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(54) **ALTERING PHYSIOLOGICAL SIGNALS BASED ON PATIENT MOVEMENT**

(71) Applicant: **Google Inc.**, Mountain View, CA (US)

(72) Inventors: **Brian Derek DeBusschere**, Los Gatos, CA (US); **Jeffrey L. Rogers**, San Carlos, CA (US)

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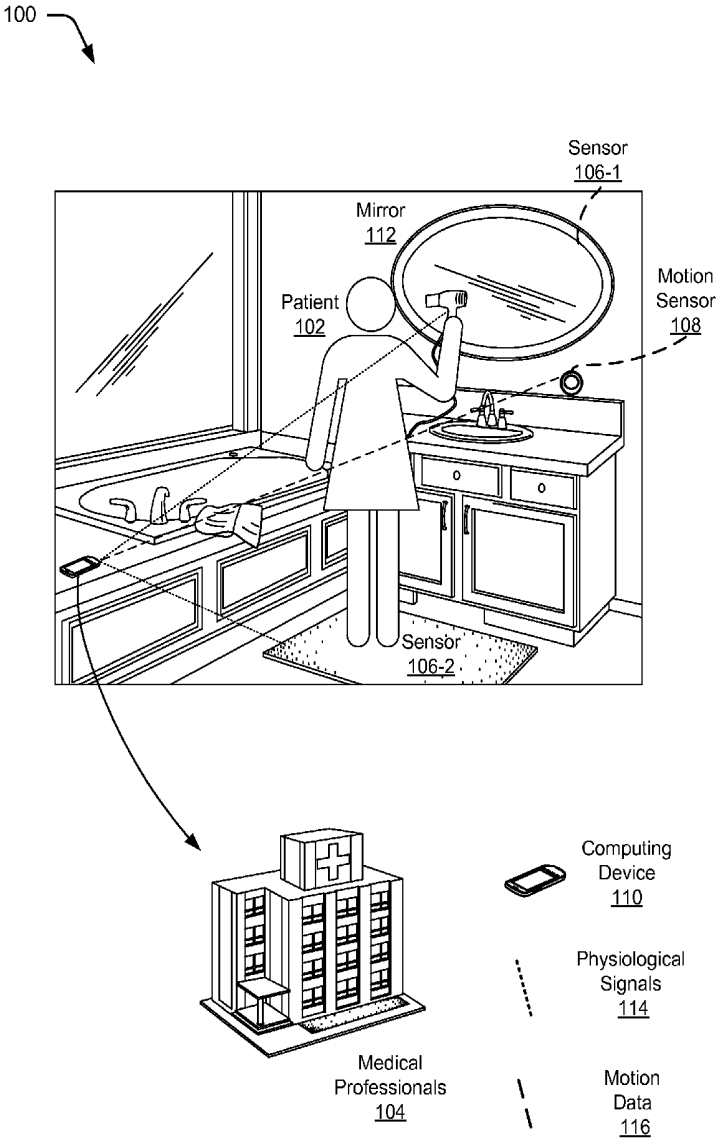
(57) **ABSTRACT**

This document describes ways in which to alter physiological signals to address corrupt, noisy, or otherwise faulty data. By so doing, accuracy and robustness in sensing and assessing a patient's cardiovascular health can be improved. These improved assessments permit better measures of health, such as relevant hemodynamics understood by heart rates, heart rate variability, cardiac arrhythmias, blood pressures, pulse-wave velocities, arterial stiffness, cardiac valve timing, thoracic fluids, ballistocardiogram force, photo-plethysmograms, blood oxygenation, and pressure-volume loops.



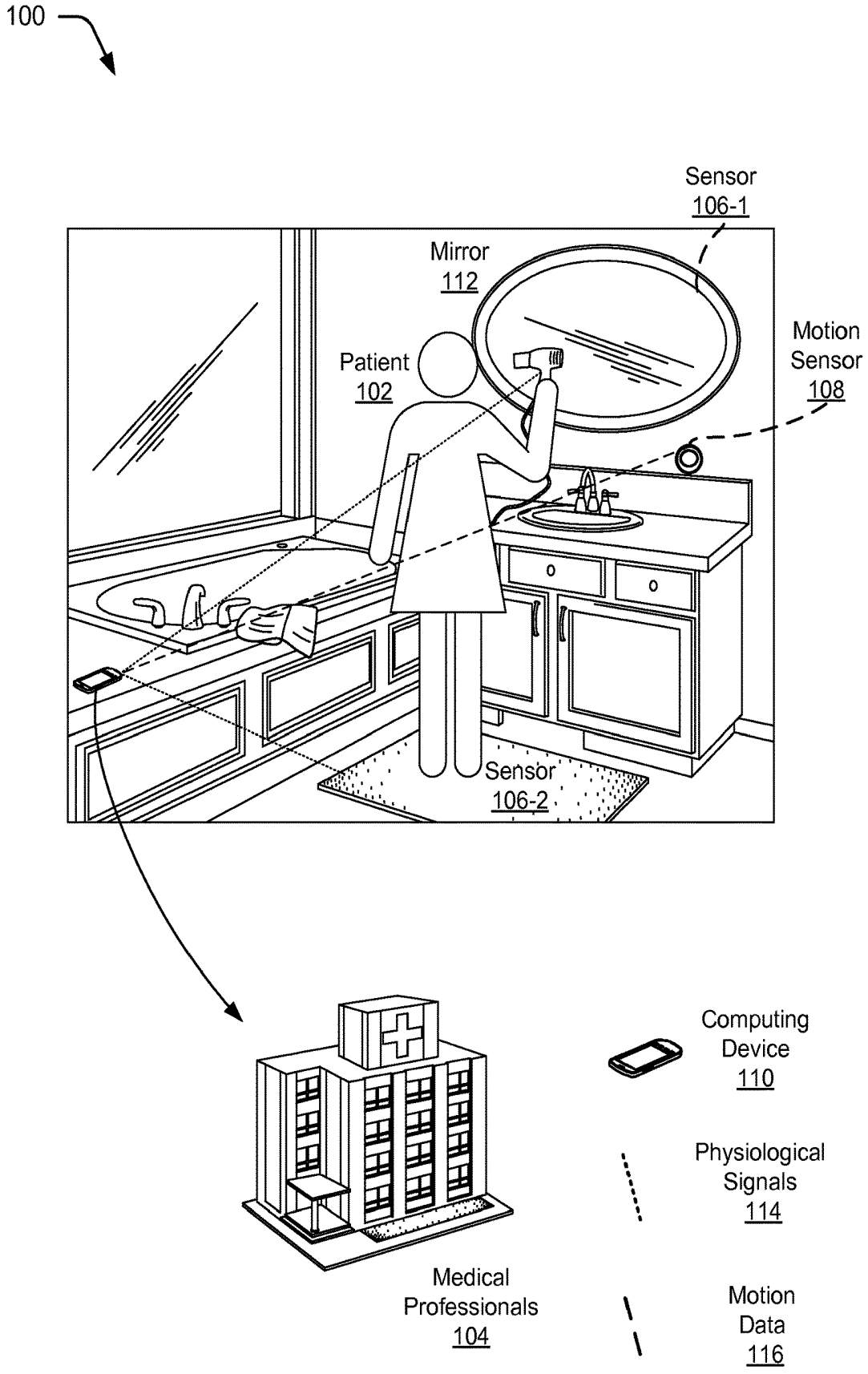

100
Sensor
106-1
Mirror
112
Patient
102
Motion
Sensor
108
Sensor
106-2
Computing
Device
110
Physiological
Signals
114
Medical
Professionals
104
Motion
Data
116

Fig. 1

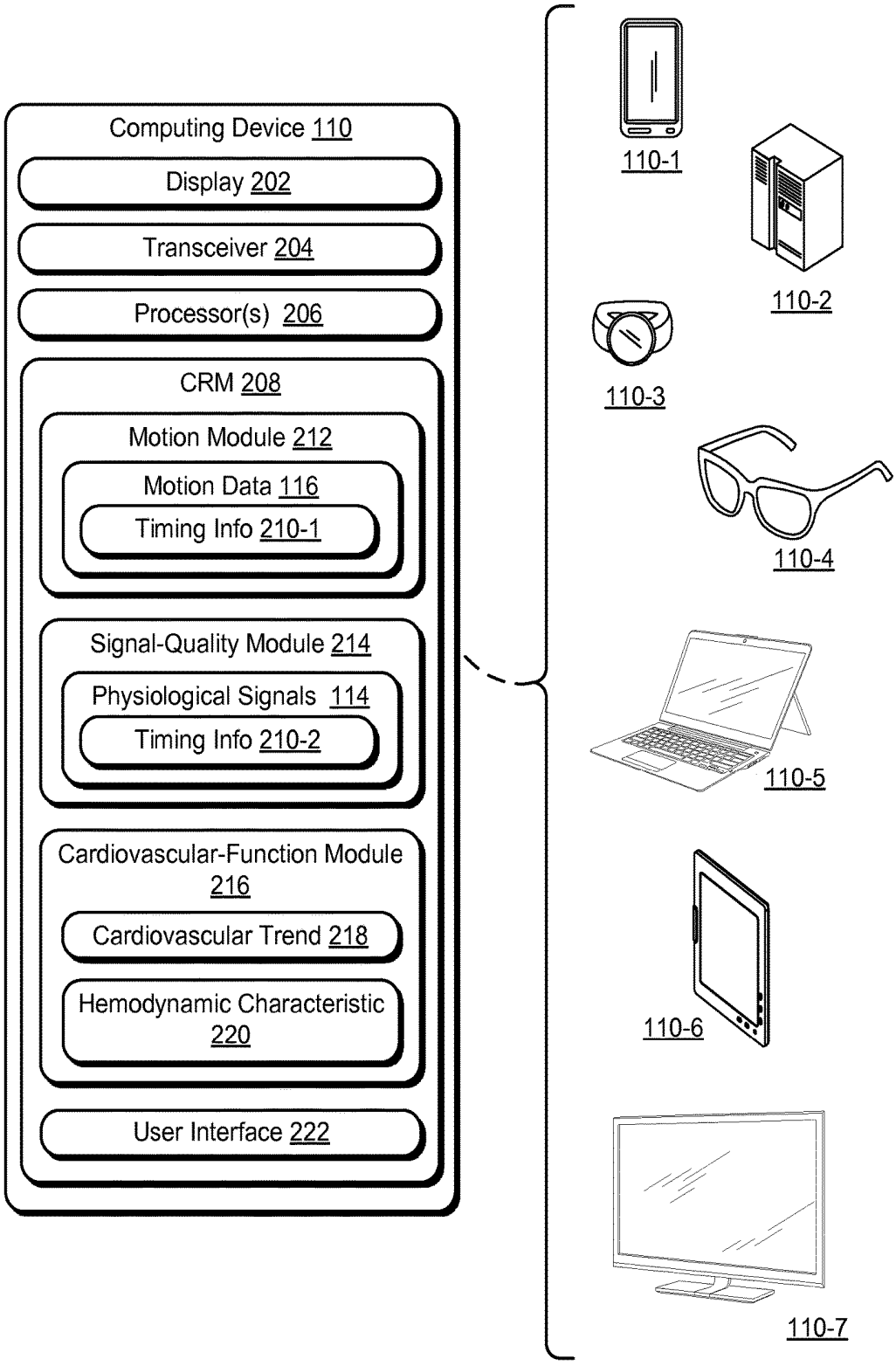

Computing Device 110
Display 202
Transceiver 204
Processor(s) 206
CRM 208
Motion Module 212
Motion Data 116
Timing Info 210-1
Signal-Quality Module 214
Physiological Signals 114
Timing Info 210-2
Cardiovascular-Function Module 216
Cardiovascular Trend 218
Hemodynamic Characteristic 220
User Interface 222
110-1
110-2
110-3
110-4
110-5
110-6
110-7

