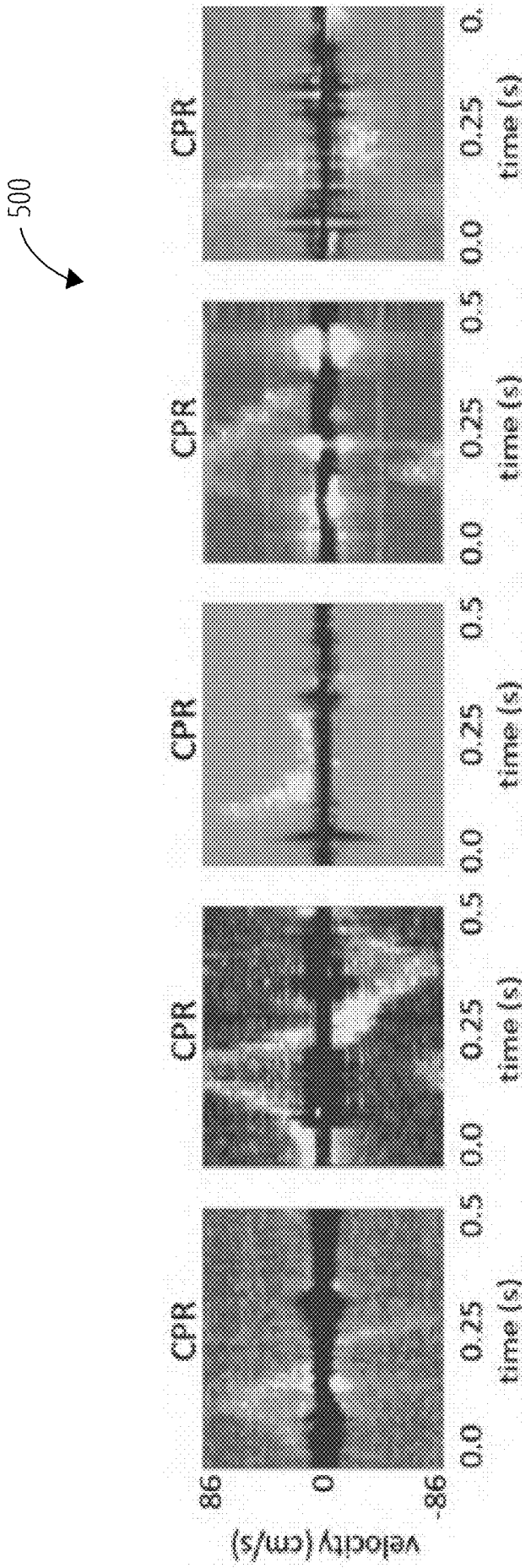


FIG. 5

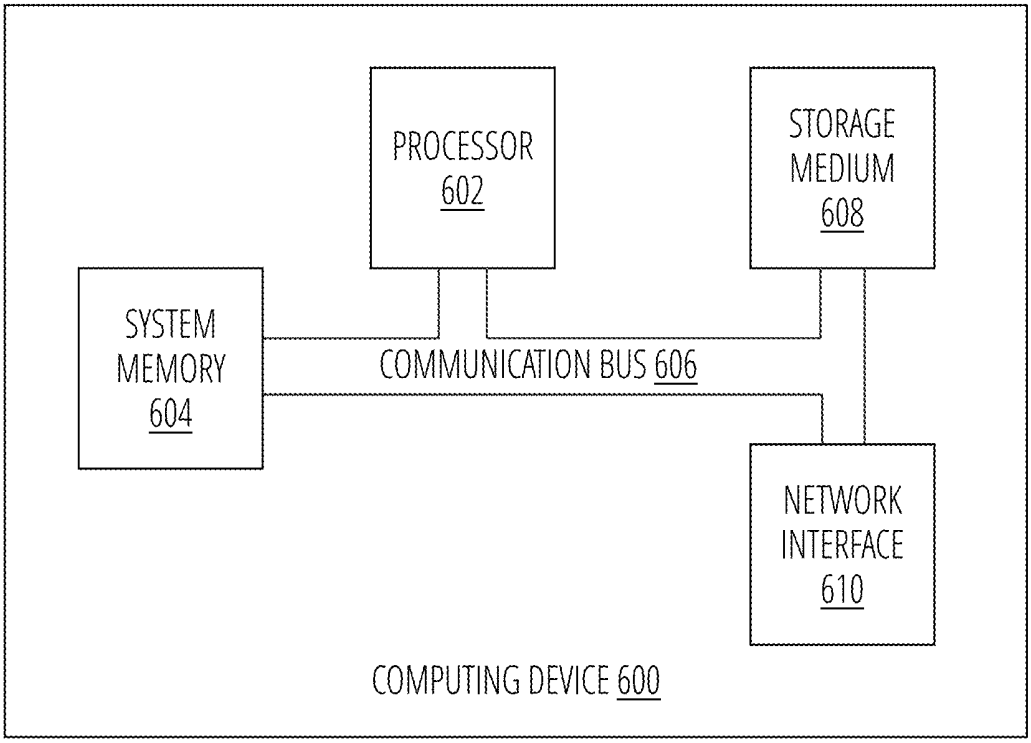

PROCESSOR
602
STORAGE
MEDIUM
608
SYSTEM
MEMORY
604
COMMUNICATION BUS 606
NETWORK
INTERFACE
610
COMPUTING DEVICE 600

FIG. 6

SYSTEM AND METHOD OF NONINVASIVE BLOOD FLOW MEASUREMENT DURING CARDIOPULMONARY RESUSCITATION USING SIGNAL GATING

CROSS-REFERENCE(S) TO RELATED APPLICATION(S)

