(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 January 2017 (05.01.2017)

WIPO | PCT

(10) International Publication Number
WO 2017/001981 A1

(51) International Patent Classification:
A61B 5/00 (2006.01) *A61B 5/0402* (2006.01)
A61B 5/021 (2006.01) *A61B 5/145* (2006.01)
A61B 5/024 (2006.01) *A61B 5/1455* (2006.01)

(21) International Application Number:
PCT/IB2016/053733

(22) International Filing Date:
23 June 2016 (23.06.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/186,397 30 June 2015 (30.06.2015) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:

— *with international search report (Art. 21(3))*

(54) Title: MEASUREMENT RE-TAKE ALERT SYSTEM

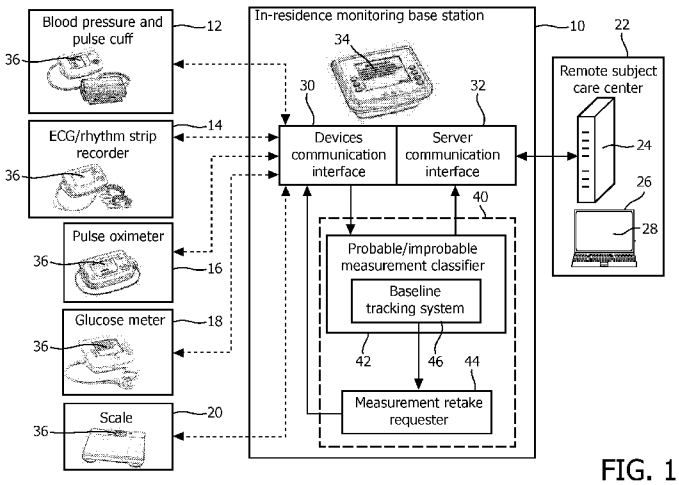

FIG. 1

(57) Abstract: One or more physiological monitoring devices (12, 14, 16, 18, 20) acquire physiological measurements of a subject. A base station (10) includes a devices communication interface (30) communicating with the physiological monitoring devices, a server communication interface (32) communicating with an electronic server (24), and an electronic data processor (40) programmed to: (i) identify physiological measurements from the physiological measurement device as probable or improbable using a probability criterion; (ii) output a message requesting a new physiological measurement be taken using the physiological measurement device in response to a physiological measurement taken using the physiological measurement device being identified as improbable; and (iii) transmit a physiological measurement taken using the physiological measurement device and identified as probable to an electronic server. The electronic data processor (40) may determine the probability criterion based on past physiological measurements from the physiological measurement device.

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MEASUREMENT RE-TAKE ALERT SYSTEM

FIELD

The following finds application in remote medical monitoring systems and devices, centralized medical monitoring systems, medical emergency response support systems, and the like.

BACKGROUND

In remote medical monitoring systems, also sometimes referred to as telehealth systems, vital signs are measured by a medical subject (e.g. patient) at home, and the self-measured vital signs are sent electronically to a nurse or other medical personnel for evaluation. This approach advantageously provides medical monitoring at frequent intervals without the cost of hospitalization or the use of visiting nurses to perform in-residence medical monitoring. In a common approach, a discharged hospital patient receives an in-residence visit from a technician who installs an in-residence base station and one or more physiological measurement devices prescribed by the patient's physician for measuring vital signs such as weight, blood pressure, heart rate, arterial blood oxygen saturation (SpO_2), blood glucose, or so forth. The devices are configured to wirelessly (or perhaps via wired connection) communicate physiological measurements to the base station. The technician trains the discharged patient to operate the physiological measurement devices to self-acquire vital sign measurements which are collected by the base station and transmitted from the base station to a centralized care server for review by a nurse or other medical personnel. Thereafter, the discharged patient performs self-measurement of vital signs using the in-residence devices on a routine basis.

In such applications, improbable measurements can arise, which are usually due to error in performing the self-measurements. For example, a blood pressure cuff may be misplaced or underinflated, or a pulse oximeter may be clipped onto a dirty fingertip. While likely due to measurement error, an improbable measurement could alternatively be a true measurement that is indicative of actual patient deterioration – thus, any improbable measurement is usually investigated by medical personnel, e.g. telephonically or by way of a visit to the residence. Dealing with such "false alarms" burdens medical monitoring personnel and can delays follow-up on improbable measurements.

Further, when medical personnel at the centralized station receive frequent improbable measurements which are mostly due to measurement error, there is a tendency to begin to assume that an abnormal measurement is probably due to measurement error. This desensitization to abnormal measurements can adversely impact prompt and effective follow-up of the (perhaps less frequent) abnormal measurement that is actually indicative of patient deterioration.

Disclosed herein are improvements that remediate the foregoing disadvantages and others.

BRIEF SUMMARY

In accordance with one aspect, a medical monitoring base station comprises: a devices communication interface configured to receive physiological measurements taken using a physiological measurement device from the physiological measurement device; a server communication interface configured to transmit physiological measurements received from the physiological measurement device to an electronic server; a measurement retake requestor (44) configured to generate a request to take a new physiological measurement using the physiological measurement device; and an electronic data processor. The electronic data processor is programmed to: (i) identify physiological measurements received via the devices communication interface from the physiological measurement device as probable or improbable using a probability criterion; (ii) cause the measurement retake requestor to request a new physiological measurement be taken using the physiological measurement device in response to a physiological measurement taken using the physiological measurement device being identified as improbable; and (iii) transmit a physiological measurement taken using the physiological measurement device and identified as probable to the electronic server via the server communication interface.

According to another aspect, a medical monitoring apparatus comprises a physiological monitoring device configured to acquire physiological measurements of a subject, and an electronic data processor programmed to: (i) identify physiological measurements from the physiological measurement device as probable or improbable using a probability criterion; (ii) output a message requesting a new physiological measurement be taken using the physiological measurement device in response to a

physiological measurement taken using the physiological measurement device being identified as improbable; and (iii) transmit a physiological measurement taken using the physiological measurement device and identified as probable to an electronic server.

According to another aspect, a medical monitoring method comprises: acquiring physiological measurements of a subject using a physiological monitoring device; identifying the acquired physiological measurements as probable or improbable using a probability criterion; outputting a human-perceptible message requesting a new physiological measurement be taken using the physiological measurement device in response to a physiological measurement being identified as improbable; and transmitting a physiological measurement identified as probable to an electronic server. In some embodiments, the physiological monitoring device is located in a residence of the subject and the method further comprises communicating the physiological measurements from the physiological monitoring device to a base station also located in the residence of the subject, wherein the physiological measurement identified as probable are transmitted from the base station to the electronic server.

