



(12) BREVET CANADIEN
CANADIAN PATENT
(13) C

(86) Date de dépôt PCT/PCT Filing Date: 2013/12/06
(87) Date publication PCT/PCT Publication Date: 2014/06/19
(45) Date de délivrance/Issue Date: 2020/10/27
(85) Entrée phase nationale/National Entry: 2015/06/10
(86) N° demande PCT/PCT Application No.: IB 2013/060707
(87) N° publication PCT/PCT Publication No.: 2014/091382
(30) Priorité/Priority: 2012/12/14 (US61/737,410)

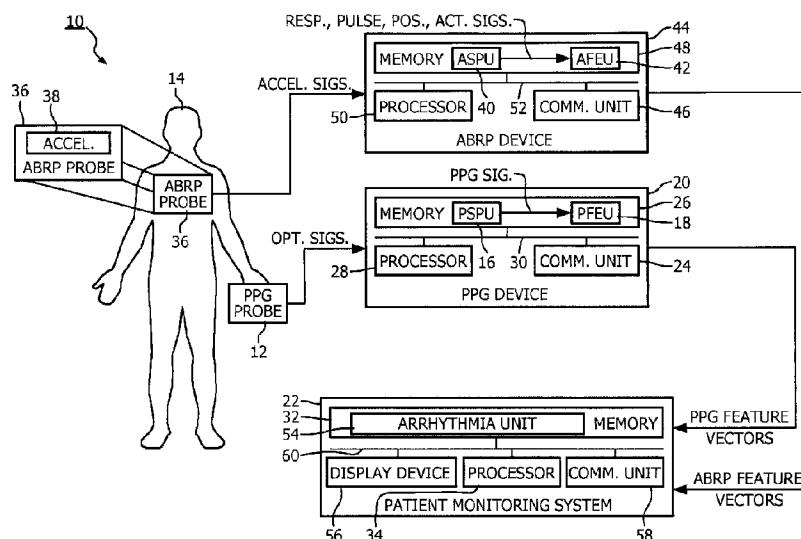
(51) CI.Int./Int.Cl. A61B 5/024 (2006.01),
A61B 5/0205 (2006.01), A61B 5/021 (2006.01),
A61B 5/11 (2006.01), A61N 1/05 (2006.01),
A61N 1/365 (2006.01), A61B 5/00 (2006.01)

(72) Inventeur/Inventor:
GROSS, BRIAN DAVID, NL

(73) Propriétaire/Owner:
KONINKLIJKE PHILIPS N.V., NL

(74) Agent: SMART & BIGGAR LLP

(54) Titre : SYSTEME ET PROCEDE POUR DETECTER DES EVENEMENTS ARYTHMIQUES IMPORTANTS A L'AIDE D'UN PHOTOPLETHYSMOGRAPHE (PPG) ET D'UN ACCELEROMETRE
(54) Title: A SYSTEM AND METHOD TO DETECT SIGNIFICANT ARRHYTHMIC EVENTS THROUGH A PHOTOPLETHYSMOGRAM (PPG) AND ACCELEROMETER



(57) Abrégé/Abstract:

A medical system (10) and method detect arrhythmic events. The medical system (10) includes at least one processor (28, 34, 50) programmed to perform the method. A photoplethysmogram (PPG) signal generated using a PPG probe (12) positioned on or within a patient (14) and a pulse signal generated using an accelerometer (38) positioned on or within the patient (14) are received. Features from the PPG signal are extracted to PPG feature vectors, and features are extracted from the pulse signal to pulse feature vectors. The PPG feature vectors are correlated with the pulse feature vectors, and correlated PPG feature vectors and correlated pulse feature vectors are evaluated to detect arrhythmic events.

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

(19) World Intellectual Property Organization International Bureau



(10) International Publication Number

WO 2014/091382 A1

(43) International Publication Date
19 June 2014 (19.06.2014)

WIPO | PCT

(51) International Patent Classification:

A61B 5/024 (2006.01) *A61N 1/05* (2006.01)
A61B 5/0205 (2006.01) *A61N 1/365* (2006.01)
A61B 5/11 (2006.01) *A61B 5/00* (2006.01)
A61B 5/021 (2006.01)

DO, DZ, FC, 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, LT, 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.