[0001] This application claims the benefit of Provisional Application No. 62/743,435, filed Oct. 9, 2018, the entire disclosure of which is hereby incorporated by reference in its entirety for all purposes.

BACKGROUND

[0002] Time-sensitive emergency conditions including traumatic injury, myocardial infarction, and out-of-hospital cardiac arrest (OHCA) are collectively the leading cause of death in the United States. The five-fold variation in survival after OHCA between communities suggests that many patients can be successfully treated if the presence of cardiac arrest is identified early enough after its onset and subsequent treatment is optimized.

[0003] Rapid and accurate manual assessment of the presence or absence of blood flow during cardiac arrest has been used to determine the need for cardiopulmonary resuscitation (CPR) by attempting to palpate over a major artery (e.g. carotid or femoral) for the presence, absence, or quality of a pulse. Unfortunately, lay persons and emergency personnel experience difficulty assessing this accurately. As a consequence of these limitations of manual assessment, potentially lifesaving CPR may be withheld from those individuals not recognized to be in cardiac arrest.

[0004] Importantly, greater blood flow as measured by invasive monitors in major vessels during attempted resuscitation from cardiac arrest is associated with greater likelihood of survival in animals and humans. However, interruptions of CPR such as to apply or use monitoring techniques are associated with decreased survival. It is plausible that real-time feedback guided by monitors to improve processes of care during attempted resuscitation could improve survival. Importantly, experience to date with such feedback has been mixed in part because the measures of blood flow use are inexact.

[0005] Thus there is a large need for an accurate non-invasive blood flow monitoring device that can be rapidly applied to subjects not in cardiac arrest to identify the onset of arrest, or to someone who is unconscious or not responding to verify the presence or absence of cardiac arrest, or to someone who is known to be in cardiac arrest to guide the adequacy of attempted resuscitation as well as to assess prognosis.

SUMMARY

[0006] This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This summary is not intended to identify key features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0007] In some embodiments, a system for measuring blood flow during cardiopulmonary resuscitation of a subject is provided. The system comprises a blood flow sensor device, a gating signal generation device, and a blood flow monitoring computing device. The blood flow monitoring computing device includes at least one processor and a non-transitory computer-readable medium having computer-executable instructions stored thereon that, in response to execution by the at least one processor, cause the blood flow monitoring computing device to perform actions. The actions comprise receiving blood flow information from the blood flow sensor device; receiving gating information from the gating signal generation device; determining time periods for sampling the blood flow information based on the gating information; and measuring blood flow indicated by the blood flow information during the time periods.

[0008] In some embodiments, a computer-implemented method of measuring blood flow during cardiopulmonary resuscitation of a subject is provided. A computing device receives blood flow information from a blood flow sensor device. The computing device receives gating information from a gating signal generation device. The computing device determines time periods for sampling the blood flow information based on the gating information. The computing device measures blood flow indicated by the blood flow information during the time periods.

DESCRIPTION OF THE DRAWINGS

[0009] The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated as the same become better understood by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

[0010] FIG. **1** is a schematic diagram that illustrates a non-limiting example embodiment of a system for monitoring blood flow during cardiopulmonary resuscitation according to various aspects of the present disclosure.

[0011] FIG. **2** is a block diagram that illustrates non-limiting example embodiments of a blood flow sensor device, a set of potential gating signal generation devices, and a blood flow monitoring computing device according to various aspects of the present disclosure.

[0012] FIG. **3** is a flowchart that illustrates a non-limiting example embodiment of a method of measuring blood flow during cardiopulmonary resuscitation according to various aspects of the present disclosure.

[0013] FIG. **4** is a chart that illustrates a non-limiting example embodiment of blood flow information generated by a blood flow sensor device according to various aspects of the present disclosure.

[0014] FIG. **5** includes charts that illustrate other non-limiting example embodiments of blood flow information generated by a blood flow sensor device according to various aspects of the present disclosure.

[0015] FIG. **6** is a block diagram that illustrates a non-limiting example embodiment of a computing device appropriate for use as a computing device with embodiments of the present disclosure.

DETAILED DESCRIPTION

[0016] Recently ultrasound was used to measure the velocity of carotid blood flow in animals and humans that were in cardiac arrest. Carotid blood flow correlates with end-tidal CO2, coronary perfusion pressure and initial response to treatment. An advantage of measuring carotid blood flow using ultrasound is that is can be readily applied to a patient without interfering with the resuscitation field (i.e. chest). A disadvantage of early approaches to carotid

ultrasound during resuscitation is that they require manual localization of the artery on the neck, which can delay visualization of flow or disrupt treatment.