One advantage resides in more accurate self-measurement of vital signs in the context of remote medical monitoring.

Another advantage resides in reduced reporting of erroneous vital sign self-measurements requiring remedial action in remote medical monitoring systems.

Further advantages of the subject innovation will be appreciated by those of ordinary skill in the art upon reading and understand the following detailed description. A given embodiment may achieve none, one, more, or all of these advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings are only for purposes of illustrating various aspects and are not to be construed as limiting.

FIGURE 1 diagrammatically shows an in-residence medical monitoring system.

FIGURE 2 diagrammatically shows illustrative approaches for identifying physiological measurement probability/improbability and issuing re-take requests performed by or in conjunction with the base station of FIGURE 1.

FIGURE 3 diagrammatically shows some suitable parameters of the baseline tracking system of FIGURES 1 and 2.

FIGURE 4 plots a comparison of actual blood oxygen saturation (SpO_2) measurements with SpO_2 measurements predictions output by an illustrative baseline tracking system described herein.

DETAILED DESCRIPTION

Improbable measurements due to measurement error could, in principle, be corrected simply by retaking the measurement. However, in the case of remote patient monitoring reliant upon self-measurement by the monitored subject (e.g. patient), the subject performing the self-measurement may lack the training, or in some cases the cognitive capacity, to recognize the improbability of the physiological measurement. Some subjects are also deferential to medical authority, even in the form of a medical device, and hence may be psychologically uncomfortable "overriding" the physiological measurement device by repeating the measurement. As a consequence, these improbable measurements are duly reported to the central server by base station, where in due course the nurse identifies the unexpected measurement and takes remedial action.

In improvements disclosed herein, the base station is programmed to use a suitable probability criterion to identify physiological measurements as probable or improbable. If the measurement is identified as probable, it is transmitted to the server in the normal course of activity. However, if a physiological measurement is identified as improbable, then a message is output requesting a new physiological measurement be taken using the physiological measurement device. This message may be output at the base station. Additionally or alternatively, the message may be output at the measurement device (e.g. if the measurement device has a programmable electronic data processor communicating with the base station and a display, voice synthesizer or the like capable of outputting the message). Outputting the message at the measurement device has the advantage that the monitored subject is located at that device since the subject just used the device to take the physiological measurement. If the new measurement performed in response to this message is identified as probable at the base station, then it is duly reported to the server. The previous, improbable measurement may be discarded, or alternatively may also be reported to the server for storage in order to maintain an auditable record but is not displayed to the nurse who is reviewing measurements coming in at the server. If the new measurement is still identified as improbable, then further new

measurements may be similarly requested by suitable messages; however, if one or more new measurements indicate the improbable measurement is reproducible then it is deemed to no longer be improbable and is reported for display to the nurse.

With reference to FIGURE 1, an illustrative embodiment of a medical monitoring apparatus includes an in-residence monitoring base station **10** and one or more physiological measurement devices, such as an illustrative blood pressure/pulse measurement cuff **12**, an electrocardiograph (ECG)/rhythm strip recorder **14**, a pulse oximeter **16**, a glucose meter **18**, and a weight scale **20**. Each physiological measurement device **12**, **14**, **16**, **18**, **20** is configured to acquire physiological measurements of a subject; that is, the physiological measurements are taken by the subject (i.e. self-measurement) using the physiological measurement devices **12**, **14**, **16**, **18**, **20**. By way of illustration, blood pressure and pulse measurements are taken using the blood pressure/pulse measurement cuff **12**, e.g. by placing the cuff over the subject's arm, inflating it, and then deflating it, with electronic sensors and an electronic data processor measuring systolic pressure, diastolic pressure, and pulse rate during the deflation. To use the ECG/rhythm strip recorder **14**, the subject attaches ECG electrodes to the body in a prescribed electrodes configuration and the ECG device processor electronically records an ECG trace and derives a heart rate from periodicity of the ECG. To use the pulse oximeter **16**, the subject clips a fingertip sensor component onto a finger and the pulse oximeter processor measures a photoplethysmography (PPG) signal at red and infrared wavelengths and determines pulse from the periodicity of the PPG signals and blood oxygen saturation based on a ratio of ratios of the PPG signals. To use the glucose meter **18**, the subject draws a blood sample and loads the blood sample onto a strip or other receptacle for blood glucose analysis by the processing device of the glucose meter **18**. To use the weight scale **20**, the subject stands on the scale **20** which automatically detects and records the subject's weight.

It will be appreciated that the illustrative physiological measurement devices **12**, **14**, **16**, **18**, **20** are merely described as illustrative examples, and that more generally the medical monitoring apparatus includes at least one physiological measurement device that can be used by the subject to take at least one physiological (self-)measurement. The level of automation of each physiological measurement device can vary widely. For example, in some embodiments the blood pressure cuff inflates automatically using an

electric pump, while in other embodiments the blood pressure cuff may need to be manually inflated using a manual hand pump. It will also be appreciated that the illustrative physiological measurement devices **12**, **14**, **16**, **18**, **20**, while designed to minimize likelihood of measurement error, still present numerous ways by which measurement error can occur. For example, the blood pressure cuff can be misplaced, the ECG electrodes can be misplaced or not connected well enough to properly measure the ECG signal, the pulse oximeter sensor can be clipped onto a dirty finger, and so forth. The various physiological measurement devices **12**, **14**, **16**, **18**, **20** may also include various levels of built-in error checking. For example, the blood pressure cuff **12** may detect insufficient inflation, the ECG **14** may detect the lack of periodicity in the ECG signal as an error, the pulse oximeter may detect lack of a pulsatile PPG signal component, or so forth. However, the various physiological measurement devices **12**, **14**, **16**, **18**, **20** may nonetheless be capable of acquiring physiological measurements that pass the various built-in error checks (if present) while still being improbable.