Fig. 2

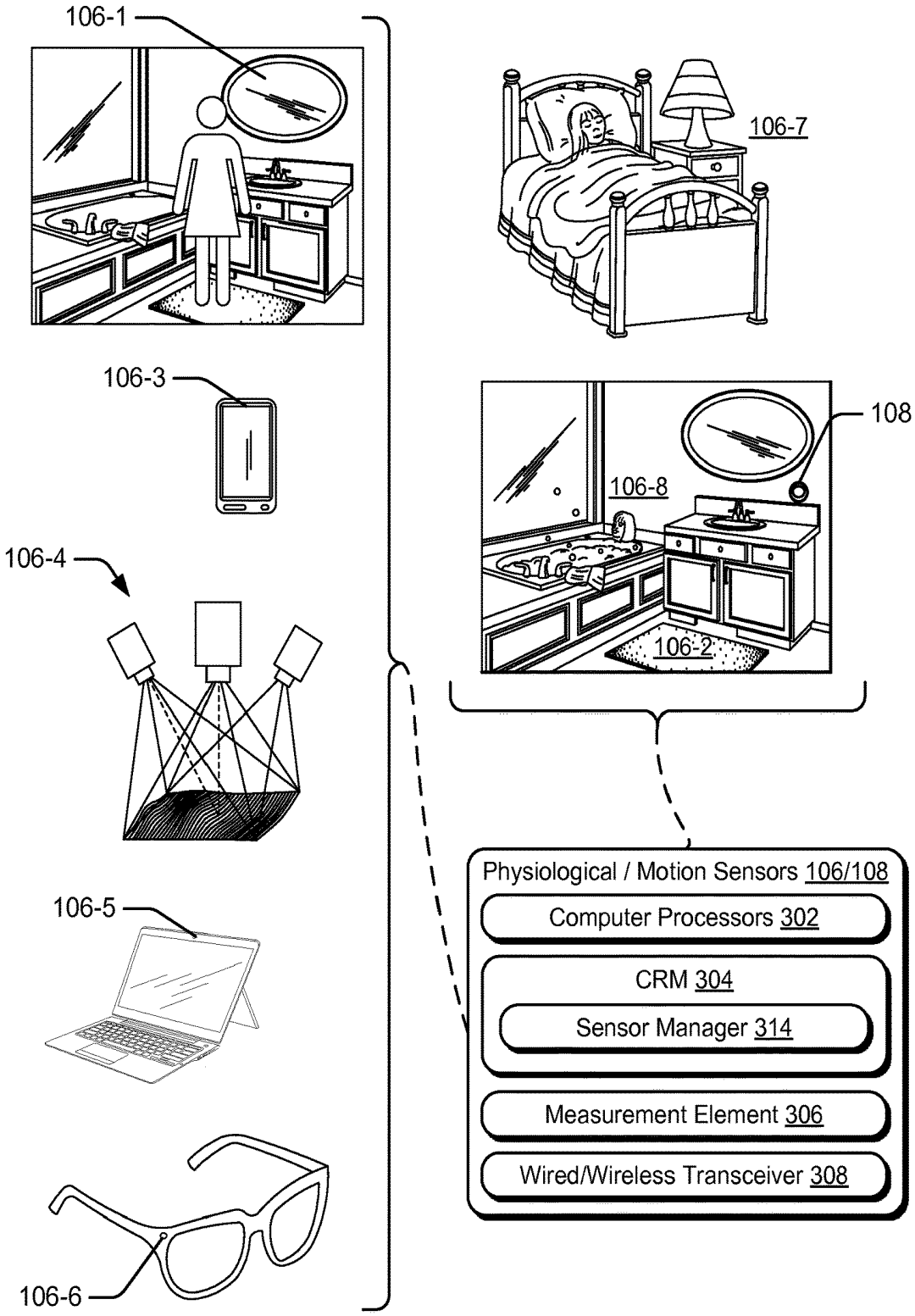

106-1
106-7
106-3
108
106-8
106-4
106-2
106-5
Physiological / Motion Sensors 106/108
Computer Processors 302
CRM 304
Sensor Manager 314
Measurement Element 306
Wired/Wireless Transceiver 308
106-6

Fig. 3

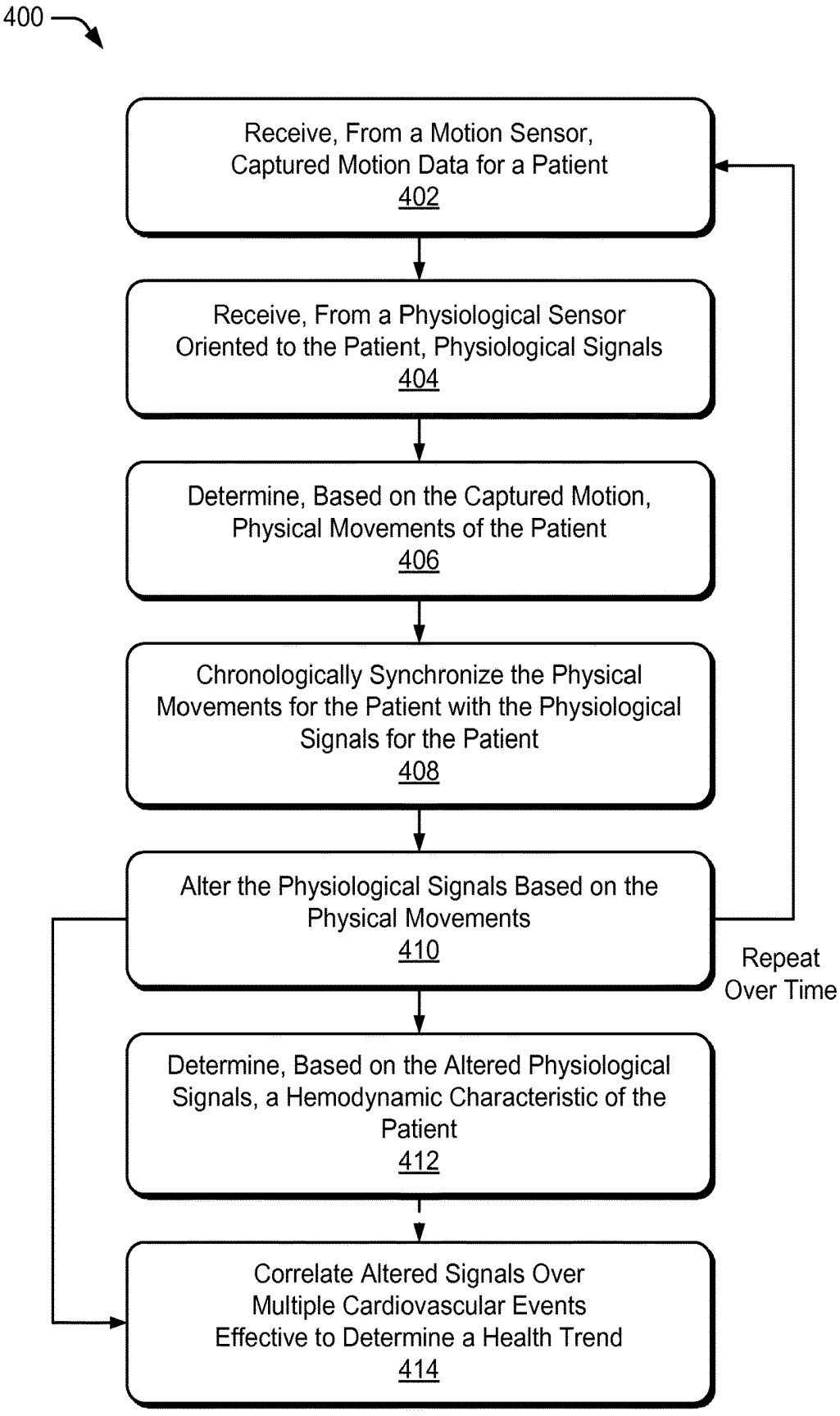

400
Receive, From a Motion Sensor, Captured Motion Data for a Patient
402
Receive, From a Physiological Sensor Oriented to the Patient, Physiological Signals
404
Determine, Based on the Captured Motion, Physical Movements of the Patient
406
Chronologically Synchronize the Physical Movements for the Patient with the Physiological Signals for the Patient
408
Alter the Physiological Signals Based on the Physical Movements
410
Repeat Over Time
Determine, Based on the Altered Physiological Signals, a Hemodynamic Characteristic of the Patient
412
Correlate Altered Signals Over Multiple Cardiovascular Events Effective to Determine a Health Trend
414