[0017] We previously proposed a non-invasive cardiac arrest monitor (NICAM), which uses imaging or non-imaging ultrasound to measure blood flow during CPR. NICAM was described in PCT Publication No. WO2014066859A1, the entire disclosure of which is hereby incorporated by reference herein for all purposes. Our approach provides blood flow measurement via a form factor that addresses the problems with use of standard ultrasound systems. The NICAM ultrasound probe is integrated with a flexible adhesive pad with preprinted anatomic cues to enable attaching and maintaining the sensor on the skin over a major artery. NICAM measures blood flow velocity and other properties of blood flow during chest compressions and interprets the height and width of the velocity signal to guide and improve the quality of chest compressions.

[0018] Animal experiments have revealed that the performance of NICAM is inhibited by motion artifacts associated with CPR. Embodiments of the present disclosure improve the accuracy of NICAM blood flow measurements around compression artifacts. By gating the blood velocity measurements of NICAM simultaneously to another physiologic signal, blood flow measurements are improved. We also present another blood flow signal obtained via near-infrared spectroscopy (NIRS), which provides information about tissue perfusion, to measure the adequacy of blood flow during CPR.

[0019] FIG. **1** is a schematic illustration of a system **100** for monitoring blood flow during cardiopulmonary resuscitation (CPR) according to various aspects of the present disclosure. As shown, a subject **108** is experiencing a cardiac incident for which CPR is appropriate. As shown, an automatic chest compression device **110** has been coupled to the subject **108**. The chest compression device **110** is configured to automatically apply forceful compressions to the chest of the subject **108** in order to circulate blood to the brain and other organs in the absence of effective cardiac activity. Though a chest compression device **110** is illustrated in FIG. **1**, in some embodiments, the technology described herein may be used alongside manual CPR administration.

[0020] In addition to the chest compression device **110**, a NICAM sensor device **104** has also been attached to the subject **108**. As illustrated, the NICAM sensor device **104** includes an ultrasound probe that is configured to measure blood flow within the carotid artery, and has been affixed via an adhesive patch to the neck of the subject **108**. In some embodiments, the NICAM sensor device **104** may be configured to measure blood flow within a different blood vessel, including but not limited to a femoral artery. In some embodiments, the adhesive patch of the NICAM sensor device **104** may include markings to help guide accurate placement of the NICAM sensor device **104** in an emergency situation.

[0021] As shown, an NIRS sensor device **106** has also been attached to the subject **108**. The NIRS sensor device **106** includes an infrared sensor that measures tissue perfusion at a peripheral location, such as a finger. The NIRS sensor device **106** is an example of a gating signal generation device, as will be described further below.

[0022] During operation, the NICAM sensor device **104** and NIRS sensor device **106** transmit information to a blood flow monitoring computing device **102**. In some embodiments, the NICAM sensor device **104** and/or NIRS sensor device **106** are communicatively coupled to the blood flow monitoring computing device **102** via any type of communication technology, including but not limited to a wireless network (including but not limited to an Ethernet network, a USB network, and/or a FireWire network) and/or a wireless network (including but not limited to a 2G, 3G, 4G, 5G, LTE, Wi-Fi, WiMAX, and/or Bluetooth network). The blood flow monitoring computing device **102** receives the information, and uses the blood flow information received from the NICAM sensor device **104** along with gating information received from the NIRS sensor device **106** to determine accurate blood flow measurements for the subject **108**. By using the gating information, the blood flow monitoring computing device **102** can compensate for motion artifacts and thereby provide accurate information to be used to help improve the administration of CPR in order to improve patient outcomes.

[0023] FIG. **2** is a block diagram that illustrates non-limiting example embodiments of a blood flow sensor device, a set of gating signal generation devices, and a blood flow monitoring computing device according to various aspects of the present disclosure. In some embodiments, the blood flow sensor device **216** and at least one gating signal generation device **204** transmit information to the blood flow monitoring computing device **202** via any suitable networking technology. The blood flow monitoring computing device **202** uses the information from the gating signal generation device **204** to determine time periods during which the information from the blood flow sensor device **216** is most likely to accurately represent the blood flow of the subject **108**. The blood flow monitoring computing device **202** then analyzes the information from the blood flow sensor device **216** during those time periods to measure the blood flow.

[0024] Though FIG. **2** illustrates the blood flow sensor device **216**, the gating signal generation device **204**, and the blood flow monitoring computing device **202** as separate devices, in some embodiments, two or more of these devices may be combined into a single device. For example, the components and functionality of the blood flow monitoring computing device **202** and the blood flow sensor device **216** may be combined into a single device.