With continuing reference to FIGURE 1, the base station **10** is located in the residence of the subject (e.g. patient) who is the subject of the medical monitoring. The base station **10** serves as a physiological measurements aggregator and transmitter that collects physiological measurements taken using the various physiological measurement devices **12**, **14**, **16**, **18**, **20** and transmits them to a remote subject care center **22** comprising an electronic server **24** (e.g. a server computer or plurality of computers, e.g. a cloud computing resource) and a user interfacing device **26** such as a computer, a dumb terminal, or so forth having a display component **28** and connected with the server **24** by a wired or wireless local area network (LAN), the Internet, or the like. (Accordingly, the server **24** and the user interfacing device **26** are not necessarily located in geographical proximity to one another; indeed, the server **24** may be a distributed computing resource having no well-defined particular physical location). To perform these communication functions, the base station **10** includes a devices communication interface **30** configured to receive physiological measurements taken using the physiological measurement devices **12**, **14**, **16**, **18**, **20** from these devices; and a server communication interface **32** configured to transmit physiological measurements received from the physiological measurement devices **12**, **14**, **16**, **18**, **20** to the electronic server **24**. The two communication interfaces **30**, **32** may in general use different communication pathways

or media and different communication protocols. The devices communication interface **30** is typically operating over relatively short distances since the base station **10** is located in the same residence (e.g. house, apartment) as the physiological measurement devices **12**, **14**, **16**, **18**, **20**. Thus, the devices communication interface **30** may by way of illustration employ a short-range wireless radio protocol such as Zigbee™ or Bluetooth™ or WiFi™, or possibly a line-of-sight infrared link or a wired link. The server communication interface **32** is a long-distance communication link, and may for example employ a landline telephonic connection, or an Internet protocol (IP) interface via a 4G wireless link or a cable television link.

The in-residence medical monitoring apparatus includes the base station **10** and the one or more physiological measurement devices **12**, **14**, **16**, **18**, **20**. To provide for user interaction (i.e. user interfacing) with this apparatus, the various devices **10**, **12**, **14**, **16**, **18**, **20** may include buttons or other user input devices, although the number or quantity of these is preferably low to limit the complexity of user actions that need to be learned in order to perform the self-measurements. Additionally, the base station **10** and/or the various measurement devices **12**, **14**, **16**, **18**, **20** may include display components, e.g. a base station LCD display **34** or the like and/or various measurement device LCD displays **36** or the like. The measurement device displays **36** may be designed to display only the measurement values, or may also be programmed to display other messages – in the latter case, it is contemplated to employ the device display **36** to display a message requesting the new physiological measurement in the case of an initially acquired improbable measurement. Additionally or alternatively, the display component **34** of the base station **10** may be used for such messaging. It is also contemplated to include other communication pathways that are not illustrated, such as an audio speaker/speech synthesizer to provide messaging by synthesized speech, or an indicator light associated with a permanently affixed indicator label such as “Please retake measurement”.

With continuing reference to FIGURE 1, the base station **10** further includes a diagrammatically indicated electronic data processor **40**, such as a microprocessor or microcontroller with appropriate ancillary components such as memory integrated circuit (IC), interfacing ICs, or so forth. The electronic data processor **40** is programmed to perform data collection (in conjunction with the devices communication interface **30**) and

processing functions, and to control transmission of measurements to the server **24** via the server communication interface **32**. The data processing functions include implementation of a probable/improbable measurement classifier **42** and a measurement retake requester **44**. The measurement retake requester **44** may take various forms, depending upon how the retake request message is communicated to the subject. In one approach, the measurement retake requestor **44** comprises the electronic data processor **40** programmed to communicate to the physiological measurement device via the devices communication interface **30** a message requesting the new physiological measurement, and the measurement device displays the message on its display component **36**. In another approach, the electronic data processor **40** is programmed to display the retake request message on the display component **34** of the medical monitoring base station **10** (in which case the measurement retake requestor **44** of the base station **10** might be viewed as including the display component **34**). These two approaches are not mutually exclusive, i.e. the retake request can be displayed on both the base station display **34** and the measurement device display **36**, and as previously mentioned other communication pathways are contemplated such as a voice synthesizer/audio speaker.

The measurement classifier **40** classifies physiological measurements as probable or improbable. The probability criterion can be variously formulated. In general, the probability criterion is based on whether the physiological measurement is in a probable value range and, in the case of a measurement that is outside of the probable value range, on reproducibility of the physiological measurement upon one or more retakings in response to message(s) requesting a new physiological measurement.

For example, consider a heart rate measurement, where the probable value range is 70-90 beats/minute. If a heart rate measurement is in this range it is deemed a probable measurement and is reported to the server **24** via the server communication interface **32**. If it is outside this range then a retake request is issued. If the retaken measurement is in the 70-90 beats/minute range then it is likely the initial measurement was invalid due to measurement error – accordingly, the new measurement is reported to the server **24** and the initial improbable measurement is either discarded or reported to the server **24** with an annotation that the initial measurement is improbable. On the other hand, if the retaken measurement is still outside of the 70-90 beats/minute range then this indicates reproducibility which increases the likelihood that the measurement is indicative of the

actual heart rate. (Alternatively, it may be indicative that the same self-measurement error is being repeated.) To generalize, N retakes are requested (where N is an integer greater than or equal to 1). If the N retakes are performed and all measurements are outside the 70-90 beats/minute range then the measurement is then deemed a probable measurement, albeit with an abnormal value, possibly indicative of deterioration of the subject's medical condition, and is reported to the server **24**. (An alternative possibility is that the repeated measurements outside the 70-90 beats/minute range indicate that the subject is unable to operate the measurement device properly; but in either case remedial action will need to be taken by personnel at the remote subject care center **22**).

The number N of retakes can be as low as N=1, in which case the subject is asked just once to retake the measurement. Then number of retakes N should be low for several reasons. First, if the subject is repeatedly making a measurement error, e.g. two or three times, then remedial action is called for at least in order to provide the subject with retraining. Second, the subject may become annoyed or alarmed by being requested to retake the physiological measurement multiple times. Third, as the number of retakes increases the possibility increases that a "true" abnormal measurement (that is, a measurement that is abnormal but physiologically real) may be masked by an erroneous measure that, by chance, falls in the probable value range. Thus, N=1 or N=2 is preferable in many contemplated implementations.

The probable value range may, in some embodiments, be subject-specific, for example being based on past physiological measurements of the subject, preferably over a limited past time horizon. To this end, a baseline tracking system **46** is optionally provided to assess the range of measurement over the past few days (for example) in order to set the subject-specific probable value range.