(21) International Application Number:

PCT/IB2013/060707

(22) International Filing Date:

6 December 2013 (06.12.2013)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

61/737,410 14 December 2012 (14.12.2012) US

(71) Applicant: KONINKLIJKE PHILIPS N.V. [NL/NL];
High Tech Campus 5, NL-5656 AE Eindhoven (NL).

(72) Inventor: GROSS, Brian David; c/o High Tech Campus 5, NL-5656 AE Eindhoven (NL).

(74) Agents: STEFFEN, Thomas et al.; High Tech Campus 5, NL-5656 AE Eindhoven (NL).

(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,

(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, 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).

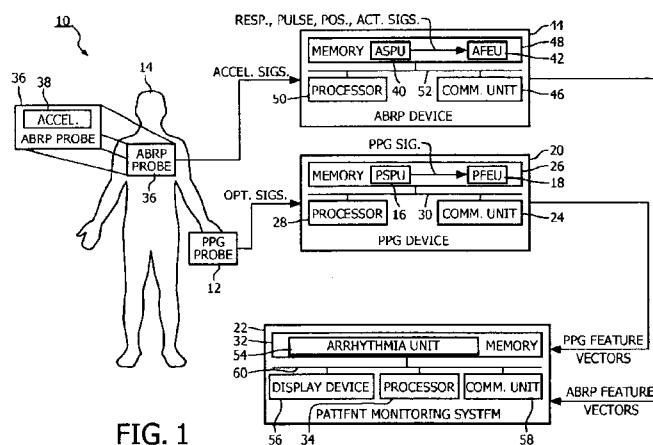
Declarations under Rule 4.17:

- as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))
- as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))

Published:

- with international search report (Art. 21(3))

(54) Title: A SYSTEM AND METHOD TO DETECT SIGNIFICANT ARRRHYTHMIC EVENTS THROUGH A PHOTOPLETHYSMOGRAM (PPG) AND ACCELEROMETER



(57) Abstract: A medical system (10) and method detect arrhythmic events. The medical system (10) includes at least one processor (28, 34, 50) programmed to perform the method. A photoplethysmogram (PPG) signal generated using a PPG probe (12) positioned on or within a patient (14) and a pulse signal generated using an accelerometer (38) positioned on or within the patient (14) are received. Features from the PPG signal are extracted to PPG feature vectors, and features are extracted from the pulse signal to pulse feature vectors. The PPG feature vectors are correlated with the pulse feature vectors, and correlated PPG feature vectors and correlated pulse feature vectors are evaluated to detect arrhythmic events.

WO 2014/091382 A1

64869-2256

**A SYSTEM AND METHOD TO DETECT SIGNIFICANT ARRHYTHMIC EVENTS
THROUGH A PHOTOPLETHYSMOGRAM (PPG) AND ACCELEROMETER**

The present application relates generally to patient monitoring. It finds particular application in conjunction with reducing false alarms and will be described with 5 particular reference thereto. However, it is to be understood that it also finds application in other usage scenarios and is not necessarily limited to the aforementioned application.

Electrocardiograph (ECG) monitoring for cardiac events, such as ischemia and arrhythmic events, is important for detecting patient deterioration. Arrhythmic events of interest include, for example, onset and end of Atrial Fibrillation or Flutter (A-Fib), 10 Ventricular Tachycardia (V-Tach), Ventricular Fibrillation (V-Fib), and Asystole. However, ECG monitoring poses a number of challenges.

Conventional ECG technologies are cumbersome, laborious with regards to maintaining signal acquisition, and costly. In many cases, continuous ECG requires significant work of clinicians to maintain proper electrode and lead contact to the skin. Failure 15 to do so can result in false detection of cardiac events and false alarms, or clinically action-less events. Further, even with the development of smaller, lower cost, and wearable technologies, many of these challenges are still present.

The present application provides new and improved methods and systems which overcome the above-referenced problems and others.