[0025] In some embodiments, the blood flow sensor device **216** includes an ultrasound probe that, when aimed toward a blood vessel from a position on the skin over the blood vessel, can detect the motion of blood within the blood vessel. The detected motion can be translated into a flow rate, a flow direction, or other values. In some embodiments, the ultrasound probe is positioned on the subject **108** using an adhesive pad. In some embodiments, the adhesive pad may include markings that help correctly position the ultrasound probe with respect to the blood vessel. One non-limiting example of such a marking is an indicator of an expected location of an anatomical landmark. In some embodiments, the blood flow sensor device **216** is provided by the NICAM sensor device described in the international patent publication incorporated by reference above. In other embodiments, any other suitable device may be used as the blood flow sensor device **216**.

[0026] Several examples of gating signal generation devices **204** are shown. The illustrated examples are an end tidal CO2 measurement device **206**, a chest compression device **208**, a motion sensing device **210**, a tissue perfusion

measurement device **212**, and a blood flow information filter device **214**. FIG. **2** illustrates multiple gating signal generation devices **204** to show multiple different types of gating signal generation device **204**, though in some embodiments, only a single type of gating signal generation device **204** may be present in a given embodiment.

[0027] In some embodiments, the end tidal CO2 measurement device **206** is any suitable device for measuring an end-tidal CO2 (ETCO2) value, including but not limited to a capnometric or capnographic device that is configured to detect CO2 concentrations within the airway of the subject **108**. The end tidal CO2 measurement device **206** may be configured to transmit ETCO2 values to the blood flow monitoring computing device **202** for use as a gating signal.

[0028] In some embodiments, the chest compression device **208** is an automatic device that is configured to generate cardiopulmonary resuscitation chest compressions while mounted to the subject **108**. One non-limiting example of a chest compression device **208** is a LUCAS® chest compression system manufactured by Jolife A B. While the chest compression device **208** may be part of the system **100** as a whole, in some embodiments, the chest compression device **208** may also serve as a gating signal generation device **204** by transmitting compression timing information to the blood flow monitoring computing device **202** for use as a gating signal.

[0029] In some embodiments, the motion sensing device **210** is any suitable device for measuring motion, including but not limited to an accelerometer, a gyroscope, an electronic compass, and/or combinations thereof. In some embodiments, the motion sensing device **210** is configured to be placed on the subject **108** in order to detect motion of the subject **108**, and to provide the detected motion to the blood flow monitoring computing device **202** as a gating signal.

[0030] In some embodiments, the tissue perfusion measurement device **212** is any suitable device for measuring a volume of blood in tissue. In some embodiments, a photoplethysmograph device that uses a near infrared spectroscope, such as a finger plethysmograph, may be used as a tissue perfusion measurement device **212**. In some embodiments, the tissue perfusion measurement device **212** may measure other values, including but not limited to an oxygen saturation and/or a pulse. In some embodiments, the tissue perfusion measurement device **212** is configured to provide the information that it collects to the blood flow monitoring computing device **202** for use as a gating signal.

[0031] In some embodiments, the blood flow information filter device **214** is a computing device that receives blood flow information from the blood flow sensor device **216**. The blood flow information filter device **214** may be configured to process the blood flow information, including but not limited to applying a band-pass filter to signals produced by the blood flow sensor device **216**. Signals determined through use of the band-pass filter may be usable to detect the occurrence of chest compressions. Accordingly, the blood flow information filter device **214** may provide the signals to the blood flow monitoring computing device **202** for use as a gating signal.

[0032] The gating signal generation devices **204** illustrated in FIG. **2** are examples only, and in some embodiments, different devices may be used. For example, in some embodiments, a transthoracic impedance sensor may be used as a gating signal generation device **204**, and transthoracic impedance signals may be used as a gating signal.

[0033] In some embodiments, the blood flow monitoring computing device **202** is a laptop computing device, a desktop computing device, a tablet computing device, a mobile computing device, a computing device integrated into a monitor/defibrillator, or any other suitable type of computing device. The blood flow monitoring computing device **202** receives signals from the blood flow sensor device **216** and at least one gating signal generation device **204**, and may present measured blood flow information to a user. In some embodiments, the blood flow monitoring computing device **202** may also transmit commands to other devices, such as the chest compression device **208**, in response to the measured blood flow information.

[0034] As shown, the blood flow monitoring computing device **202** includes a processor **220**, a user interface **222**, one or more communication interface(s) **224**, and a computer-readable medium **218**. In some embodiments, the processor **220** may be any suitable type of computing processor that is configured to process computer-executable instructions or other logic stored on the computer-readable medium **218**. In some embodiments, the computer-readable medium "Computer-readable medium" refers to a removable or nonremovable device that implements any technology capable of storing information in a volatile or non-volatile manner to be read by a processor of a computing device, including but not limited to: a hard drive; a flash memory; a solid state drive; random-access memory (RAM); read-only memory (ROM); a CD-ROM, a DVD, or other disk storage; a magnetic cassette; a magnetic tape; and a magnetic disk storage.