It is also contemplated to incorporate cross-modality factors into the probability criterion. For example, if two (or more) different physiological measurements are taken at the same time using the same physical device (e.g., pulse and oxygen saturation in the case of the pulse oximeter **16**) then if both these measurements lie outside of their respective probable values ranges this may be more indicative of an improbable measurement as compared with if only one of these measurements is outside of its probable value range. This follows since one measurement being in its probable value range is suggestive that the measurement device was being used properly.

As another example of a cross-modality factor that may be incorporated into the probability criterion, if two (or more) different physiological measurement devices measure the same physiological parameter (e.g., the blood pressure cuff **12**, the ECG **14**, and the pulse oximeter **16** each measure cardiac pulse) then these nominally duplicative measurements may be leveraged in assessing probability. For example, if the blood pressure cuff **12** and ECG **14** indicate a pulse in the probable value range but the pulse oximeter **16** produces a pulse outside of the probable value range, this reinforces the likelihood that the pulse oximeter **16** is producing an erroneous pulse value.

As yet another example of a cross-modality factor, the probable value range for one physiological measurement may be a function of the value of another physiological measurement. For example, a high pulse may indicate exertion or stress which is normally accompanied by an elevated blood pressure due to the exertion or stress, so that the probable value range for blood pressure may be increased upward with increasing heart rate. It is also contemplated for the probable value range to be dependent on factors such as time of day, e.g. pulse rate may tend to be lower immediately after waking as compared with in the middle of the day.

The probable value range for a given physiological measurement may be the same as the range for that measurement for normal physiology, but this is not necessarily the case. For example, one practical choice for the probable value range is that range over which personnel at the remote subject care center **22** are not required to take remedial action. Since the goal is to reduce the frequency at which such remedial action is required, using this choice for the probable value range ensures that any measurement that would require remedial action is first retaken by the patient to verify its value. By contrast, a measurement could be slightly above (or below) the range for normal physiology without reaching the threshold for remedial action, so the normal range in this case is smaller than the probable value range.

With reference to FIGURE 1 and with further reference to FIGURE 2, a suitable processing flow for identifying and retaking improbable physiological measurements is illustrated. In an operation **60** the subject acquires the self-measurement. In an operation **62**, the measurement classifier **42** is identifies whether the measurement is within the probable value range for that physiological parameter. If it is in the probable value range then the measurement is deemed a probable measurement and is transmitted via the

server communication interface **32** to the server **24** in an operation **64**. On the other hand, if the operation **62** identifies the measurement as outside of the probable value range then in an operation **66** it is checked whether the number of retakes has reached the maximum designated by the integer N. Since N is at least one, the first pass through operation **66** always outputs the negative (since no retakes have yet been performed) and flow passes to an operation **68** where the measurement retake requester **44** is invoked to present a message requesting a measurement retake. The existing measurement is discarded or, in an optional operation **70**, is transmitted to the server **24** with a suitable annotation indicating the measurement should merely be logged in a data log for auditing purposes. In response to the retake request message **68**, the subject re-executes operation **60** to acquire a new self-measurement, and process flow continues thusly until either (1) a new measurement is identified in operation **62** as within the probable range and transmitted as per operation **64**; or (2) the maximum number of retakes N is reached as detected in check operation **66**, at which point process flow passes to operation **70** which transmits the last new measurement which, in view of its being reproducible, is now deemed a probable measurement. (Alternatively, the operation **70** in this case may transmit a median, average, or other aggregate value of the N measurements).

With continuing reference to FIGURES 1 and 2, the optional subject-specific baseline tracking system **46** operates in parallel, i.e. in an operation **74** the physiological self-measurement **60** is added to the measurement history and used to update or refine the subject-specific probable value range used in the operation **62**.

The disclosed approach immediately notifies the patient (i.e. subject) when a physiological self-measurement is improbable, and requests a new measurement be taken. Optionally, the request includes a recommendation on how to use the physiological measurement device to acquire the new physiological measurement. Such a recommendation may be made based on common causes of a given improbable measurement. For example, if the failure to secure a particular ECG electrode commonly produces a certain type of improbable measurement, then a request to retake an ECG trace using the ECG recorder **14** may optionally include a recommendation to check that particular ECG electrode. Similarly, if a failure to sufficiently pressurize the blood pressure cuff of the blood pressure measurement device **12** commonly produces an improbably low systolic pressure reading then the request to retake a blood pressure

measurement using the blood pressure measurement device **12** may include a recommendation to increase the inflation of the cuff.

With continuing reference to FIGURE 1 and with further reference to FIGURE 3, an illustrative embodiment of the optional subject-specific baseline tracking system **46** is described. The baseline tracking system (BTS) **46** takes new physiological measurements as input and creates a personalized (i.e. subject-specific) profile for the subject. This profile is used to estimate the probable value range of the probability criterion used to identify a measurement as probable or improbable. In the illustrative BTS embodiment described with reference to FIGURE 3, the BTS evaluates each vital sign in isolation (i.e. no cross-modality information is utilized). The illustrative BTS of FIGURE 3 uses up to 5 days of previous data in assessing the probable value range. In the case of complete historical data (i.e. a full 5 days of data), the mean of the 5 previous days are used to create an estimate of the probable value range for the physiological measurement for Day 5. When only 4 days of data are available, the 4-day mean is used. When fewer than 4 days are available, the mean of up to 3 days' values are used as reference, allowing 1 or 2 missing values. In this illustrative example no reference is available on the first day, but if a baseline value is manually entered or is carried over from a hospital system then this value may be used as a substitute.

With reference to FIGURE 4, an example is shown of the performance of such a single-parameter baseline tracker system, as applied to SpO_2 values measured by a pulse oximeter. In this example, individual historical measurements were used as described previously herein with reference to FIGURE 3 to create predictions of new SpO_2 measurements. The correlation of predictions to actual measurements was 0.87, indicating that the BTS can create a reliable estimate of the expected value, which in turn can be used by the probable/improbable measurement classifier **42**.

Additional embodiments are contemplated to make use of additional information to create improved estimates of the probable value range. For example, in a multi-parameter estimation technique, related vital signs (e.g. systolic and diastolic blood pressure) are considered in concert when determining their expected future values. Another contemplated embodiment combines historical data of a vital sign (e.g. heart rate) with the current value of other vital signs, such as systolic and diastolic blood pressure, in order to estimate the probable value range of a new heart rate measurement.