Fig. 4

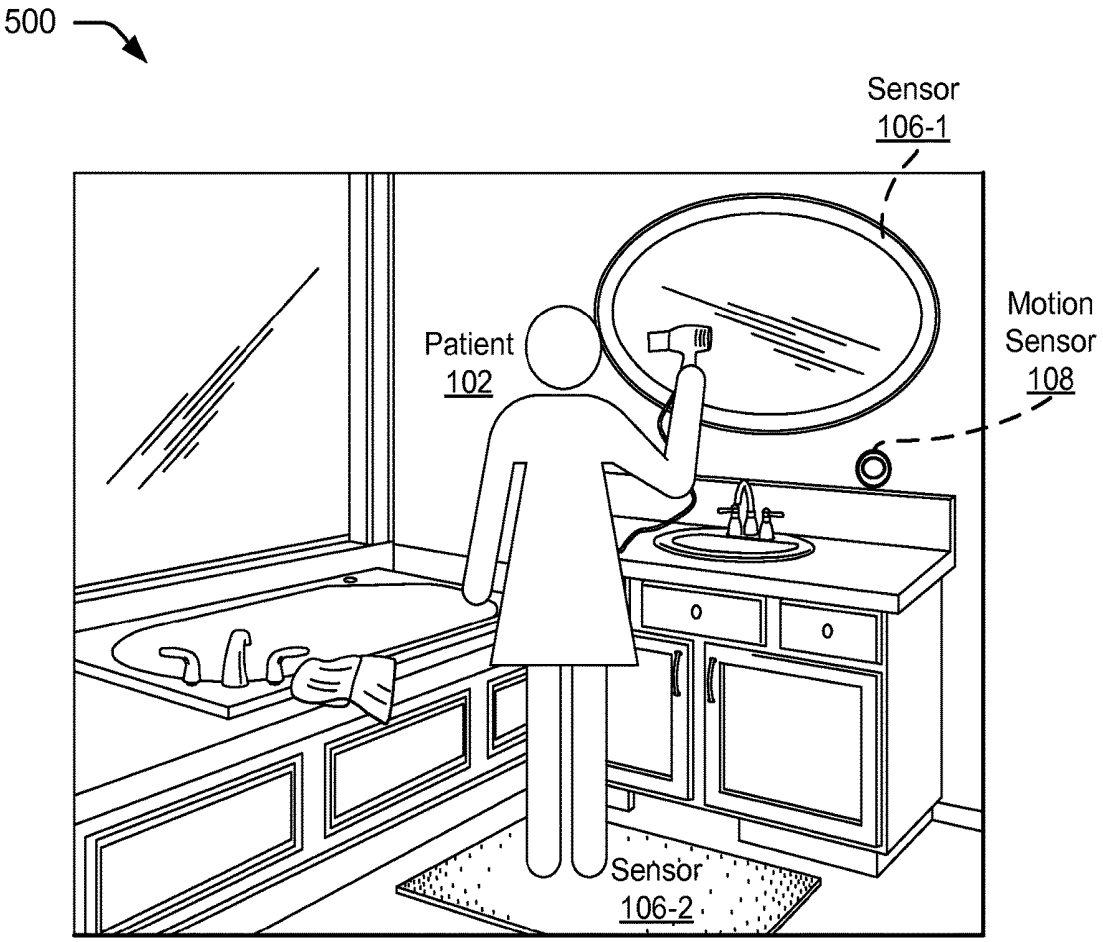


Fig. 5

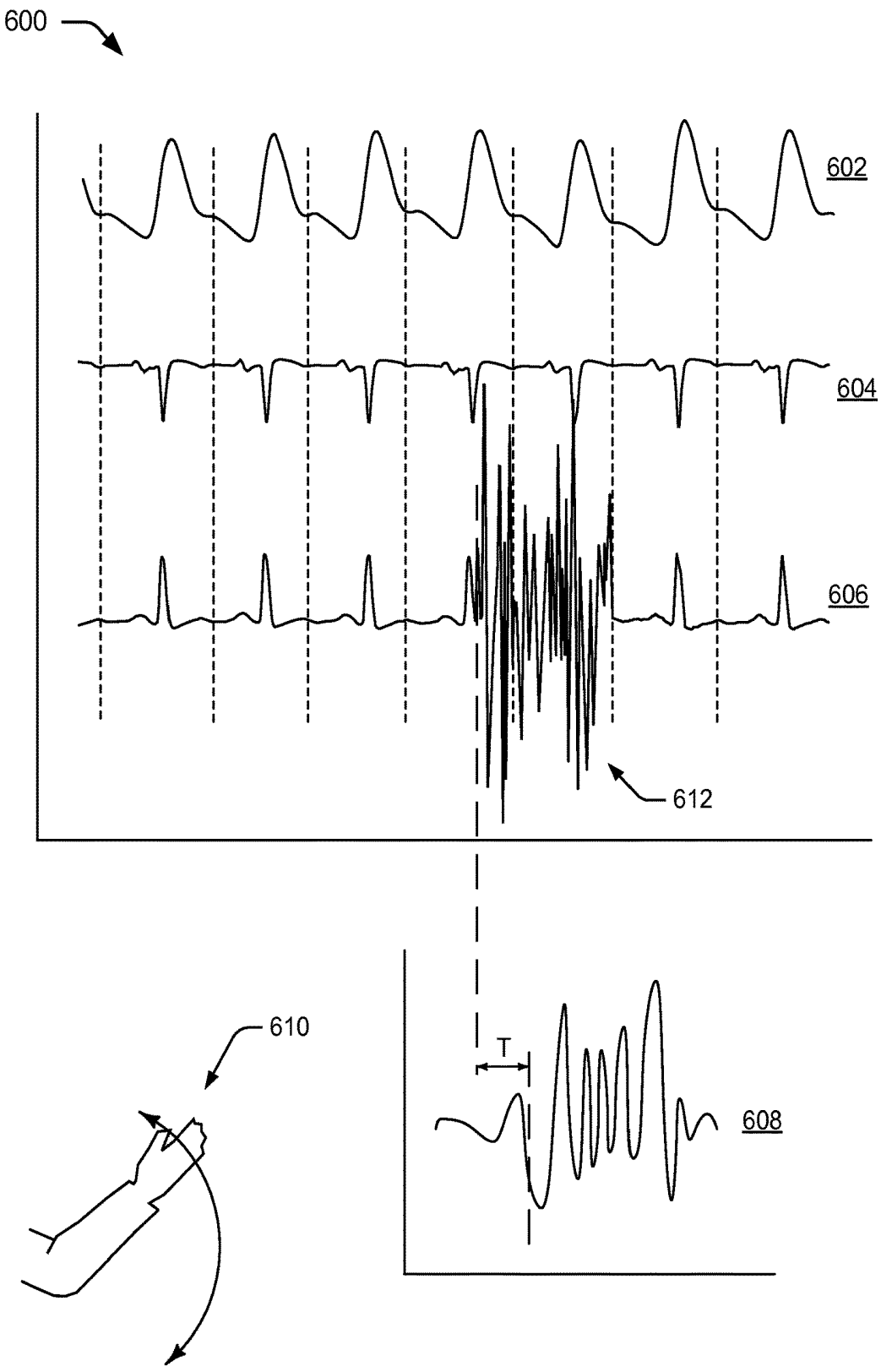


Fig. 6

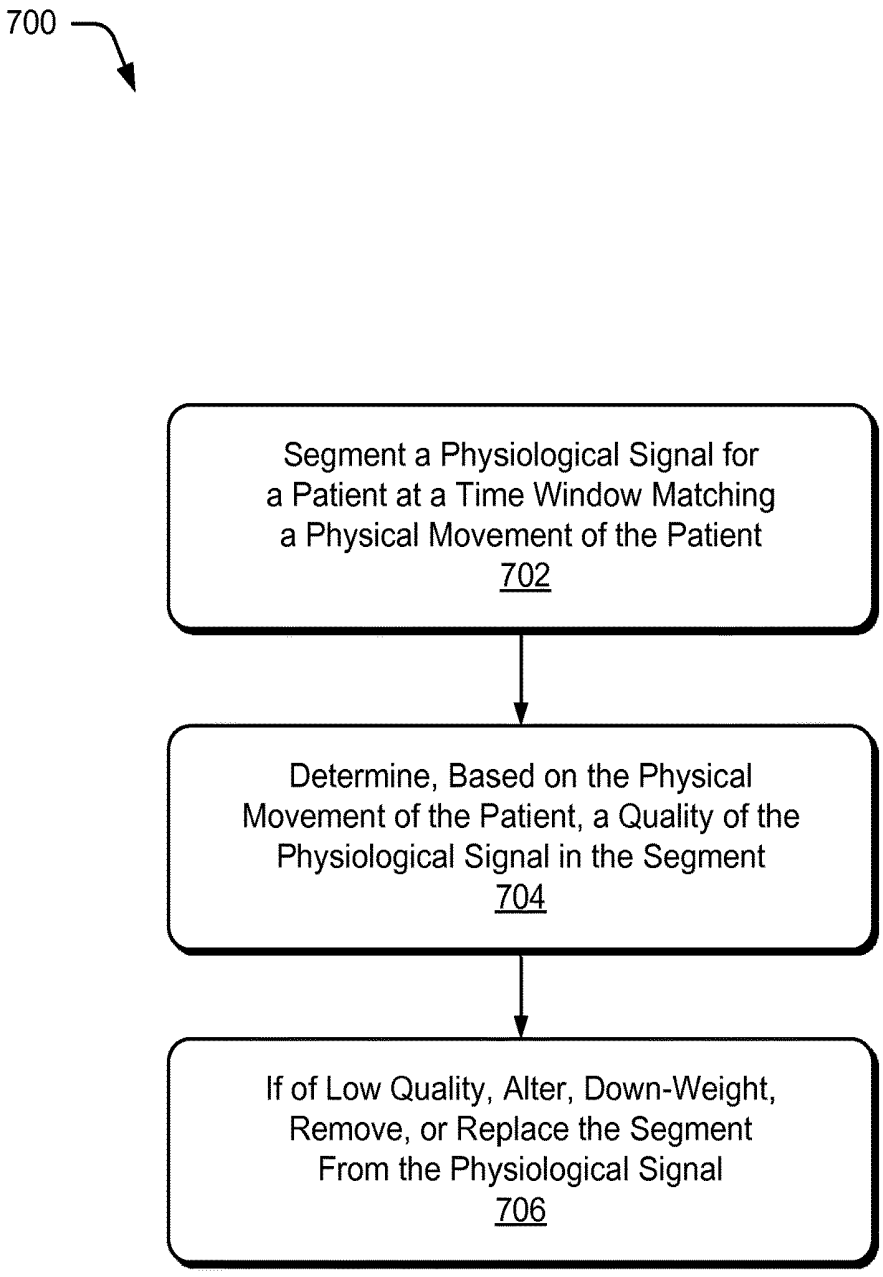

700
Segment a Physiological Signal for a Patient at a Time Window Matching a Physical Movement of the Patient
702
Determine, Based on the Physical Movement of the Patient, a Quality of the Physiological Signal in the Segment
704
If of Low Quality, Alter, Down-Weight, Remove, or Replace the Segment From the Physiological Signal
706