[0035] In some embodiments, the user interface **222** may include a display device configured to present one or more user interface elements. The user interface elements may show components of the measured blood flow information to a user. In some embodiments, the display device may be a flat-screen display, a touch-screen display, or any other suitable type of multi-purpose display device. In some embodiments, the display device may be a multiple-segment display for the sake of simplicity. In some embodiments, the at least one communication interface **224** may include one or more wired communication interfaces (including but not limited to an Ethernet interface, a USB interface, or a FireWire interface) and/or one or more wireless communication interfaces (including but not limited to 2G, 3G, 4G, 5G, LTE, Wi-Fi, WiMAX, or Bluetooth interfaces).

[0036] As shown, the computer-readable medium **218** includes a gating determination engine **226** and a blood flow measurement engine **228**. In some embodiments, the gating determination engine **226** is configured to receive gating information from at least one gating signal generation device **204**, and to use the gating information to determine time periods during which the blood flow information should be sampled. In some embodiments, the blood flow measurement engine **228** analyzes the blood flow information during the time periods in order to determine the measured blood flow. Further details of the actions taken by these components are described below.

[0037] FIG. **3** is a flowchart that illustrates a non-limiting example embodiment of a method of measuring blood flow during cardiopulmonary resuscitation according to various aspects of the present disclosure.

[0038] From a start block, the method **300** proceeds to block **302**, where a blood flow sensor device **216** and at least one gating signal generation device **204** are applied to a subject **108**. In some embodiments, applying the blood flow sensor device **216** may involve positioning an adhesive pad that is associated with an ultrasound probe in an appropriate location, such as over a carotid or femoral artery. Application of the gating signal generation device **204** will depend on the type of gating signal generation device **204** used. As some non-limiting examples, a motion sensing device **210** may include an adhesive pad, clip, elastic band, or other means for attaching the motion sensing device **210** to the subject **108**. An end tidal CO2 measurement device **206** may be inserted into an airflow device such as a tracheal tube. A tissue perfusion measurement device **212** may include a clip or strap that allows the device to be coupled to the subject **108**. A blood flow information filter device **214** may be communicatively coupled to the blood flow sensor device **216** to receive information therefrom for deriving gating information.

[0039] At optional block **304**, a chest compression device **208** is applied to a subject **108**. In some embodiments, applying the chest compression device **208** to the subject **108** may involve positioning the chest compression device **208** around the chest of the subject **108**, and may involve positioning the arms of the subject **108** with respect to the chest compression device **208**. Block **304** is illustrated as optional because, in some embodiments, manual chest compressions may be performed instead of using an automatic chest compression device **208**.

[0040] At block **306**, a gating determination engine **226** of a blood flow monitoring computing device **202** receives gating information from a gating signal generation device **204**. The type of gating information will depend on the type of gating signal generation device **204** used. For example, an end tidal CO2 measurement device **206** may transmit ETCO2 data, a tissue perfusion measurement device **212** may transmit blood volume and/or oxygen saturation data, a motion sensing device **210** may transmit motion data, a chest compression device **208** may transmit chest compression timing data, and a blood flow information filter device **214** may transmit data filtered from blood flow information.

[0041] At block **308**, a blood flow measurement engine **228** of a blood flow monitoring computing device **202** receives blood flow information from a blood flow sensor device **216**. In some embodiments, the blood flow information indicates speed of the motion of blood within a blood vessel. In some embodiments, the blood flow information may indicate a directionality of the motion of blood within the blood vessel. In some embodiments, the blood flow information may also include motion artifacts that are induced by the chest compression device **208** and/or other movement of the subject **108**.

[0042] As illustrated, block **306** and block **308** are performed in parallel. Typically, the gating information and the blood flow information are both collected continuously by the gating signal generation device **204** and the blood flow sensor device **216**, respectively, throughout execution of the method **300**.

[0043] At block **310**, the gating determination engine **226** determines time periods for sampling blood flow information based on the gating information. The technique used by the gating determination engine **226** to determine the time periods depends on the type of gating signal generation device **204** that is generating the gating information. Once the gating information is generated, it is used to detect time periods during which the blood flow information is least likely to be affected by compression-induced motion artifacts. In some embodiments, the gating determination engine **226** may use a point detected using a technique described below to determine a start time of each time period. The gating determination engine **226** may use the determined point as the start of the time period, or may choose a time that is a predetermined amount of time after the determined point, such as a tenth of a second, as the start of the time period. The gating determination engine **226** may then choose a time that is a predetermined amount of time after the start time, such as a tenth of a second (or about a tenth of a second, such as between 0.09 and 0.11 of a second), to be used as the end of the time period.

[0044] Typically, the time periods immediately follow the top and/or the bottom of a compression stroke. Accordingly, each type of gating information may be processed in a different way to detect the top and/or the bottom of the compression strokes, or some other time periods during the compression cycles at which motion artifacts would be least likely to affect the blood flow information.

[0045] For example, if the gating signal generation device **204** is a tissue perfusion measurement device **212**, the gating determination engine **226** may analyze a waveform transmitted by the tissue perfusion measurement device **212** that represents blood volume in the tissue under the tissue perfusion measurement device **212**. The gating determination engine **226** may detect inflection points in the waveform that indicate points where the changes in blood volume transition from increasing to decreasing to determine the start of each time period.