For example, if a subject is taking blood pressure and heart rate self-measurements every day (days 0 to n-1), on a next day n the subject takes a new set of readings for blood pressures and heart rate. To estimate the probable value range of the heart rate, historical heart rate values are used to create an initial estimate, while the other vital signs (e.g. systolic and diastolic blood pressure) taken on day n are used to adjust this expectation. For example, if the historical heart rate values would suggest an estimate of 60 beats/minute for the heart rate on day n, but the blood pressure readings are elevated on day n, it may be expected that the heart rate is also elevated on day n, and thus the average or centroid of the probable value range for heart rate may be adjusted upward to 64 beats/minute (as an example).

The probable/improbable measurement classifier **42** takes as input the probable value range from the baseline tracker system **46** (or, alternatively, uses a fixed probable value range chosen on some other basis, such as designated as the range of values for which no remedial action by medical personnel is required) and the current set of physiological measurements acquired by the subject using the various measurement devices **12**, **14**, **16**, **18**, **20**. The measurement classifier **42** uses this information to evaluate the plausibility of physiological measurements, in the context of the patient's physiological history in embodiments that employ the baseline tracking system **46**.

In some embodiments, the probable value range is specified in a manner other than by specifying lower and upper limits. For example, the measurement classifier **42** can compare the physiological measurement with the probable value range using a deviation test, where the probable value range is defined as some deviation from a most probable measurement value, i.e. expected measurement value. In this test, the absolute or relative difference between the acquired physiological measurement and the prediction (i.e. most probable value) is calculated, and measurement is accepted if it is within a range of values around the prediction (i.e. deemed probable), or is deemed improbable if it is outside this range. The acceptable range of values may be determined by a deviation threshold value, which can be manually input by the care provider (e.g. 5% deviation considered acceptable), or can be learned by the system as part of the baseline tracking component **46**. In this embodiment, the system **46** suitably learns the appropriate value of the threshold based on manually labeled patient data, and using manual labels of outliers to characterize the definition of outlier values. In one test of this approach for SpO_2 data,

a threshold of 1.5% deviation resulted in a test for outliers with 99% sensitivity and 99% specificity.

The maximum number of measurement retakes, designated as N herein without loss of generality, impacts the measurement filtering provided by the disclosed approach. The maximum number N of requested measurement retakes can be set to balance workflow requirements (additional numbers of repeats improve filtering quality, reducing false positives and improving nurse workflow) and patient convenience (fewer measurements reduce measurement time for patients). Depending on the number of measurements, different filtering mechanisms may be deployed, as in the following illustrative examples.

In the illustrative example of FIGURE 1, the probable/improbable measurement classifier **42** (with optional baseline tracker **46**) and the measurement retake requester **44** are implemented by suitable programming of the electronic data processor **40** of the in-residence base station **10**. This approach has certain advantages, including enabling leveraging of the components **42**, **44**, **46** for assessing probability of different physiological measurements from different measurement devices, facilitating using cross-modality probability criteria (since data from different modalities are collected at the base station **10**) and minimizing latency (since the base station **10** communicates directly with the various measurement devices **12**, **14**, **16**, **18**, **20** via relatively reliable short-range communication pathways.

Alternatively, the measurement classifier and retake request functionality may be implemented at the remote server **24** which has sufficient processing capacity. In this approach all measurements are transmitted from the base station to the central server without probability filtering which is performed at the server. A disadvantage of this approach is potentially longer latency times between measurement acquisition and the retake request, and the need for the server to be programmed to handle all different types of measurement devices used by all residential subjects serviced by the server.

In another alternative, the measurement classifier and retake request funcationality may be implemented at each respective measurement device **12**, **14**, **16**, **18**, **20**. This approach advantageously has the smallest potential latency, but requires that each measurement device **12**, **14**, **16**, **18**, **20** have sufficient processing capacity (i.e. includes an electronic data processor that can be suitably programmed to implement

measurement probability assessment and to make the measurement retake request as appropriate). Also, implementation at the measurement device limits the possibilities for cross-modality probability criterion factors to those modalities supported by the device (e.g. since the pulse oximeter **16** measures both cardiac pulse and blood oxygen saturation cross-modality factors between pulse and oxygenation are feasible.

The illustrative embodiments are directed to in-residence self-monitoring. However, it will be appreciated that the disclosed medical monitoring base station embodiments and medical monitoring apparatus embodiments may be readily employed in other contexts where physiological measurements are collected by person(s) with limited medical training and conveyed to a central server for more detailed evaluation by more highly trained personnel. For example, another contemplated application is patient monitoring at rural medical centers that may be staffed by local volunteers with limited medical training. In this application the base station **10** and measurement devices **12**, **14**, **16**, **18**, **20** are not located in an individual's residence but rather in the rural medical center, and the measurements may not necessarily be self-performed but rather may be performed by a volunteer medical center staffer with limited medical training.

The innovation has been described with reference to several embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the innovation be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS

Having thus described the preferred embodiments, the invention is now claimed to be:

1. A medical monitoring base station (10) comprising:

a devices communication interface (30) configured to receive physiological measurements taken using a physiological measurement device (12, 14, 16, 18, 20) from the physiological measurement device;

a server communication interface (32) configured to transmit physiological measurements received from the physiological measurement device to an electronic server (24);

a measurement retake requestor (44) configured to generate a request to take a new physiological measurement using the physiological measurement device; and

an electronic data processor (40) programmed to:

(i) identify physiological measurements received via the devices communication interface from the physiological measurement device as probable or improbable using a probability criterion and

(ii) cause the measurement retake requestor to request a new physiological measurement be taken using the physiological measurement device in response to a physiological measurement taken using the physiological measurement device being identified as improbable and

(iii) transmit a physiological measurement taken using the physiological measurement device and identified as probable to the electronic server via the server communication interface.

2. The medical monitoring base station (10) of claim 1 wherein the measurement retake requestor (44) comprises the electronic data processor (40) programmed to communicate to the physiological measurement device (12, 14, 16, 18, 20) via the devices communication interface (30) a message requesting the new physiological measurement be taken using the physiological measurement device.

3. The medical monitoring base station (10) of claim 1 wherein the measurement retake requestor (44) comprises:

a display component (34) of the medical monitoring base station (10); and

the electronic data processor (40) programmed to display a message on the display component of the medical monitoring base station requesting the new physiological measurement be taken using the physiological measurement device (12, 14, 16, 18, 20).