20 In accordance with one aspect, a medical system for detecting arrhythmic events is provided. The system includes at least one processor programmed to receive a photoplethysmogram (PPG) signal generated using a PPG probe positioned on or within a patient and receive a pulse signal generated using an accelerometer positioned on or within the patient. Further, the at least one processor is programmed to extract features from the PPG 25 signal to generate PPG feature vectors, extract features from the pulse signal to generate pulse feature vectors, correlate the PPG feature vectors with the pulse feature vectors, and evaluate

.64869-2256

1a

correlated PPG feature vectors and correlated pulse feature vectors to detect arrhythmic events, wherein features extracted from the PPG signal include inter pulse intervals (IPIs) for pairs of adjacent pulses of a last predetermined number of pulses; and wherein features extracted from the pulse signal include inter pulse intervals (IPIs) for pairs of adjacent pulses
5 of a last predetermined number of pulses.

In accordance with another aspect, a medical method for detecting arrhythmic events is provided. A PPG signal generated using a PPG probe is positioned on

or within a patient and a pulse signal generated using an accelerometer positioned on or within the patient are received. Features are extracted from the PPG signal to PPG feature vectors, and features are extracted from the pulse signal to pulse feature vectors. The PPG feature vectors are correlated with the pulse feature vectors, and correlated PPG feature 5 vectors and correlated pulse feature vectors are evaluated to detect arrhythmic events.

In accordance with another aspect, a medical system for detecting arrhythmic events is provided. The system includes a first feature extraction unit extracting features from a PPG signal to PPG feature vectors. The PPG signal is generated using a PPG probe positioned on or within a patient. The system further includes a second feature extraction 10 unit extracting features from a pulse signal and a respiration signal to pulse feature vectors and respiration feature vectors, respectively. The pulse and respiration signals are generated using an accelerometer positioned on or within the patient. The system further includes an arrhythmia unit configured to correlate the PPG feature vectors with the pulse and respiration feature vectors and evaluate correlated PPG feature vectors and correlated pulse 15 and respiration feature vectors to detect arrhythmic events.

One advantage resides in more reliable detection of arrhythmic events.

Another advantage is in detecting arrhythmic events without the need for electrocardiograph (ECG) monitoring.

Another advantage resides in the ability to detect arrhythmic events 20 periodically without the need for continuous monitoring.

Still further advantages of the present invention will be appreciated to those of ordinary skill in the art upon reading and understand the following detailed description including detection of other physiologic conditions that warrant notification to the patient's care provider or suitable responder to the detected condition.

25

The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings are only for purposes of illustrating the preferred embodiments and are not to be construed as limiting the 30 invention.

FIGURE 1 illustrates one embodiment of a medical system for detecting arrhythmic events.

FIGURE 2 illustrates another embodiment of a medical system for detecting arrhythmic events.

FIGURE 3 illustrates a flow chart for detecting arrhythmic events with the systems of FIGURES 1 or 2.

5 The present invention proposes to detect arrhythmic events by use of a photoplethysmogram (PPG) signal and respiration and pulse signals, the respiration and pulse signals being determined from an accelerometer. These events can be detected with high confidence by cross correlation of the accelerometer based respiration and pulse signals with the PPG signal. Further, detected events can be used to generate alerts to clinicians with high
10 confidence.

With reference to FIGURES 1 and 2, a medical system **10** includes a PPG probe **12** facilitating the generation of a PPG signal and/or other signals. Typically, the PPG signal is generated using pulse oximetry, but other approaches for generating the PPG signal are contemplated. The PPG probe **12** is placed on or within an associated patient **14**.

15 When pulse oximetry is employed to generate the PPG signal, the PPG probe **12** is placed on or around a thin part of the patient **14**. In the case of an infant, the PPG probe **12** is usually placed across a foot. Otherwise, the PPG probe **12** is usually placed across a fingertip, across an earlobe, in the web between the index finger and thumb (princeps pollicis artery), or on the forehead. Further, when pulse oximetry is employed, the PPG probe **12**
20 includes one or more light sources which are controlled to pass light at red (e.g., around 660 nm) and infrared (e.g., around 940 nm) wavelengths sequentially through the patient **14** to a photo-detector of the PPG probe **12**. The changing absorbance at each of the two wavelengths is measured by the photo-detector to create an optical signal.