[0046] As another example, if the gating signal generation device **204** is a motion sensing device **210**, the gating determination engine **226** may analyze indications of motion transmitted by the motion sensing device **210** to detect points with a minimum of motion, and may use those points to determine the start of each time period.

[0047] As yet another example, if the gating signal generation device **204** is an end tidal CO2 measurement device **206**, the gating determination engine **226** may analyze a waveform transmitted by the end tidal CO2 measurement device **206** that represents the partial pressure of CO_2 in the respiratory gasses to find a point between an inhalation and an exhalation. This point may then be used to determine the start of a time period. Chest compressions may also create artifacts in the ETCO2 signal. These artifacts could be detected and used to determine the start of each time period. In some embodiments, the waveform transmitted by the end tidal CO2 measurement device **206** may include a significant temporal offset from the signal from the blood flow sensor device **216**, and so the temporal offset would be determined before using the signal from the end tidal CO2 measurement device **206** for gating.

[0048] As still another example of a gating signal generation device **204**, if the gating signal generation device **204** is a chest compression device **208**, then the gating determination engine **226** may analyze the signals transmitted by the chest compression device **208** to find points when the signals indicate the top and/or bottom of the compression strokes occur. These points may then be used to determine the start of time periods.

[0049] As a final example of a gating signal generation device **204**, if the gating signal generation device **204** is a blood flow information filter device **214**, the gating determination engine **226** may analyze a waveform transmitted by the blood flow information filter device **214** that represents background tissue motion that the blood flow information filter device **214** filtered out of the blood flow information. The gating determination engine **226** may detect points at peaks and valleys of the waveform, or, if the waveform represents an absolute value of detected motion, the gating determination engine **226** may detect points where the absolute value of detected motion is zero. Those points may then be used to determine the start of time periods. In some embodiments, instead of using the background tissue motion information directly, the gating determination engine **226** may subtract the background tissue motion from the blood flow information, and may then use the peaks and valleys of the blood flow information itself to determine the points to use to determine the starts of the time periods.

[0050] FIG. **4** is a chart that illustrates a non-limiting example embodiment of blood flow information generated by a blood flow sensor device **216** according to various aspects of the present disclosure. The dark, regular waveform near the velocity axis of the chart **400** indicates a signal filtered out by a band pass filter of the blood flow information filter device **214** because it is likely to indicate background tissue motion. Each point where this dark waveform crosses the velocity axis (i.e., each point where the background tissue motion is determined to be zero) may indicate points to use to determine a start of a time period. FIG. **5** includes multiple charts that illustrate other non-limiting example embodiments of blood flow information generated by a blood flow sensor device **216** according to various aspects of the present disclosure. Again, the dark waveforms near the velocity axes of the charts **500** indicate a signal filtered out by a band pass filter of the blood flow information filter device **214** because they are likely to indicate background tissue motion.

[0051] Returning to FIG. **3**, at block **312**, the blood flow measurement engine **228** measures blood flow indicated by the blood flow information during the time periods. In some embodiments, the blood flow measurement engine **228** may use the magnitude of the blood flow indicated by the blood flow information during the time period as the measured blood flow. In some embodiments, the blood flow measurement engine **228** may first filter the blood flow information using the blood flow information filter device **214** to remove background motion values from the blood flow information. In some embodiments, the blood flow measurement engine **228** may also determine a directionality of the blood flow (e.g., away from the head or towards the head).

[0052] At optional block **314**, the blood flow measurement engine **228** presents the measured blood flow via a user interface **222** of the blood flow monitoring computing device **202**. In some embodiments, the blood flow measurement engine **228** may present a numeric value that indicates a flow rate. In some embodiments, the blood flow measurement engine **228** may present a qualitative value (e.g., excellent, good, fair, poor) that represents the measured blood flow. In some embodiments, the blood flow measurement engine **228** may also present the directionality of the measured blood flow. In some embodiments, the user interface **222** may include a display device, and the measured blood flow may be shown via the display device. In some embodiments, the user interface **222** may include a loudspeaker, and the measured blood flow may be presented in an audio format, including but not limited to by synthesized speech, an alarm tone, or an instruction. In some embodiments, the blood flow measurement engine **228** may use the communication interface **224** to transmit the presentation of the measured blood flow to a remote computing device for review by a remote care provider or for storage in a health data record.

[0053] At optional block **316**, the blood flow measurement engine **228** transmits a command to the chest compression device **208** based on the measured blood flow. In some embodiments, the blood flow measurement engine **228** may determine that changing the rate of compressions, changing the timing between compressions, changing the strength of compressions, or changing some other characteristics of the compressions would improve the blood flow, and the command may cause the chest compression device **208** to implement the changes. In some embodiments, the blood flow measurement engine **228** may determine that the measured blood flow indicates the return of cardiac activity, and so the command may cause the chest compression device **208** to pause compressions. In some embodiments, instead of transmitting a command to the chest compression device **208**, a command for changing the compressions (e.g., "rate faster," "rate slower," "press deeper," "stop compressions," etc.) may be generated by a loudspeaker in order to guide manual compressions.