4. The medical monitoring base station (10) of any one of claims 2-3 wherein the message requesting the new physiological measurement be taken using the physiological measurement device (12, 14, 16, 18, 20) includes a recommendation on how to use the physiological measurement device to acquire the new physiological measurement.

5. The medical monitoring base station (10) of any one of claims 1-4 wherein the electronic data processor (40) is further programmed to:

(iv) transmit a physiological measurement taken using the physiological measurement device (12, 14, 16, 18, 20) and identified as improbable to the electronic server (24) via the server communication interface (32) with the transmitted physiological measurement annotated as improbable.

6. The medical monitoring base station (10) of any one of claims 1-5 wherein:

the probability criterion identifies a physiological measurement as probable if the physiological measurement is within a probable value range or if the physiological measurement has been retaken via the operation (ii) a number N times where N is an integer greater than or equal to one, and

the probability criterion identifies a physiological measurement as improbable if the physiological measurement it is outside the probable value range and the physiological measurement has been retaken via the operation (ii) less than the number N times.

7. The medical monitoring base station (10) of claim 6 wherein the identify operation (i) employs a subject-specific probable value range.

8. The medical monitoring base station (10) of claim 7 wherein the electronic data processor (40) is further programmed to determine the subject-specific probable value range based on past physiological measurements of the subject received from the physiological measurement device (12, 14, 16, 18, 20).

9. A medical monitoring apparatus comprising:

a physiological monitoring device (12, 14, 16, 18, 20) configured to acquire physiological measurements of a subject; and

an electronic data processor (40) programmed to:

(i) identify physiological measurements from the physiological measurement device as probable or improbable using a probability criterion,

(ii) output a message requesting a new physiological measurement be taken using the physiological measurement device in response to a physiological measurement taken using the physiological measurement device being identified as improbable, and

(iii) transmit a physiological measurement taken using the physiological measurement device and identified as probable to an electronic server (24).

10. The medical monitoring apparatus of claim 9 further comprising:

a base station (10) including a devices communication interface (30) communicating with the physiological monitoring device (12, 14, 16, 18, 20), a server communication interface (32) communicating with the electronic server (24), and the electronic data processor (40).

11. The medical monitoring apparatus of claim 10 wherein the server communication interface (32) is an Internet protocol (IP) interface.

12. The medical monitoring apparatus of any one of claims 9-11 wherein the physiological measurement device (12, 14, 16, 18, 20) includes one or more physiological measurement devices selected from the group consisting of a blood pressure measurement

device (12), an electrocardiogram (14), a pulse oximeter (16), a glucose meter (18), and a weight scale (20).

13. The medical monitoring apparatus of any one of claims 9-12 wherein the electronic data processor (40) is further programmed to:

(iv) transmit a physiological measurement taken using the physiological measurement device (12, 14, 16, 18, 20) and identified as improbable to the electronic server (24) with the transmitted physiological measurement annotated as improbable.

14. The medical monitoring apparatus of any one of claims 9-13 wherein:

the probability criterion identifies a physiological measurement as probable if the physiological measurement is within a probable value range or has been reproduced over N new physiological measurements performed in response to operation (ii) where N is an integer greater than or equal to one, and

the probability criterion identifies a physiological measurement as improbable otherwise.

15. The medical monitoring apparatus of any one of claims 9-14 wherein the electronic data processor (40) is further programmed to determine the probability criterion based on past physiological measurements from the physiological measurement device (12, 14, 16, 18, 20).

16. The medical monitoring apparatus of claim 15 wherein the electronic data processor (40) determines the probability criterion based on past physiological measurements only over a finite past time horizon.

17. A medical monitoring method comprising:

acquiring physiological measurements of a subject using a physiological monitoring device (12, 14, 16, 18, 20);

identifying the acquired physiological measurements as probable or improbable using a probability criterion;

outputting a human-perceptible message requesting a new physiological measurement be taken using the physiological measurement device in response to a physiological measurement being identified as improbable; and

transmitting a physiological measurement identified as probable to an electronic server (24).

18. The medical monitoring method of claim 17 wherein the physiological monitoring device (12, 14, 16, 18, 20) is located in a residence of the subject and the method further comprises:

communicating the physiological measurements from the physiological monitoring device to a base station (10) also located in the residence of the subject;

wherein the transmitting comprises transmitting the physiological measurement identified as probable from the base station to the electronic server (24).

19. The medical monitoring method of any one of claims 17-18 further comprising:

transmitting a physiological measurement identified as improbable to the electronic server (24) with an annotation that the physiological measurement is improbable;

storing all measurements received at the electronic server; and

displaying at a display component (28) in communication with the electronic server only those measurements received at the electronic server that are not annotated as improbable.

20. The medical monitoring method of any one of claims 17-19 wherein the physiological measurements include at least one of blood pressure measurements, electrocardiographic measurements, cardiac pulse measurements, blood oxygen saturation measurements, blood glucose measurements, and weight measurements.