Fig. 7

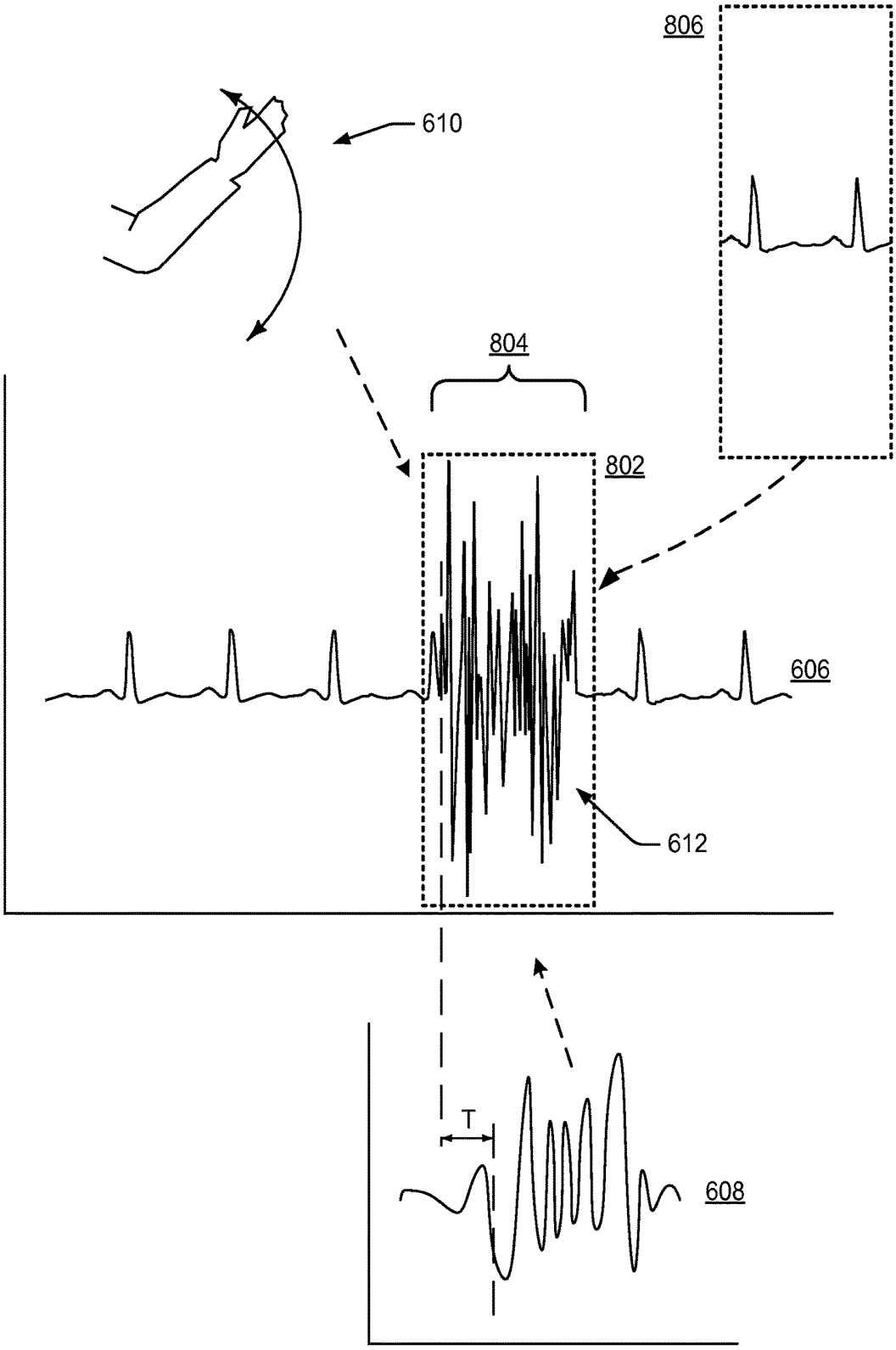


Fig. 8

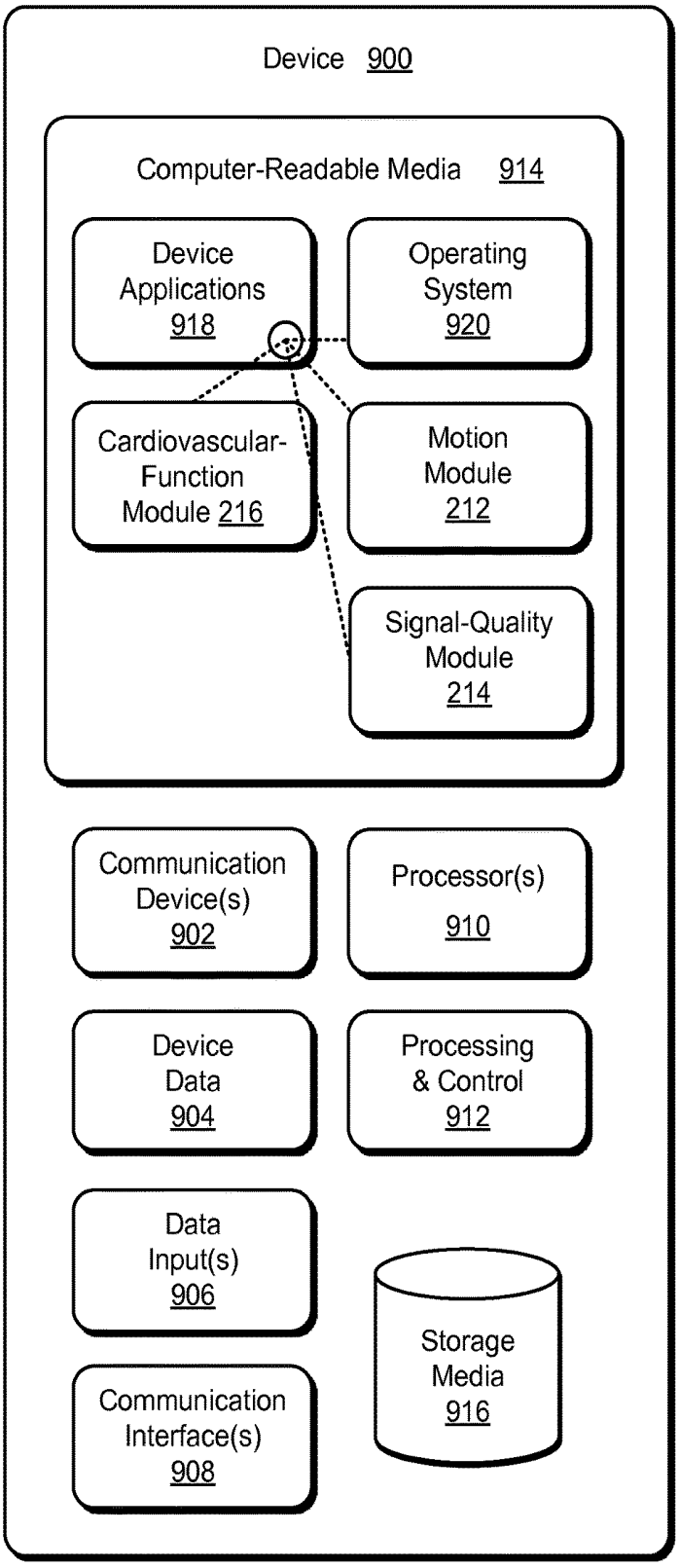

Device 900
Computer-Readable Media 914
Device Applications 918
Operating System 920
Cardiovascular-Function Module 216
Motion Module 212
Signal-Quality Module 214
Communication Device(s) 902
Processor(s) 910
Device Data 904
Processing & Control 912
Data Input(s) 906
Storage Media 916
Communication Interface(s) 908

Fig. 9

ALTERING PHYSIOLOGICAL SIGNALS BASED ON PATIENT MOVEMENT

BACKGROUND

[0001] Cardiovascular disease is the leading cause of morbidity and mortality worldwide. At the same time, this chronic disease is largely preventable. Medical science knows how to save most of these lives by removing the major risk factors of smoking, diabetes, and hypertension. In addition, many people are told just what they need to do to reduce these risk factors—stop smoking, reduce sugar intake, eat healthier, reduce alcohol intake, increase cardiovascular exercise, lose weight, and, if needed, take blood-pressure medication. Nevertheless, many people do not follow this good advice. Because of this, millions of people needlessly die from cardiovascular disease.

[0002] People do not follow this good medical advice because they think they are different, they do not want to change their behaviors that are causing the disease, or they do not know what to change in their particular case. When a physician tells them that they are at risk from heart disease because they are overweight, for example, many people know that this judgment is not necessarily specific to them—it is based on averages and demographics. So being a particular weight may not negatively affect a particular patient's heart. Further, a lack of feedback that their behavior is harming their heart results in a lack of incentive for them to change their behavior.

[0003] This lack of incentive to follow good advice can be addressed by monitoring the state of the patient's cardiovascular system both on occasion or over time to show trends in heart health. Hard, physiological data often motivates patients to modify their behavior, such as data indicating that their heart shows measurable signs of heart disease. Unfortunately, current methods for measuring heart health can be inconvenient, inaccurate, and expensive. Simple home monitor products exist for measuring heart rate and blood pressure, but long-term user compliance is a problem due to inconvenience, and accuracy can easily suffer from patient misuse, signal noise, or signal corruption for all but the simplest monitors. More advanced cardiovascular monitoring, such as heart rate variability, arterial stiffness, cardiac output, and atrial fibrillation, involve expensive and time-consuming trips to a medical facility for a skilled assessment and, even when performed, often suffers from corrupt, noisy, or otherwise faulty physiological signals.