A PPG signal processing unit (PSPU) **16** processes one or more signals
25 generated by the PPG probe **12** (e.g., the optical signal) to generate the PPG signal and/or the other signals. Suitably, the PPG signal and/or the other signals are continuous.

Further, a PPG feature extraction unit (PFEU) **18** processes the PPG signal to extract one or more features to PPG feature vectors. Features that can be extracted include signal quality index (SQI) for the PPG signal, signal stability of the PPG signal, pulse
30 references (i.e., detected pulse identifiers (IDs)) for a last n pulses (e.g., $n = 4$ or 8), inter pulse intervals (IPIs) for the pairs of adjacent pulses of the last n pulses, median IPI for the last n pulses, and inop messaging. A pulse reference for a pulse can, for example, be a master clock index. Typically, all of these features are extracted to a PPG feature vector.

The PFEU 18 typically only extracts the features to a PPG feature vector when the SQI of the PPG signal exceeds a predetermined threshold. The predetermined threshold is set at a level where a user of the medical system 10 deems the signal quality sufficiently high to reliably extract the features. Further, the PFEU 18 typically only extracts the features 5 according to a predetermined sampling rate, such as, for example, 10 milliseconds. The predetermined sampling rate can be set by a user of the medical system 10 based upon the computational resources (e.g., processing power and memory) of the medical system 10 and/or the granularity of PPG feature vectors needed to reliably monitor patients.

The PSPU 16 and the PFEU 18 can each be software (i.e., processor 10 executable instructions), hardware, or a combination of the two. When the PSPU 16 or the PFEU 18 is, or includes, software, the software is stored on one or more program memories and executed by one or more processors.

A PPG device 20 is positioned proximate to the patient 14, typically at the patient's bedside or in a self-contained device. Further, the PPG device is typically worn by 15 the patient 14. Further, the PPG device 20 can be integrated with the PPG probe 12. The PPG device 20 controls the PPG probe 12 and receives the signals generated by the PPG probe 12. The PPG device 20 includes the PSPU 16 and typically the PFEU 18. However, the PFEU 18 can be remote from the PPG device 20, for example, within a patient monitoring system (PMS) or data aggregator.

20 Using the PSPU 16, the PPG device 20 processes the signals to generate the PPG signal. Where the PPG device 20 includes the PFEU 18, the PPG device 20 uses the PFEU 18 to process the PPG signal and generate the PPG feature vectors. The PPG feature vectors are then relayed to a PMS 22 as they are generated using a communication unit 24 of the PPG device 20. Where the PPG device 20 does not include the PFEU 18, the PPG device 25 20 relays the PPG signal to the PFEU 18 using the communication unit 24. Alternately the raw PPG signal can be sent to the PMS 22 where the signal extraction can be accomplished on the reconstruction of the waveform.

One or more program memories 26 of the PPG device 20 store any software of the PSPU 16 and/or the PFEU 18. Further, one or more processors 28 of the PPG device 20 30 execute the software on the program memories 26. One or more system buses 30 interconnect the components of the PPG device 20, such as the processors 28, the program memories 26 and the communication unit 24.

As illustrated in FIGURE 1, both the PSPU 16 and the PFEU 18 are software stored on the program memories 26 of the PPG device 20, where the processors 28 of the

PPG device 20 execute the software. As illustrated in FIGURE 2, both the PSPU 16 and the PFEU 18 are software. The PSPU 16 is stored on the program memories 26 of the PPG device 20, where the processors 28 of the PPG device 20 execute the software. Further, the PFEU 18 is stored on one or more program memories 32 of the PMS 22, where one or more processors 34 of the PMS 22 execute the software.

An acceleration based respiration and pulse (ABRP) probe 36 is positioned on or within the patient 14, typically proximate to the heart (e.g., within the thorax) or the anterior costal cartilage. Further, the ABRP probe 36 can be integrated with, positioned on, or positioned proximate to the PPG probe 12. The ABRP probe 36 includes an accelerometer 38. Typically, the accelerometer 38 is a three-dimensional (3D) or 3-axis accelerometer. However, the accelerometer 38 can measure acceleration in less than three dimensions. The accelerometer 38 generates one or more accelerometer signals indicative of acceleration. Typically, the accelerometer signals include an accelerometer signal for each dimension of the accelerometer 38.