[0054] Block **314** and block **316** are illustrated as optional because, in some embodiments, only one of block **314** and block **316** may be performed. In some embodiments, both block **314** and block **316** may be performed.

[0055] The method **300** then proceeds to an end block and terminates. The method **300** is illustrated in FIG. **3** as operating a single time and then terminating. However, in some embodiments, the method **300** generally loops back from block **316** to block **306**/block **308** to operate continually while cardiopulmonary resuscitation continues.

[0056] FIG. **6** is a block diagram that illustrates aspects of an exemplary computing device **600** appropriate for use as a computing device of the present disclosure. While multiple different types of computing devices were discussed above, the exemplary computing device **600** describes various elements that are common to many different types of computing devices. While FIG. **6** is described with reference to a computing device that is implemented as a device on a network, the description below is applicable to servers, personal computers, mobile phones, smart phones, tablet computers, embedded computing devices, and other devices that may be used to implement portions of embodiments of the present disclosure. Some embodiments of a computing device may be implemented in or may include an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), or other customized device. Moreover, those of ordinary skill in the art and others will recognize that the computing device **600** may be any one of any number of currently available or yet to be developed devices.

[0057] In its most basic configuration, the computing device **600** includes at least one processor **602** and a system memory **604** connected by a communication bus **606**. Depending on the exact configuration and type of device, the system memory **604** may be volatile or nonvolatile memory,

such as read only memory ("ROM"), random access memory ("RAM"), EEPROM, flash memory, or similar memory technology. Those of ordinary skill in the art and others will recognize that system memory **604** typically stores data and/or program modules that are immediately accessible to and/or currently being operated on by the processor **602**. In this regard, the processor **602** may serve as a computational center of the computing device **600** by supporting the execution of instructions.

[0058] As further illustrated in FIG. **6**, the computing device **600** may include a network interface **610** comprising one or more components for communicating with other devices over a network. Embodiments of the present disclosure may access basic services that utilize the network interface **610** to perform communications using common network protocols. The network interface **610** may also include a wireless network interface configured to communicate via one or more wireless communication protocols, such as Wi-Fi, 2G, 3G, LTE, WiMAX, Bluetooth, Bluetooth low energy, and/or the like. As will be appreciated by one of ordinary skill in the art, the network interface **610** illustrated in FIG. **6** may represent one or more wireless interfaces or physical communication interfaces described and illustrated above with respect to particular components of the computing device **600**.

[0059] In the exemplary embodiment depicted in FIG. **6**, the computing device **600** also includes a storage medium **608**. However, services may be accessed using a computing device that does not include means for persisting data to a local storage medium. Therefore, the storage medium **608** depicted in FIG. **6** is represented with a dashed line to indicate that the storage medium **608** is optional. In any event, the storage medium **608** may be volatile or nonvolatile, removable or nonremovable, implemented using any technology capable of storing information such as, but not limited to, a hard drive, solid state drive, CD ROM, DVD, or other disk storage, magnetic cassettes, magnetic tape, magnetic disk storage, and/or the like.

[0060] Suitable implementations of computing devices that include a processor **602**, system memory **604**, communication bus **606**, storage medium **608**, and network interface **610** are known and commercially available. For ease of illustration and because it is not important for an understanding of the claimed subject matter, FIG. **6** does not show some of the typical components of many computing devices. In this regard, the computing device **600** may include input devices, such as a keyboard, keypad, mouse, microphone, touch input device, touch screen, tablet, and/or the like. Such input devices may be coupled to the computing device **600** by wired or wireless connections including RF, infrared, serial, parallel, Bluetooth, Bluetooth low energy, USB, or other suitable connection protocols using wireless or physical connections. Similarly, the computing device **600** may also include output devices such as a display, speakers, printer, etc. Since these devices are well known in the art, they are not illustrated or described further herein.

[0061] While illustrative embodiments have been illustrated and described, it will be appreciated that various changes can be made therein without departing from the spirit and scope of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A system for measuring blood flow during cardiopulmonary resuscitation of a subject, the system comprising:

a blood flow sensor device;

a gating signal generation device; and

a blood flow monitoring computing device that includes at least one processor and a non-transitory computer-readable medium having computer-executable instructions stored thereon that, in response to execution by the at least one processor, cause the blood flow monitoring computing device to perform actions comprising:

receiving blood flow information from the blood flow sensor device;

receiving gating information from the gating signal generation device;

determining time periods for sampling the blood flow information based on the gating information; and

measuring blood flow indicated by the blood flow information during the time periods.

2. The system of claim **1**, wherein the blood flow sensor device includes a non-imaging ultrasound probe.

3. The system of claim **2**, wherein the blood flow sensor device includes an adhesive pad to affix the non-imaging ultrasound probe to the subject.