SUMMARY

[0004] This document describes ways in which to alter physiological signals to address corrupt, noisy, or otherwise faulty data. By so doing, accuracy and robustness in sensing and assessing a patient's cardiovascular health can be improved. These improved assessments permit better measures of health, such as relevant hemodynamics understood by heart rates, heart rate variability, cardiac arrhythmias, blood pressures, pulse-wave velocities, arterial stiffness, cardiac valve timing, thoracic fluids, ballistocardiogram force, photo-plethysmograms, blood oxygenation, and pressure-volume loops.

[0005] The techniques disclosed in this document use various sensors to sense the effects of cardiovascular hemodynamics. As noted, one challenge associated with using physiological sensors is signal corruption. The techniques determine if physiological signals are corrupt based on patient movement, such as respiration or major body movements. By so doing, these corrupt physiological signals can be altered, removed, or otherwise addressed to improve assessment of a patient's heart health.

[0006] Through these techniques, health assessments using physiological signals can be improved, whether at one particular time or over time to provide a health trend. Trends can aid a patient by helping them know if the effort they are expending to improve their heart health is actually making a difference. Further, negative trends or conditions, such as cardiac irregularities or some asymmetries can be found that can spur people to improve their health or to get medical attention. By so doing, these techniques may save many people from dying of heart disease.

[0007] This summary is provided to introduce simplified concepts concerning the techniques, which are further described below in the Detailed Description. This summary is not intended to identify essential features of the claimed subject matter, nor is it intended for use in determining the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Embodiments of techniques and devices for sensing cardiovascular health and altering physiological signals based on patient movement are described with reference to the following drawings. The same numbers are used throughout the drawings to reference like features and components:

[0009] FIG. **1** illustrates an example environment in which the techniques can be implemented.

[0010] FIG. **2** illustrates an example computing device of FIG. **1**.

[0011] FIG. **3** illustrates example physiological/motion sensors of FIG. **1**.

[0012] FIG. **4** illustrates a method for altering physiological signals based on patient movement, including to assess hemodynamic characteristics for a patient.

[0013] FIG. **5** illustrates a sensing milieu in which a female patient is measured by physiological sensors and a motion sensor.

[0014] FIG. **6** illustrates various captured physiological signals and a motion data signal for the patient of FIG. **5**.

[0015] FIG. **7** illustrates a method for altering physiological signals based on patient movement, including by determining that a segment of the physiological signal is corrupt.

[0016] FIG. **8** illustrates a time window for the arm movement of FIGS. **5** and **6**, along with a corresponding segment of a physiological signal.

[0017] FIG. **9** illustrates an example device in which techniques may be implemented that alter physiological signals based on patient movement.

DETAILED DESCRIPTION

Overview

[0018] This document describes techniques and devices for altering physiological signals based on patient movement. These altered signals permit better measurement of a patient's health.

[0019] Consider non-invasive, automated monitors of cardiovascular health. These types of monitors tend to have

excellent user compliance when used in the patient's home. These types of monitors, however, tend to have signals with poor signal-to-noise ratios, that are at least partially corrupt, and that include artifacts. The less noticeable or invasive that they are made, the more their signal quality often suffers. As a result, there is decreased diagnostic confidence in the automated measurements from these sensors, reducing their utility and deployment.

[0020] By way of example, consider an integrated floormat capable of sensing data to create an electrocardiograph (ECG) and ballistocardiogram (BCG). The floormat offers the advantage of an inconspicuous measurement device that is much less disruptive to the patient than standard ECG electrodes or blood-pressure cuffs. Beyond the standard vitals of heart rate, heart rate variability, and respiration rate, the ECG and BCG can nominally be combined to monitor the timing of important cardiac events, such as contraction and aortic valve opening. They can also be combined with a photo-plethysmogram (PPG) to measure pulse transit time, allowing for an estimation of pulse wave velocity, which correlates with arterial blood pressures. This type of monitor, however, often has low signal quality and susceptibility to artifacts, such as a muscle's EMG corrupting the ECG or physical body motion corrupting BCG.

[0021] The techniques, however, can determine a patient's movement during this monitoring, thereby enabling alteration of these physiological signals. A camera may track a patient's arm movement sufficient to calculate a potential muscle EMG corruption, or a shift in the patient's body standing on the floormat sufficient to indicate a possible BCG corruption as the patient's weight shifts from one side to another. The techniques, with this physical movement matched to the physiological signals from the floormat, can improve the quality of the physiological signals and therefore of the health assessment that is based on those physiological signals.

[0022] These are but a few examples in which altering physiological signals based on patient movement can be performed, other examples and details are provided below. This document now turns to an example environment, after which example physiological sensors and methods, and an example computing system are described.

Example Environment

[0023] FIG. **1** is an illustration of an example environment **100** in which physiological signals are altered based on patient movement. Environment **100** illustrates a patient **102** and a medical professional **104**, family member, or other caretaker that, in some cases, will receive results of the health monitoring. This example employs physiological sensors **106** and a motion sensor **108**, optionally in communication with computing device **110**, a hyperspectral sensor **106-1**, which is located within mirror **112**, and a pressure and electrical-sensing mat **106-2**.

[0024] Physiological signals **114** are provided by each of physiological sensors **106** to some computing device. These signals are effective to measure a hemodynamic characteristic of a patient, as such as a pulse-wave velocity or pressure waves representing blood flow through an artery or vein.

[0025] As shown, physiological signals **114** are passed from sensors **106** to computing device **110**, though they may instead be integral with a computing device. Computing device **110** then performs some or all of the techniques, or passes those physiological signals to some other computing device, such as a remote server through a communication network (not shown).

[0026] As shown with this example environment **100**, a sensing milieu (e.g., physiological sensors **106** in patient **102**'s bathroom) in which a patient lives can be used that are capable of determining a hemodynamic characteristic of a human cardiovascular system. This sensing milieu is capable of non-invasively and remotely determining this hemodynamic characteristic and trends thereof This sensing milieu senses various regions of the patient, which can then be compared, synchronized, aggregated, averaged, and so forth. These hemodynamic characteristics can be represented by cardiovascular asymmetries (e.g., due to a stoke), cardiac irregularities (e.g. atrial fibrillation), blood pressure, pulse-wave velocity, waveforms of circulating blood, photoplethysmograms (PPG), ballistocardiograms, and pressure-volume loops, to name a few.

[0027] Each of these physiological sensors **106** provide physiological signals **114** that include some error, noise, and so forth. Motion sensor **108** also provides motion data **116** to computing device **110**. As noted above, the techniques permit alteration of these signals to improve medical assessment of patients based on movement of patient **102**.

[0028] With regard to computing device **110** of FIG. **1**, consider a detailed illustration in FIG. **2**. Computing device **110** can be one or a combination of various devices, here illustrated with seven examples: a smartphone **110-1**, a server **110-2**, a computing watch **110-3**, computing spectacles **110-4**, a laptop **110-5**, a tablet computer **110-6**, and a desktop **110-7**, though other computing devices and systems, such as one of physiological sensors **106** that includes computing capabilities, a netbook, or a set-top box may also be used. As noted above, in some embodiments the techniques operate, in whole or in part, through a remote device such as server **110-2**. In such cases, some computing can be forgone locally, e.g., through a communication device having limited computing operations or even directly from physiological sensors **106** and/or motion sensor **108** to server **110-2**.

[0029] Computing device **110** may include or be able to communicate with a display **202** (six are shown in FIG. **2**), though a display is not required. Computing device **110** includes or is able to communicate with a transceiver **204**, one or more processors **206**, and computer-readable storage media **208** (CRM **208**). Transceiver **204** is capable of sending and receiving data directly or through a communication network, such as physiological signals **114** from physiological sensors **106** through a local area, wide area, cellular, or near-field network.

[0030] CRM **208** includes motion data **116** and physiological signals **114**. Motion data **116** is received from motion sensor **108** and physiological signals **114** from sensors **106**, as shown in FIG. **1**. Motion data **116** and physiological signals **114** include timing information **210-1** and **210-2**, respectively. Timing information **210** indicates a time or mark sufficient to chronologically synchronize physical movements of patient **102** (determined from motion data **116**) to physiological signals **114** for patient **102**.

[0031] CRM **208** also includes a motion module **212** and a signal-quality module **214**. Motion module **212** is configured to determine, based on the captured motion data (motion data **116**), physical movements of patient **102**. This motion data **116** can be captured by various types of motions

sensors **108**, such as those determining movement through SONAR (SOund Navigation And Ranging), infrared, radar, an optical camera capturing multiple still images over time, and so forth. Further, this motion data **116** can be received with timing information **210-1** or timing can be determined for the data based on when it is received, latency due to capture, processing, and transmission times, and so forth.

[0032] Signal-quality module **214** is configured to receive physiological signals from physiological sensors oriented to the patient, such as physiological signals **114** captured for patient **102** of FIG. **1** and chronologically synchronize physical movements for the patient with the physiological signals. Thus, based on physical movements determined by motion module **212**, signal-quality module **214** can synchronize those movements with physiological signals **114**. Once synchronized, signal-quality module **214** then alters physiological signals **114** based on the physical movements.

[0033] Signal-quality module **214** may alter physiological signals in various manners. Signal-quality module **214** may down-weight the physiological signals based on the physical movement determined to be a large physical movement of the patient. These large physical movements often have a negative effect on the quality, or the usefulness, of the signal. Thus, in some cases a person walking, or shifting his weight, or moving his arms up and down causes the signal to be inaccurate, noisy, and so forth. These signals can be down-weighted when such movements are taking place, thereby reducing their value for multiple signals over multiple similar events, like heartbeats. In some other cases, the signal is still of high quality, but the usefulness is reduced (in some it is increased, discussed below). A blood pressure reading via a physiological signal, for example, may be accurate but less useful when the reading is made when a person is in the process of standing up, as often a measurement is desired at a relatively steady or resting state of the patient.

[0034] Similarly, signal-quality module **214** may alter physiological signals by removing parts of the physiological signals where the physical movement of the patient is disruptive. Assume, for example, that for a particular cardiovascular event, like a single heartbeat, that the patient makes a jerky or major body movement. This movement may render the physiological signals for that heartbeat not reliable or useful for measuring the patient's heart health.

[0035] Signal-quality module **214** may alter physiological signals based on the patient's respiration. Thus, after determining that the physical movement represents the patient breathing, signal-quality module alters the physiological signals based on this known, well-understood movement. Respiration and other common movements have a known effect, either for patients generally, or learned over prior physiological signals and respirations being chronologically synchronized and physiological signal differences based on respiration learned.