An ABRP signal processing unit (ASPU) 40 processes the acceleration signals to generate pulse, respiration, position and activity signals from the acceleration signals. Other signals can also be generated from the acceleration signals, such as a ballistocardiograph (BCG) signal or a heart rate signal. The position signal indicates changes in positioning of the ABRP probe 36 over time, and the activity signal indicates the activity level of the patient 14. The activity level can, for example, be determined through analysis of change in position over a last predetermined period of time. Suitably, the signals are continuous or intermittent with the periodicity in concordance with the PPG periodicity.

Further, an ABRP feature extraction unit (AFEU) 42, for each of the pulse, respiration, position and activity signals, processes the signal to extract one or more features to ABRP feature vectors. An ABRP feature vector can be an ABRP pulse feature vector, an ABRP respiration feature vector, an ABRP position feature vectors or an ABRP activity feature vectors depending upon the signal from which the features were extracted. ABRP pulse feature vectors are created together with ABRP respiration feature vectors. Hence, when an ABRP pulse feature vector is created, an ABRP pulse feature vector is created for the same time window. Similarly, ABRP position feature vectors are created together with ABRP activity feature vectors.

Features that can be extracted for the pulse signal include SQI of the pulse signal, pulse references (i.e., detected pulse IDs) for a last n pulses (e.g., $n = 4$ or 8), inter pulse intervals (IPIs) for the pairs of adjacent pulses of the last n pulses, median IPI for the

last n pulses, and inop messaging. A pulse reference for a pulse can, for example, be a master clock index. Features that can be extracted for the respiration signal include SQI of the respiration signal, respiration references (i.e., detected respiration IDs) for a last n breaths (e.g., $n = 4$ or 8), inter breath intervals (IBI) for the pairs of adjacent breaths of the last n breaths, median IBI for the last n breaths, and inop messaging. A respiration reference for a breath can, for example, be a master clock index. Features that can be extracted for the position signal include position, position history (e.g., position over the last predetermined amount of time), and end user messaging interface. Features that can be extracted for the activity signal include activity level, activity level history (e.g., activity over the last predetermined amount of time), and end user messaging interface. Typically, all of the above enumerated features for all the signals are extracted.

The AFEU **42** only extracts features to an ABRP feature vector when the SQI of the corresponding signal exceeds a predetermined threshold. The predetermined threshold is set at a level where a user of the medical system deems the signal quality sufficiently high to reliably extract the features. An ABRP pulse feature vector is created only when both the SQI for the pulse signal exceeds the corresponding predetermined threshold and the SQI for the respiration signal exceeds the corresponding predetermined threshold. The same applies to an ABRP respiration feature vector. Similarly, an ABRP position feature vector is created only when both the SQI for the position signal exceeds the corresponding predetermined threshold and the SQI for the activity signal exceeds the corresponding predetermined threshold. The same applies to an ABRP activity pulse feature vector.

Further, the AFEU **42** typically only extracts features from a signal according to a predetermined sampling rate, such as, for example, 10 milliseconds. The predetermined sampling rate can be set by a user of the medical system **10** based upon the computational resources (e.g., processing power and memory) of the medical system **10** and/or the granularity of ABRP feature vectors needed to reliably monitor patients.

The processing and generation of the ABRP feature vectors are suitably performed in parallel with, and independent of, the processing and generation of the PPG feature vectors. Further, the ASPU **40** and/or AFEU **42** can each be software (i.e., processor executable instructions), hardware, or a combination of the two. When the ASPU **40** or the AFEU **42** is, or includes, software, the software is stored on one or more program memories and executed by one or more processors.

An ABRP device **44** is positioned proximate to the patient **14**, typically at the patient's bedside. Further, the ABRP device **44** can be integrated with the ABRP probe **36**

and/or the PPG device 20. The ABRP device 44 controls the ABRP probe 36 and receives the acceleration signals generated by the ABRP probe 36. The ABRP device 44 includes the ASPU 40 and typically the AFEU 42. However, the ASPU 40 can be remote from the ABRP device 44, for example, within a PMS.