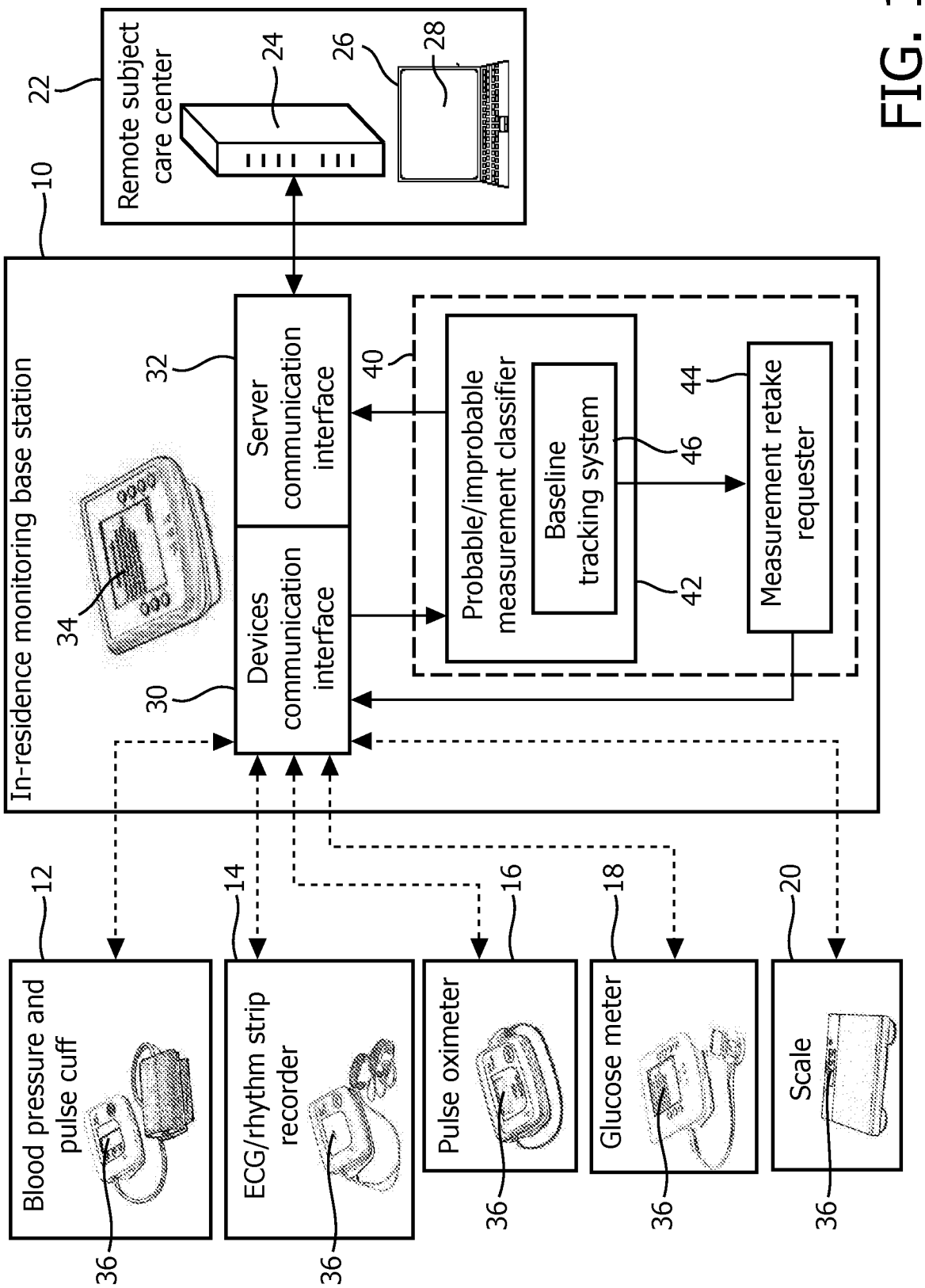
Remote subject care center
22
24
26
28
10
In-residence monitoring base station
32
Server communication interface
40
Probable/improbable measurement classifier
Baseline tracking system
46
44
Measurement retake requester
42
34
30
Devices communication interface
Blood pressure and pulse cuff
12
ECG/rhythm strip recorder
14
Pulse oximeter
16
Glucose meter
18
Scale
20
36
36
36
36
36

FIG. 1

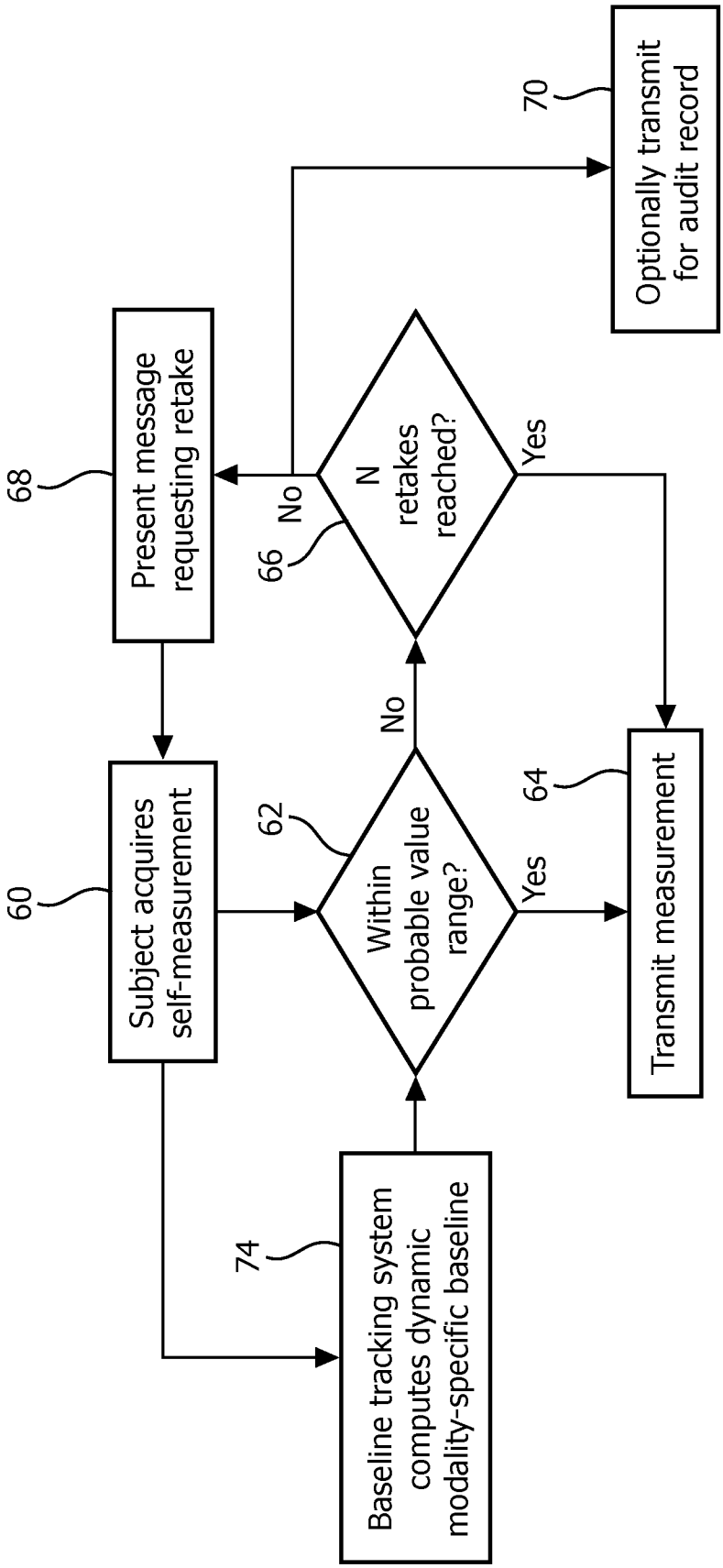
Subject acquires self-measurement
60
Within probable value range?
62
No
Yes
Transmit measurement
64
N retakes reached?
66
No
Yes
Present message requesting retake
68
Optionally transmit for audit record
70
Baseline tracking system computes dynamic modality-specific baseline
74