[0036] In some cases these alterations compensate for an impact of a physical movement. This compensation enable the physiological signals to be correlated with other physiological signals having a same type.

[0037] In addition to the above alterations, signal-quality module **214** can alter after first determining a portion of the physiological signal that is likely to include noise or signal error. In such a case, the portion of the physiological signal is then chronologically synchronized to the physical movements for the patient. When those physical movements for the patient are determined likely to cause noise or signal error, the alteration reduces a weight of, corrects, or removes the portion of the physiological signal.

[0038] As noted above, some physical movements can be useful in assessing a patient's health. In such a case, signal-quality module **214** annotates the physiological signals based on the physical movement determined to match one of a set of previously determined physical movements useful in assessing cardiovascular health. Assume, for example, that bowel movements are useful in assessing cardiovascular health. A physical movement consistent with this bodily function is determined, and physiological signals matched to the bodily function are annotated. This permits later analysis, or current analysis of the patient's health, oftentimes in a manner that is either more helpful, or simply offering different data, than low-activity states of the patient. Other physical movements can also be annotated, such as a patient moving up her arms, singing, breathing, walking, and so forth.

[0039] CRM **208** also includes cardiovascular-function module **216**, which is configured to use altered physiological signals **114** to determine a health condition or trend. In the case of trends, cardiovascular-function module **216** uses physiological signals **114** (altered or unaltered) that are associated with particular dates to determine cardiovascular trends **218** in a hemodynamic characteristic **220**. CRM **208** also includes or has access to a user interface **222**, that, while not required, can be used to present determined trends, health, and medical advice to patient **102**.

[0040] Generally, cardiovascular-function module **216** is capable of determining, based on altered and unaltered physiological signals **114**, a hemodynamic characteristic of a cardiovascular system of a patient, such as patient **102** of FIG. **1**. With this hemodynamic characteristic, cardiovascular-function module **216** may alert patient **102** or medical professionals **104** or family members/caretakers of a negative health condition needing immediate care, for example. Medical professional **104**, or a specialized machine intelligence, can schedule an in-person appointment or remotely adjust patient care through changes in medication or lifestyle. Cardiovascular-function module **216** is also configured to determine trends based on the current hemodynamic characteristic and prior-determined hemodynamic characteristics.

[0041] More specifically, cardiovascular-function module **216** is capable of receiving and using physiological signals **114**, which indicates a patient's skin color, displacement, heart rate, blood pressure, and various other factors. This data may come from single or multiple physiological sensors **106** measuring the same or different locations on the patient's body. With this data, cardiovascular-function module **216** can determine pulse pressure waveforms and asymmetries in a patient's cardiovascular system. With this data and a circulatory distance between data from different regions of the patient, cardiovascular-function module **216** can determine a pulse-wave velocity and various simple or highly sophisticated measures of cardiovascular health, including charts of blood pressure, a ballistocardiogram, a photo-plethysmogram (PPG), and pressure-volume loops.

[0042] With regard to physiological sensors **106**, two examples of which are shown in FIG. **1**, and motion sensor **108**, consider a detailed illustration in FIG. **3**. Generally, physiological sensors **106** are capable of detecting blood pressure, blood volume, skin color, displacement and so

forth at one or more regions of a patient. Physiological sensors **106** may include a radar emitter and receiver, a standard RGB (red, green, blue) camera sensor, a monochrome sensor, a hyperspectral sensor, a stereoscopic sensor, a structured light sensor, a pressure sensor, an ultrasonic sensor, an electrical sensor (e.g., electrocardiograph (ECG) or an impedance cardiograph (ICG)), a reflective or transmissive PPG sensor, an audio sensor, or combinations of multiple sensors. Example emitters for sensing include one or a combination of nearly any of the electromagnetic spectrum in various forms, such as a combination of sources such as uniform, infrared, tangential, modulated/coded, or coherent (e.g., laser).

[0043] Motion sensors **108** are capable of detecting movement of patient **102**. This may include movement from as small as a chest movement from a heartbeat or breathing and a slight shiver from being cold, to as large a physical movement as walking, moving arms, standing or sitting, lying down or getting up, and so forth. Some of physiological sensors **106** are also capable of sensing movement, such as sensors **106-1**, **106-3**, **106-4**, **106-5**, **106-6**, and **106-7**. Further, in some cases motion sensor **108** is specialized to determine movement, such as some types of gesture sensors used in gaming systems, SONAR systems, and so forth.

[0044] For example, motion sensor **108** can be an electromagnetic sensor capable of capturing motion data as a signal in an optical, radio-frequency, or infrared bandwidth. Motion sensor **108** may capture multiple images over a short time frame to enable chronological synchronization on a sub-millisecond range, or at least multiple images within a single time period smaller than a smallest time period of a cardiovascular event. By so doing, physiological signals for even a single heartbeat can be altered to improve a portion of the signal.

[0045] Consider, by way of example, pressure and electrical-sensing mat **106-2** and the motion-sensing capabilities of a camera, e.g., motion sensor **108** or sensors **106-3**, **106-5**, or **106-6**. Patient **102** stands on the mat, which records physiological signals during a cardiovascular event (a heartbeat) of patient **102** through a pressure sensor sufficient to generate a BCG. Motion sensor **108** captures motion data as a video during the cardiovascular event. Both sensors include some sort of timing marker or are received at a same time. Motion module **212** of FIG. **2** determines, based on the video, physical movements of patient **102** leaning toward a mirror and thus putting more weight on the balls of her feet than on her heels, among other changes. Signal-quality module **214** receives the physiological signals from pressure and electrical-sensing mat **106-2**, and then chronologically synchronizing the physical movement to the physiological signals. Signal-quality module **214** then alters the physiological signals or portions thereof based on the physical movement. Cardiovascular-function module **216** may then determine a hemodynamic characteristic for the heartbeat, such as a pressure wave, blood pressure, or pressure-volume loop. If the physical movement is too large or disruptive, signal-quality module **214** may down-weight or delete the physiological signal. If the physical movement is useful diagnostically, signal-quality module **214** may instead annotate the physiological signal for later analysis, trending with similar movements, and so forth.

[0046] Physiological sensors **106** and motion sensor **108** may also have a fixed position or consist of one or more mechanical targeting platforms or those that simply move due to being part of a mobile device. These sensors may also be separated into physically and spatially distinct devices capable of monitoring the body from multiple view angles or observing different regions of the body. Thus, one of these sensors may capture an image indicating blood volume at two different regions of patient **102**.

[0047] In more detail, physiological sensor **106** can be one or a combination of various devices, whether independent, integral with, or separate but in communication with computing device **110**. Eight examples are illustrated in FIG. **3**, including hyperspectral sensor **106-1**, pressure and electrical-sensing mat **106-2**, color, displacement, and movement sensor **106-3** (e.g., a camera of computing device **110**), structured-light or stereoscopic sensor system **106-4**, optic sensor **106-5** of laptop **110-5**, a wearable color, displacement, and movement sensor **106-6**, which is part of computing spectacles **110-4**, radar lamp **106-7**, and ultrasonic bathtub **106-8**.

[0048] Hyperspectral sensor **106-1** is capable of capturing images in an ultraviolet, visible, or infrared optical wavelength. Images recording these wavelengths can be used to determine various changes in blood movement or as calibration signals to detect changes in illumination or patient movement. In some cases blood perfusion and oxygen content can be ascertained, thereby further enabling robust measurement of cardiac function. Due to differential wavelength absorption between human tissue and blood, a hyperspectral sensor can also be used to penetrate the skin to map out veins and arteries to target closer examination for displacement and other measurements.

[0049] As noted in part above, pressure and electrical-sensing mat **106-2** is configured to measure the arrival times of cardiac electrical signals (e.g., ECG), cardiac generated forces (e.g., BCG), and cardiac driven blood flow pulsatility (e.g., PPG). The combination of these can sense a pulse-wave velocity of patient **102**'s blood. This pulse-wave velocity is a measure of a patient's cardiovascular health.

[0050] The signal-to-noise ratio of the signals from pressure and electrical-sensing mat **106-2** can be improved through synchronization with the other sensors, including motion sensor **108** of FIG. **1**, to perform correlation techniques such as ensemble averaging and artifact rejection techniques through motion compensation. Further, the modules can synchronize physiological sensors **106** to enhance the processing of the physiological signals based on patient movement. Assume that motion sensor **108** or some other sensor **106** detects or determines physical movement of patient **102**. With this movement known, signal-quality module **214** alters, compensate, and/or selectively weight the physiological signals gathered by pressure and electrical-sensing mat **106-2**.

[0051] Structured-light sensor system **106-4** is capable of projecting structured light at patient **102** and sensing, often with two or more optical sensors, the projected structured light on patient **102** effective to enable capture of images having surface information. This surface information can be used to calculate depth and surface changes for a region of patient **102**, such as skin, another organ, or other structure. These changes can be highly accurate, thereby indicating small vibrations and other changes in an organ or structure caused by the cardiovascular system, and thus how that system is operating. Structured-light sensor system **106-4** can, alternatively, be replaced with or supplemented with a targeted, coherent light source for more-accurate displace-

ment measurements. This may include LIDAR (e.g., "light radar" or the process measuring distance by illuminating a target with a laser and analyzing light reflected from the target), laser interferometry, or a process of analyzing light speckle patterns produced by a coherent light on a skin's surface through optical tracking, which enables detection of very small skin displacements. These signals can be used a physiological signals or as motion data or both.

[0052] Radar lamp **106-7** is configured to reflect radiation from human tissue to measure heart rate, respiration rate, and skeletal movement, to name just three examples. Ultrasonic bathtub **106-8** is configured to generate high-frequency sound waves and to evaluate an echo from those waves. This echo is received at one or more sensors and the time interval between sending and receiving can be measured. These echoes enable analysis of internal body structures. In some cases, acoustic impedance of a two-dimensional cross-section of tissue can be measured, which can measure current heath or a health trend of the measured tissue. Blood flow, tissue movement, blood location, and three-dimensional measurements of structures can also be made. Non-active (no sound waves generated, just receiving sensors) can also be used, though accuracy and robust measurements are more difficult to achieve.