5 Using the ASPU 40, the ABRP device 44 processes the accelerometer signals to generate the pulse, respiration, position and activity signals. Where the ABRP device 44 includes the AFEU 42, the ABRP device 44 uses the AFEU 42 to process the signals and generate the ABRP feature vectors. The ABRP feature vectors are then relayed to the PMS 22 as they are generated using a communication unit 46 of the ABRP device 44. Where the
10 ABRP device 44 does not include the AFEU 42, the ABRP device 44 relays the signals to the AFEU 18 using the communication unit 46.

One or more program memories 48 of the ABRP device 44 store any software of the ASPU 40 and/or the AFEU 42. Further, one or more processors 50 of the ABRP device 44 execute the software on the program memories 48. One or more system buses 52 15 interconnect the components of the ABRP device 44, such as the processors 50, the program memories 48 and the communication unit 46.

As illustrated in FIGURE 1, both the ASPU 40 and the AFEU 42 are software stored on the program memories 48 of the ABRP device 44, where the processors 50 of the ABRP device 44 execute the software. As illustrated in FIGURE 2, both the ASPU 40 and 20 the AFEU 42 are software. The ASPU 40 is stored on the program memories 48 of the ABRP device 44, where the processors 50 of the ABRP device 44 execute the software. Further, the AFEU 42 is stored on the program memories 32 of the PMS 22, where the processors 34 of the PMS 22 execute the software.

An arrhythmia unit 54 of the PMS 22 receives or generates the PPG feature 25 vectors and the ABRP feature vectors from the PFEU 18 and the AFEU 42, respectively. Based on the feature vectors, the arrhythmia unit 54 detects arrhythmic events, such as Atrial Fibrillation or Flutter (A-Fib), Ventricular Tachycardia (V-Tach), Ventricular Fibrillation (V-Fib), and Asystole. The arrhythmia unit 54 can be software (i.e., processor executable instructions), hardware, or a combination of the two.

30 When PPG feature vectors, ABRP pulse feature vectors, and ABRP respiration feature vectors temporally corresponding to the ABRP pulse feature vectors are received, the arrhythmia unit 54 employs a segment alignment routine to align the PPG feature vectors with the ABRP feature vectors. Notably, the ABRP respiration feature vectors and the ABRP pulse feature vectors are already aligned since these feature vectors are

generated from the same time window or derived from data collected and transmitted on the same period.

The segment alignment routine aligns the PPG feature vectors with the ABRP feature vectors by aligning the pulses of the PPG feature vectors to the pulses of the ABRP 5 pulse feature vectors. Alternatively, the ABRP pulse feature vectors can also be aligned to the PPG feature vectors. However, this would require the additional action of aligning the ABRP respiration feature vectors. Hence, for ease of discussion, it is assumed that the PPG feature vectors are aligned to the ABRP feature vectors.

One approach for aligning the features vectors is to employ trend analysis of 10 the IBIs. In such a case, the trend of the IBIs of the PPG feature vectors are aligned to the trend of the IBIs of the ABRP pulse feature vectors. If the trends can be aligned, the pulse references of the PPG feature vectors are shifted so the pulse references of pulses in the PPG feature vectors match the pulse references of the corresponding pulses in the ABRP pulse feature vectors. Other approaches to aligning the PPG feature vector with the ABRP feature 15 vectors are equally amenable.

After performing the segment alignment routine, a determination is made as to whether the PPG feature vectors are aligned with the ABRP feature vectors. This determination is typically based on the IBIs and performed in case the segment alignment routine isn't able to align the PPG feature vectors and the ABRP feature vectors. Insofar as 20 this is the case, the arrhythmia unit **54** waits for additional data. Further, a user of the medical system **10** can be prompted, using, for example, a display device **56** of the PMS **22** or a message initiated by the PMS **22** to the user, to verify the ABRP feature vectors and PPG feature vectors are from the same patient. Otherwise, the arrhythmia unit **54** evaluates the ABRP feature vectors and the PPG feature vector for arrhythmic events. This includes 25 identifying patterns indicative of arrhythmic events.