FIG. 2

Raw Values	Reference values	Number of allowed missing reference values
Day 0	None	---
Day 1	Day 0	3-day mean Allows 1 or 2 missing
Day 2	mean(Days 0,1)	3-day mean Allows 1 or 2 missing
Day 3	mean(Days 0,1,2)	3-day mean Allows 1 or 2 missing
Day 4	mean(Days 0,1,2,3)	4-day mean No missing values allowed
Day 5	mean(Days 0,1,2,3,4)	5-day mean No missing values allowed
Missing	mean(Days 1,2,3,4,5)	5-day mean No missing values allowed
Day 7	mean(Days 4,5)	3-day mean Allows 1 or 2 missing
Day 8	mean(Days 5,7)	3-day mean Allows 1 or 2 missing
Day 9	mean(Days 7,8)	3-day mean Allows 1 or 2 missing

FIG. 3

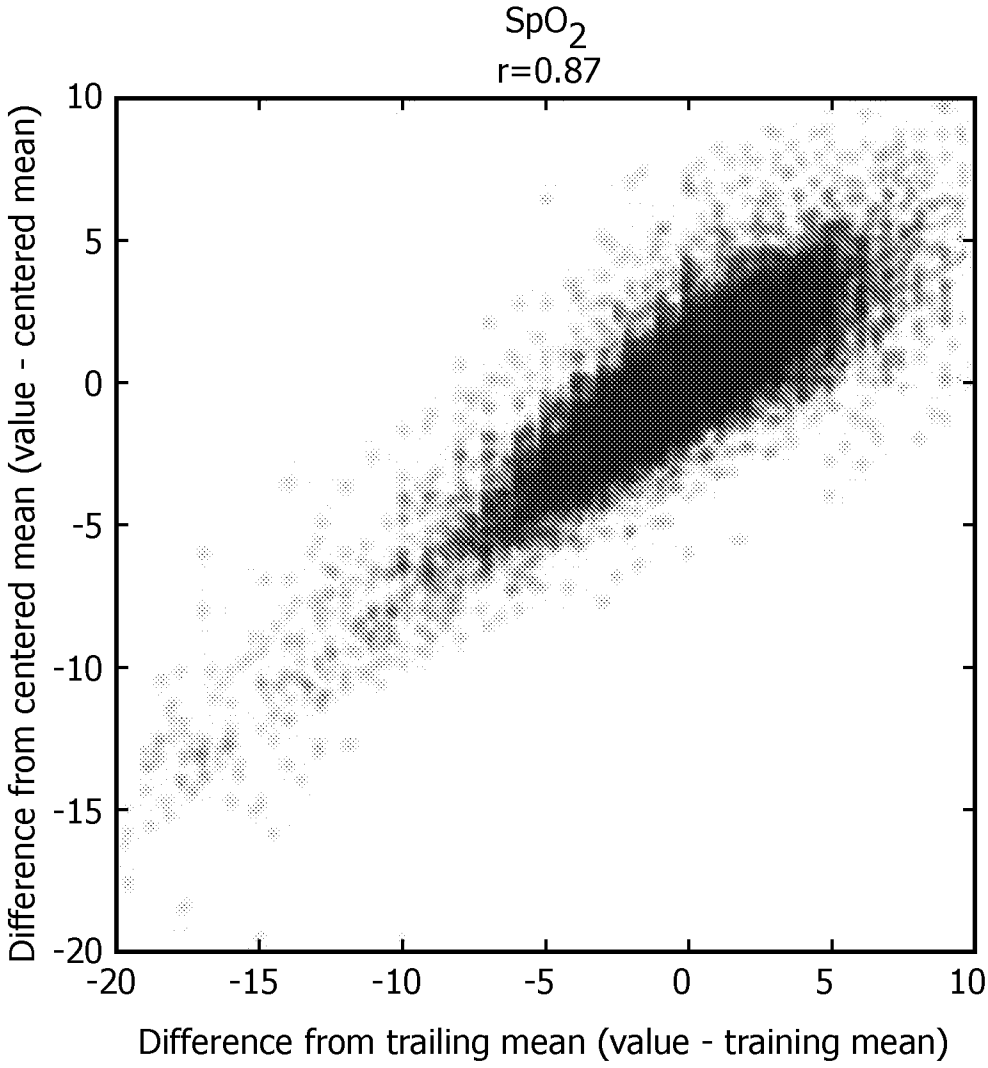
SpO2
r=0.87
Difference from centered mean (value - centered mean)
Difference from trailing mean (value - training mean)
10
5
0
-5
-10
-15
-20
-20
-15
-10
-5
0
5
10

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2016/053733

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/00
ADD. A61B5/021 A61B5/024 A61B5/0402 A61B5/145 A61B5/1455

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/171749 A1 (CHIN HON WAH [US] ET AL) 19 June 2014 (2014-06-19)	1-7, 9-14, 17-20
Y	paragraphs [0009], [0043], [0057], [0081], [0088], [0089], [0097], [0111], [0119], [0163], [0223], [0225], [0226] figures 1, 2, 4, 5	8,15,16
Y	EP 2 851 820 A1 (FUJITSU LTD [JP]) 25 March 2015 (2015-03-25) paragraphs [0016], [0018], [0040]	8,15,16
A	WO 2014/027298 A1 (KONINKL PHILIPS NV [NL]) 20 February 2014 (2014-02-20) page 7, lines 22-26, 32 - page 8, line 16	1-20

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 September 2016	16/09/2016

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2016/053733

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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EP 2851820 A1	25-03-2015	EP 2851820 A1	25-03-2015
		US 2015088463 A1	26-03-2015
WO 2014027298 A1	20-02-2014	CN 104519790 A	15-04-2015
		EP 2884885 A1	24-06-2015
		JP 2015529099 A	05-10-2015
		US 2015216437 A1	06-08-2015
		WO 2014027298 A1	20-02-2014