[0053] Some of these physiological sensors **106** capture images with sufficient resolution and at sufficient shutter speeds to show detailed colors and displacement, and thus enable determination of mechanical movements or vibrations. These mechanical movements and mechanical vibrations are sufficient to determine a ballistocardiogram (BCG) showing patient **102**'s cardiac function. Other sensing manners, such as color change or skin displacement in a different region of a patient's body, can be used to establish motion frequency bands to amplify, as well as a timing reference for aggregating multiple heartbeat measurements to improve accuracy of a BCG motion. This BCG information can also be used to provide reference timing information about when a blood pressure pulse leaves the left ventricle and enters the aorta, which combined with the other measurements across the body allow for more-precise estimates of pulse transit times and pulse-wave velocities.

[0054] While the BCG signal indicates the timing of the aortic valve, the timing of the atrial valve can be monitored by tracking atrial pressure waveforms visible in the external or internal jugular. This also allows the opportunity to detect atrial fibrillation by detecting missing atrial-pressure pulses. Additionally, aortic-wall stiffness has proven prognostic value in predicting cardiovascular morbidity and mortality. Measuring the pulse-transit time from the start of ejection from the left ventricle into the aorta and up the carotid allows an estimate of that aortic stiffness as well as trending of changes in that stiffness. Thus, determination of arterial-wall stiffness can made independent of blood pressure measurements.

[0055] In more detail, physiological sensors **106** are configured to capture sufficient information for the techniques to determine blood asymmetries and other cardiac function, including a pulse-wave velocity of patient **102**'s blood. This pulse-wave velocity is a measure of a patient's arterial health. In healthy arteries, the pulse-wave velocity is low due to the elasticity of the arteries but, as they harden and narrow, the pulse-wave velocity rises. As blood pressure increases and dilates the arteries, the walls become stiffer, increasing the pulse-wave velocity. While a particular pulse-wave velocity as a snapshot in time may or may not accurately indicate cardiovascular health (e.g., a one-time test at a doctor's office), a change in this pulse-wave velocity (that is, a trend), can be an accurate measure of a change in patient **102**'s cardiovascular health. If a positive trend, this can reinforce patient **102**'s healthy habits and, if negative, encourage changes to be made.

[0056] Cardiac-related measurements of a patient can include a patient's skin color sufficient to determine a photo-plethysmogram. This PPG measures variations in a size or color of an organ, limb, or other human part from changes in an amount of blood present in or passing through it. These colors and color variations in a patient's skin can show heart rate and efficiency.

[0057] Many of these physiological sensors **106** are non-invasive and even completely obscure to a patient. This often results in physiological signals that include errors, noise, and so forth. As noted, the techniques described herein alter those physiological signals to better permit accurate health conditions or trends for patients.

[0058] Returning to FIG. **3**, physiological sensor **106** or motion sensor **108** may have various computing capabilities, though it may instead be a low-capability device having little or no computing capability. Here physiological sensor **106** or motion sensor **108** includes one or more computer processors **302**, computer-readable storage media (CRM) **304**, measurement element **306**, and a wired or wireless transceiver **308** capable of receiving and transmitting information (e.g., to computing device **110**).

[0059] Measurement element **306** may include various different sensors, from optics, radar, pressure, movement, acceleration, and so forth. Examples includes ultrasonic, pressure, and simple or complex cameras, such as those having low or high shutter speeds, low or high frame rates, low or high resolutions, and having or not having non-visible imaging capabilities.

[0060] Computer-readable storage media **304** includes sensor manager **314** and sync-management module **316**. Sensor manager **314** is capable of processing physiological signals and recording and transmitting physiological signals, as well as receiving or assigning appropriate time markers by which to mark or compare the time of various captured images. These time markers can later be used by modules of computing device **110** to compare physical movement of a patient with a portion of physiological signal.

[0061] Sensor manager **314** and cardiovascular-function module **216** may also calibrate measurement element **306** through use of an external sensor. This can aid in calibrating skin colors or displacements to a calibration color or displacement, or even to a cardiac function, such as to a blood pressure or pulse-wave velocity. Thus, assume that one of physiological sensors **106** captures images for two regions while a blood pressure between those regions is also measured through a different device, thereby enabling more-accurate determination of cardiac functions for the physiological sensor and for that patient. Other potential calibration sensors include, but are not limited to, ECG, conventional BCG, digital stethoscopes, ultrasound, and the like. Another example is the use of an external blood pressure meter to calibrate the pulse wave velocity over time to determine long-term changes in arterial-wall stiffness by separating arterial stiffness due to blood pressure versus that due to the dilation by blood pressure.

[0062] These and other capabilities, as well as ways in which entities of FIGS. **1-3** act and interact, are set forth in greater detail below. These entities may be further divided, combined, and so on. The environment **100** of FIG. **1** and the detailed illustrations of FIGS. **2** and **3** illustrate some of many possible environments capable of employing the described techniques.

Example Methods

[0063] FIGS. **4** and **7** depict methods **400** and **700**, which alter physiological signals based on patient movement. These methods are shown as sets of blocks that specify operations performed but are not necessarily limited to the order or combinations shown for performing the operations by the respective blocks. In portions of the following discussion, reference may be made to environment **100** of FIG. **1** and entities detailed in FIGS. **2** and **3**, reference to which is made for example only. The techniques are not limited to performance by one entity or multiple entities operating on one device.

[0064] At **402**, captured motion data for a patient is received from a motion sensor. By way of an ongoing example, consider FIG. **5**, which shows a sensing milieu **500** in which patient **102** stands on pressure and electrical-sensing mat **106-2** and in front of hyperspectral sensor **106-1** and motion sensor **108**. Here motion sensor **108** captures motion data for patient **102** and passes it to a computing device, such as server **110-2** of FIG. **2**.

[0065] At **404**, physiological signals are received from a physiological sensor oriented to the patient. Continuing the example, assume hyperspectral sensor **106-1** captures a physiological signal for patient **102**, shown in FIG. **6** in physiological signal chart **600**, at PPG waveform **602**. Pressure and electrical-sensing mat **106-2** captures two physiological signals for patient **102**, ECG signal **604** and BCG signal **606**.

[0066] At **406**, physical movements of the patient are determined based on the captured motion data. As noted, motion sensor **108** captures motion data, here shown in a simplified form at motion data **608** in FIG. **6**. Based on this motion data **608**, motion module **212** determines a physical motion of patient **102**, here shown in picture form (though a signal form can instead be used), at arm motion **610**.

[0067] At **408**, the physical movements for the patient are chronologically synchronized with the physiological signals for the patient. Here signal-quality module **214** synchronizes arm motion **610** by synchronizing motion data **608** to physiological signals **602**, **604**, and **606** by a time period T illustrated in FIG. **6**.

[0068] At **410**, the physiological signals are altered based on the physical movements. As noted, signal-quality module **214** is configured to alter physiological signals **114**, such as a respiration physical movement used to improve a blood pressure physiological signal or a heart rate physical movement being used to alter a physiological signal for a skin color or skin volume change. In the ongoing example, signal-quality module **214** alters a portion **612** that likely includes noise or a signal error of BCG signal **606**. In this example the alteration to BCG signal **606** is simply to remove it and corresponding cardiac cycles of physiological signals **602** and **604** from use to determine a hemodynamic characteristic. These other physiological signals **602** and **604** may instead by used during those cardiac cycles, however. In this case many cardiac cycles and physiological signals are available, reducing any need to rely on the cardiac cycles having the noise or error. As noted, however, signal-quality module **214** may instead replace, annotate, or down-weight portion **612**.

[0069] At **412**, a hemodynamic characteristic of the patient is determined based on the altered physiological signals. Concluding the example of FIGS. **5** and **6**, portion **612** is removed, along with corresponding portions of physiological signals **602** and **604**. Cardiovascular-function module **216** then determines the hemodynamic characteristic for patient **102**.

[0070] At **414**, the altered signals from multiple cardiovascular events are correlated effective to determine a health trend. As noted with the Repeat Over Time arrow, multiple captured motion data and physiological signals can be attained and altered physiological signals determined. With these multiple, altered physiological signals, a trend can be determined by correlating these altered signals. By so doing, a health trend over extended periods, such as days, weeks, or even years can be determined. Or, for shorter periods where more than one signal for one type of event is desired, multiple altered physiological signals enable determination of better graphs representing heart health, such as a pressure-volume loop.

[0071] Signal-quality module **214** and cardiovascular-function module **216** may also use physiological signals where the alteration is an annotation indicating a particular physical movement. This particular physical movement can be correlated to the altered physiological signals of multiple same or similar physical movements to provide a robust hemodynamic measurement or trend for the particular physical movement. Examples of useful movements are provide above. In the example of FIGS. **5** and **6**, arm motion **610**, and similar other movements, may be useful in assessing some hemodynamic characteristics, such as determining blood pressure when an arm is in a high position over patient **102**'s heart, especially when using an imaging sensor, as vessels of patient **102**'s arm show blood pressure based on the arm's position relative to patient **102**'s heart.

[0072] FIG. **7** illustrates method **700**, in which physiological signals are altered based on patient movement, including through determining that a segment of the physiological signal is corrupt.

[0073] At **702**, a physiological signal for a patient is segmented at a time window, the time window matching a physical movement of the patient. Consider, for example, FIG. **8**, which includes portions of FIG. **6**. Here time window **802** is determined to match arm motion **610** and motion data **608**, thereby segmenting BCG signal **606** to include segment **804**.

[0074] At **704**, a quality of the physiological signal during the segment is determined based on the physical movement of the patient during the segment. This can be performed before, after, or concurrent with segmenting the physiological signal above. Thus, on determining that a patient is running, rapidly moving her arm and holding a loud hair dryer, driving, and so forth, a physiological signal measured during that physical movement can be determined to be of low quality. The information about the physical movement may indicate that this type of movement renders the physiological signal less accurate, less useful, or otherwise corrupt.

[0075] This determination of low quality can be dispositive, causing the physiological signal of the segment to be

altered or discarded. In some cases, however, further analysis is performed. For example, assume that signal-quality module **214** determines, based on the segment of the physiological signal and information about the physical movement, that the physiological signal in the segment is of low quality. After, concurrent, even prior to this determination, assume that signal-quality module **214** determines that the physiological signal of the segment resides outside of possible parameters for the physiological signal or its corresponding hemodynamic function, either generally, or for the patient based on prior data about the patient.

[0076] At **706**, responsive to the segment of the physiological signal being determined to be of low-quality, the segment is altered, down-weighted, removed, or replaced in the physiological signal. In some cases, altering the segment includes matching the segment with a previously calculated template, finding a prefix that minimizing a cost of the matching, aligning boundaries of the segment, and updating the physiological signal with the altered segment.