The onset of A-Fib is detected if the trend of the IPI goes from regular to persistently irregularly irregular and the activity level is below a predetermined threshold. The predetermined threshold is set by a user of the medical system at levels deemed sufficiently indicative of the onset of A-Fib. Similarly, the end of A-Fib is detected if the 30 trend of IPI goes from irregularly irregular to persistently regular and the activity level is below the predetermined threshold. Tachyarrhythmia with hemodynamic compromise is detected if the IPI becomes regular, fast, and persistent AND the activity level is below the predetermined threshold and PPG signal amplitude drops.

If any of the foregoing events are detected, clinicians can be prompted, for example, by way of the display device **56** to check for the detected event. Further, if any of the foregoing events are detected and either position indicates a fall or the activity level acutely decreases in activity, the event is deemed more severe. In this case, an alert can be 5 provided to clinicians, for example, by way of the display device **56** or alternative wireless messaging methods, such as e-mail, text, short messaging service (SMS), audio, suitable haptic devices, etc.

When the PMS **22** includes software, from, for example, the arrhythmia unit **54**, the AFEU **42**, or the PFEU **18**, the PMS **22** includes one or more program memories **32** 10 storing the software and one or more processors **34** executing the software. Further, communication with remote devices and/or systems, such as devices and/or systems including the PFEU **18** or AFEU **42**, is suitably performed over a communication network using a communication unit **58** of the PMS **22**. The components of the PMS **22** are suitably interconnected by way of a system bus **60** and/or a communication network.

15 With reference to FIGURE 3, a flow chart **100** illustrates how the PFEU **18**, AFEU **42** and arrhythmia unit **54** coordinate to detect arrhythmic events. The PFEU **18** receives the PPG signal from, for example, the PSPU **16**. Typically, the PPG signal is continuous. The PFEU **18** determines **102** whether the SQI exceeds a threshold. If the SQI does not exceed the threshold, the determination **102** is repeated, optionally after a delay. If 20 the SQI exceeds the threshold, PPG feature vectors are created **104** from the PPG signal and the determination **102** is repeated, optionally after a delay.

The AFEU **42** operates in parallel with, and independent of, the PFEU **18** and receives respiration, pulse, position and activity signals from, for example, the ASPU **40**. Typically, the signals are continuous. The AFEU **42** determines **106** whether the SQIs of 25 these signals both exceed corresponding thresholds. If the SQIs do not both exceed corresponding thresholds, the determination **106** is repeated, optionally after a delay. If the SQIs both exceed corresponding thresholds, ABRP respiration and pulse feature vectors are created **108** from the pulse and respiration signals and the determination **106** is repeated, optionally after a delay.

30 Further, after creating ABRP respiration and pulse feature vectors, the AFEU **42** determines **110** whether the SQIs of these signals both exceed corresponding thresholds. If the SQIs do not both exceed corresponding thresholds, the determination **110** is repeated, optionally after a delay. If the SQIs both exceed corresponding threshold, ABRP position

and activity feature vectors are created 112 from the position and activity signals and the determination 110 is repeated, optionally after a delay.

The arrhythmia unit 54 receives PPG feature vectors, as well as ABRP respiration and pulse feature vectors, from the PFEU 18 and the AFEU 42. When it is 5 determined 114 that both PPG feature vectors and ABRP respiration and pulse feature vectors are available, a segment alignment routine is performed 116 to attempt to align the PPG feature vectors to the ABRP respiration and pulse feature vectors, or vice versa. Otherwise, the determination 114 is repeated after waiting for new data 118. Suitably, alignment is performed based on IPIs.

10 After performing 116 the segment alignment routine, a determination 120 is made as to whether the IPIs of the PPG feature vectors are aligned to the ABRP respiration and pulse feature vectors. If not aligned, the determination 114 of availability is repeated after waiting 118 for new data. If aligned, the PPG feature vectors and the ABRP respiration, 15 pulse, position and activity feature vectors are evaluated 122 for patterns of arrhythmia. For example, the onset of A-Fib is detected if the trend of the IPI goes from regular to persistently irregular AND the activity level is below a predetermined threshold.