4. The system of claim **1**, wherein the gating signal generation device is a photoplethysmograph device or an end tidal CO2 measurement device.

5. The system of claim **1**, wherein the gating signal generation device is a motion sensing device.

6. The system of claim **1**, wherein the system includes a chest compression device.

7. The system of claim **6**, wherein the actions further comprise transmitting a command to the chest compression device based on the measured blood flow.

8. The system of claim **6**, wherein the gating signal generation device is included within the chest compression device, and wherein the gating information indicates timing of operation of the chest compression device.

9. A computer-implemented method of measuring blood flow during cardiopulmonary resuscitation of a subject, the method comprising:

receiving, by a computing device, blood flow information from a blood flow sensor device;

receiving, by the computing device, gating information from a gating signal generation device;

determining, by the computing device, time periods for sampling the blood flow information based on the gating information; and

measuring, by the computing device, blood flow indicated by the blood flow information during the time periods.

10. The computer-implemented method of claim **9**, wherein determining the time periods for sampling the blood flow information based on the gating information includes:

detecting, based on the gating information, inter-compression events of the cardiopulmonary resuscitation; and

determining the time periods for sampling the blood flow information based on the inter-compression events.

11. The computer-implemented method of claim **10**, wherein determining the time periods for sampling the blood flow information based on the inter-compression events includes, for each inter-compression event:

determining a start time for the inter-compression event; and

determining a time period that begins at the start time and ends a predetermined amount of time after the start time.

12. The computer-implemented method of claim **11**, wherein the predetermined amount of time after the start time is about one-tenth of a second.

13. The computer-implemented method of claim **10**, wherein receiving the gating information from the gating signal generation device includes receiving tissue perfusion information from a photoplethysmograph device, and wherein detecting the inter-compression events of the cardiopulmonary resuscitation includes detecting minima of the tissue perfusion information.

14. The computer-implemented method of claim **10**, wherein receiving the gating information from the gating signal generation device includes receiving motion information from a motion sensing device, and wherein detecting the inter-compression events of the cardiopulmonary resuscitation includes using the motion information to detect the inter-compression events.

15. The computer-implemented method of claim **10**, wherein receiving the gating information from the gating signal generation device includes receiving signals from a chest compression device indicating compression timing, and wherein detecting the inter-compression events of the cardiopulmonary resuscitation includes using the signals indicating the chest compression timing to detect the inter-compression events.

16. The computer-implemented method of claim **10**, wherein receiving the gating information from the gating signal generation device includes receiving signals from a blood flow information filter device, and wherein detecting the inter-compression events of the cardiopulmonary resuscitation includes detecting motion based on tissue-related backscatter signals indicated by the signals from the blood flow information filter device.

17. The computer-implemented method of claim **9**, wherein receiving the blood flow information from a blood flow sensor device includes receiving the blood flow information from an ultrasound sensor.

18. The computer-implemented method of claim **17**, wherein measuring the blood flow indicated by the blood flow information during the time periods includes filtering, by the computing device, the blood flow information using a high-pass filter to screen out slow and bright tissue-related backscatter signals.

19. The computer-implemented method of claim **9**, further comprising transmitting, by the computing device, a command to a chest compression device based on the measured blood flow.

20. The computer-implemented method of claim **19**, wherein the command includes at least one of an instruction to change a compression rate, an instruction to change a compression depth, and an instruction to change a compression duty cycle.

* * * * *

专利名称(译)	信号门控的心肺复苏过程中无创血流测量的系统和方法		
公开(公告)号	US20200107989A1	公开(公告)日	2020-04-09
申请号	US16/597656	申请日	2019-10-09
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申请(专利权)人(译)	华盛顿大学 匹兹堡大学 - 英联邦系统的高等教育的		
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IPC分类号	A61H31/00 A61B8/08 A61B8/06 A61B8/00 A61B5/026 A61B5/08 A61B5/00 A61B5/0295		
CPC分类号	A61B5/082 A61B5/0295 A61B5/0261 A61B8/4272 A61H2230/405 A61H2201/501 A61H2230/255 A61B8/06 A61H31/006 A61B5/7271 A61B8/5215 A61B5/11 A61B5/14551 A61B5/7292 A61B8/065 A61B8/0883 A61B8/4236 A61B8/5284 A61H31/007 A61H2201/1619 A61H2205/084 A61H2230/206 A61H2230/208 A61H31/00		
优先权	62/743435 2018-10-09 US		
外部链接	Espacenet USPTO		

摘要(译)

在一些实施例中，使用超声来检测血流的诸如非侵入性心脏骤停监测器（NICAM）之类的血流传感器设备用于监测心肺复苏期间的血流。 一个或多个选通信号生成设备将选通信号发送到血流监测计算设备。 血流监测计算设备使用门控信号来确定由血流传感器设备生成的血流信息最可能准确的时间段。 血流监视计算装置测量该时间段内的血流。 在一些实施例中，血流监测计算设备将测量的血流呈现给用户。 在一些实施例中，血流监测计算设备基于所测量的血流将命令发送到胸部按压设备。