[0077] Consider a segment that indicates, on its face, a heart rate of **490** beats per minute in a healthy adult. This would be considered by signal-quality module **214** to be corrupt or at least suspect, which can then be confirmed based on the physical movement. To alter this, an immediately prior heart rate of **82** beats per minute, or after of **84** beats per minute, can replace the segment. Further, other physiological signals may be used that, for the same physical movement, do not appear to be corrupt. These signals in turn indicate that a heartbeat of **85** is appropriate. To replace the segment, a previously calculated template for the patient for a heartbeat of **85** can be used, this is shown with alteration **806** of FIG. **8**, which is then used to replace segment **804**.

[0078] Signal-quality module **214** may instead down-weight the segment effective to reduce, in a combination of physiological signals of multiple similar cardiovascular events, a weight of the segment. By so doing, the weight of the segment is reduced in determining a hemodynamic characteristic for the patient during the physical movement, such as to rely on physiological signals **602** and **604** instead of **606** as shown in FIG. **6**.

[0079] The preceding discussion describes methods relating to assessing cardiac function and altering physiological signals based on patient movement for a human cardiovascular system. Aspects of these methods may be implemented in hardware (e.g., fixed logic circuitry), firmware, software, manual processing, or any combination thereof These techniques may be embodied on one or more of the entities shown in FIGS. **1-3**, **5**, **6**, and **9** (computing system **900** is described in FIG. **9** below), which may be further divided, combined, and so on. Thus, these figures illustrate some of the many possible systems or apparatuses capable of employing the described techniques. The entities of these figures generally represent software, firmware, hardware, whole devices or networks, or a combination thereof.

Example Computing System

[0080] FIG. **9** illustrates various components of example computing system **900** that can be implemented as any type of client, server, and/or computing device as described with reference to the previous FIGS. **1-8**. In embodiments, computing system **900** can be implemented as one or a combination of a wired and/or wireless wearable device, System-on-Chip (SoC), and/or as another type of device or portion thereof. Computing system **900** may also be associated with a user (e.g., a patient) and/or an entity that operates the device such that a device describes logical devices that include users, software, firmware, and/or a combination of devices.

[0081] Computing system **900** includes communication devices **902** that enable wired and/or wireless communication of device data **904** (e.g., received data, data that is being received, data scheduled for broadcast, data packets of the data, etc.). Device data **904** or other device content can include configuration settings of the device, media content stored on the device, and/or information associated with a user of the device. Media content stored on computing system **900** can include any type of audio, video, and/or image data, including complex or detailed results of cardiac function determination. Computing system **900** includes one or more data inputs **906** via which any type of data, media content, and/or inputs can be received, such as human utterances, user-selectable inputs (explicit or implicit), messages, music, television media content, recorded video content, and any other type of audio, video, and/or image data received from any content and/or data source.

[0082] Computing system **900** also includes communication interfaces **908**, which can be implemented as any one or more of a serial and/or parallel interface, a wireless interface, any type of network interface, a modem, and as any other type of communication interface. Communication interfaces **908** provide a connection and/or communication links between computing system **900** and a communication network by which other electronic, computing, and communication devices communicate data with computing system **900**.

[0083] Computing system **900** includes one or more processors **910** (e.g., any of microprocessors, controllers, and the like), which process various computer-executable instructions to control the operation of computing system **900** and to enable techniques for, or in which can be embodied, such as altering physiological signals based on patient movement. Alternatively or in addition, computing system **900** can be implemented with any one or combination of hardware, firmware, or fixed logic circuitry that is implemented in connection with processing and control circuits, which are generally identified at **912**. Although not shown, computing system **900** can include a system bus or data transfer system that couples the various components within the device. A system bus can include any one or combination of different bus structures, such as a memory bus or memory controller, a peripheral bus, a universal serial bus, and/or a processor or local bus that utilizes any of a variety of bus architectures.

[0084] Computing system **900** also includes computer-readable media **914**, such as one or more memory devices that enable persistent and/or non-transitory data storage (i.e., in contrast to mere signal transmission), examples of which include random access memory (RAM), non-volatile memory (e.g., any one or more of a read-only memory (ROM), flash memory, EPROM, EEPROM, etc.), and a disk storage device. A disk storage device may be implemented as any type of magnetic or optical storage device, such as a hard disk drive, a recordable and/or rewriteable compact disc (CD), any type of a digital versatile disc (DVD), and the like. Computing system **900** can also include a mass storage media device **916**.

[0085] Computer-readable media **914** provides data storage mechanisms to store device data **904**, as well as various

device applications **918** and any other types of information and/or data related to operational aspects of computing system **900**. For example, an operating system **920** can be maintained as a computer application with computer-readable media **914** and executed on processors **910**. Device applications **918** may include a device manager, such as any form of a control application, software application, signal-processing and control module, code that is native to a particular device, a hardware abstraction layer for a particular device, and so on.

[0086] Device applications **918** also include any system components, modules, or managers to implement the techniques. In this example, device applications **918** include motion module **212**, signal-quality module **214**, and cardiovascular-function module **216**.

Conclusion

[0087] Although embodiments of techniques for, and apparatuses enabling, altering physiological signals based on patient movement have been described in language specific to features and/or methods, it is to be understood that the subject of the appended claims is not necessarily limited to the specific features or methods described. Rather, the specific features and methods are disclosed as example implementations of these techniques.

1. A system comprising:

one or more computer processors;

a physiological sensor configured to measure a physiological characteristic of a patient;

a motion sensor configured to capture motion data for the patient, the motion data comprising physical movement of the patient separate from the physiological characteristic of the patient;

one or more computer-readable media having instructions stored thereon that, responsive to execution by the one or more computer processors, perform operations comprising:

determining, based on the captured motion data, the physical movement of the patient;

receiving a physiological signal from the physiological sensor;

synchronizing chronologically the determined physical movement of the patient with the received physiological signal; and

altering the received physiological signal based on the determined physical movement.

2. The system of claim **1**, wherein the altering the received physiological signal down-weights the received physiological signal based on determining the physical movement comprises a physical movement indicative of a non-steady state or a non-resting state of the patient.

3. The system of claim **1**, wherein the altering the received physiological signal removes the received physiological signal or a portion thereof based on determining the physical movement comprises a disruptive physical movement of the patient.

4. The system of claim **1**, wherein the altering the received physiological signal alters the received physiological signal for a particular cardiovascular event based on determining the physical movement comprises a respiration of the patient, the respiration having a known effect on cardiovascular events.

5. The system of claim **1**, wherein the altered received physiological signal is effective to measure a hemodynamic characteristic of the patient.

6. The system of claim **5**, wherein the hemodynamic characteristic includes a pulse-wave velocity or pressure waves representing blood flow through an artery or vein of the patient.

7. The system of claim **1**, the operations further comprising determining, prior to the altering, a portion of the received physiological signal that is likely to include noise or signal error, and wherein the altering of the received physiological signal is based on the chronological synchronization matching a portion of the physical movement for the patient determined to cause noise or signal error with the determined portion of the received physiological signal that is likely include noise or signal error.

8. The system of claim **1**, the operations further comprising annotating the received physiological signal based on determining the physical movement comprises one of a set of previously determined physical movements useful in assessing cardiovascular health.

9. The system of claim **1**, wherein the motion sensor is an electromagnetic sensor and the captured motion data is captured as a signal in an optical, radio-frequency, or infrared bandwidth.

10. The system of claim **1**, wherein the motion sensor is camera configured to capture multiple images over a single time period smaller than a time period of a cardiovascular event.

11. The system of claim **1**, wherein the received physiological signal includes an electrocardiograph (ECG), a ballistocardiogram (BCG), a blood pressure, or a photoplethysmogram (PPG).

12. The system of claim **1**, wherein the physiological sensor comprises a pressure sensor and the physiological characteristic comprises pressure and wherein the pressure sensor senses the patient during a cardiovascular event, the motion sensor comprises a camera, the captured motion data comprises a video captured during the cardiovascular event, and the altering the received physiological signal is effective to down-weight noise in the received physiological signal.

13. A computer-implemented method comprising:

receiving, from a physiological sensor configured to measure a physiological characteristic of a patient, a physiological signal;

receiving, from a motion sensor configured to capture motion data for the patient, captured motion data comprising physical movement of the patient separate from the physiological characteristic of the patient;

chronologically synchronizing the physical movement for the patient with the received physiological signal for the patient; and

altering the received physiological signal based on the physical movement.

14. The computer-implemented method as described in claim **13**, further comprising determining, based on the altered received physiological signal, a hemodynamic characteristic of the patient.

15. The computer-implemented method as described in claim **13**, wherein the captured motion data and the received physiological signal is for a first cardiovascular event and further comprising repeating the method for a second cardiovascular event to provide a second altered received physiological signal and correlating the first and second

altered received physiological signals for the first and second cardiovascular events, respectively, effective to determine a health trend for the patient.

16. The computer-implemented method as described in claim **13**, wherein the physical movement is a respiration of the patient and altering the received physiological signal based on the physical movement alters the received physiological signal to improve a blood pressure measurement.

17. The computer-implemented method as described in claim **13**, wherein altering the received physiological signals annotates the received physiological signals, the annotation indicating a particular physical movement, and further comprising correlating the altered received physiological signal with a second altered received physiological signal having a same particular physical movement effective to provide a hemodynamic measurement of the patient for the particular physical movement.

18. A computer-implemented method comprising:

segmenting a physiological signal for a patient at a time window, the time window matching a physical movement of the patient, the physiological signal sensed by a physiological sensor and the physical movement sensed by a motion sensor, the physical movement separate from a physiological characteristic sensed by the physiological sensor;

determining, based on the physical movement of the patient, a quality of the physiological signal in the segment; and

responsive to the quality being determined to be a quality indicative of signal corruption, altering, down-weighting, removing, or replacing the segment of the physiological signal.

19. The computer-implemented method as described in claim **18**, wherein altering, down-weighting, removing, or replacing the segment replaces the segment with a previously calculated template.

20. The computer-implemented method as described in claim **18**, wherein altering, down-weighting, removing, or replacing the segment down-weights the segment effective to reduce, in a combination of physiological signals of multiple similar cardiovascular events, a weight of the segment in determining a hemodynamic characteristic or a trend in the hemodynamic characteristic.

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