Although memories 26, 32 and 48 are shown as separate memories for ease of explanation, in some embodiments two or all of these memories are embodied in a single memory. Similarly, although processors 28, 34, 50 are shown as separate processors for ease 20 of explanation, in some embodiments two or all of these processors are embodied in a single processor. Even more, messages, alerts, and the like which have been described above can be conveyed to users by way of display devices or alternative wireless messaging methods, such as e-mail, text, short messaging service (SMS), audio, suitable haptic devices, etc.

As used herein, a memory includes one or more of a non-transient computer 25 readable medium; a magnetic disk or other magnetic storage medium; an optical disk or other optical storage medium; a random access memory (RAM), read-only memory (ROM), or other electronic memory device or chip or set of operatively interconnected chips; an Internet/Intranet server from which the stored instructions may be retrieved via the Internet/Intranet or a local area network; or so forth. Further, as used herein, a processor 30 includes one or more of a microprocessor, a microcontroller, a graphic processing unit (GPU), an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), and the like; a controller includes: 1) at least one memory with processor executable instructions to perform the functionality of the controller; and 2) at least one processor executing the processor executable instructions; a user output device includes a printer, a

display device, and the like; and a display device includes one or more of a liquid crystal display (LCD), an light-emitting diode (LED) display, a plasma display, a projection display, a touch screen display, and the like.

The invention has been described with reference to the preferred 5 embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description.

.64869-2256

12

CLAIMS:

1. A medical system for detecting arrhythmic events, said system comprising:
 - at least one processor programmed to:
 - receive a photoplethysmogram (PPG) signal generated using a PPG probe
 - 5 positioned on or within a patient;
 - receive a pulse signal generated using an accelerometer positioned on or within the patient;
 - extract features from the PPG signal to generate PPG feature vectors;
 - extract features from the pulse signal to generate pulse feature vectors;
 - 10 correlate the PPG feature vectors with the pulse feature vectors; and
 - evaluate correlated PPG feature vectors and correlated pulse feature vectors to detect arrhythmic events;
 - wherein features extracted from the PPG signal include inter pulse intervals (IPIs) for pairs of adjacent pulses of a last predetermined number of pulses; and
 - 15 wherein features extracted from the pulse signal include inter pulse intervals (IPIs) for pairs of adjacent pulses of a last predetermined number of pulses.
2. The medical system according to claim 1, wherein the at least one processor is further programmed to:
 - receive a respiration signal generated using the accelerometer positioned on or 20 within the patient;
 - extract features from the respiration signal to generate respiration feature vectors;

12

64869-2256

13

correlate the PPG feature vectors with the respiration feature vectors; and
evaluate correlated respiration feature vectors to detect arrhythmic events.

3. The medical system according to claim 2, wherein features are extracted from
the pulse and respiration signals when both a signal quality index (SQI) of the pulse signal
5 exceeds a predetermined threshold and an SQI of the respiration signal exceeds a
predetermined threshold.

4. The medical system according to any one of claims 1-3, wherein correlating
the PPG feature vectors with the pulse feature vectors includes:

10 aligning inter pulse interval (IPI) trends of the pulse feature vectors with IPI
trends of the PPG feature vectors.

5. The medical system according to any one of claims 1-4, wherein the at least
one processor is further programmed to:

receive a position signal, and an activity signal, generated using the
accelerometer;

15 extract features from the position and activity signals to generate position
feature vectors and activity feature vectors, respectively, wherein evaluating the correlated
PPG feature vectors and the correlated pulse feature vectors to detect the arrhythmic events
uses the position and activity feature vectors.

6. The medical system according to any one of claims 1-5, wherein features are
20 extracted from the PPG signal in parallel with, and independent of, extraction of features from
the pulse signal.

7. The medical system according to any one of claims 1-6, wherein evaluating the
correlated PPG feature vectors and the correlated pulse feature vectors to detect the
arrhythmic events includes at least one of:

13

64869-2256

14

detecting onset of atrial fibrillation or flutter (A-Fib) in response to inter pulse interval (IPI) trend going from regular to persistently irregularly irregular and activity level being below a predetermined threshold;

detecting end of the A-Fib in response to IPI trend going from irregularly

5 irregular to persistently regular and the activity level being below the predetermined threshold; and

detecting tachyarrhythmia with hemodynamic compromise in response to IPI becoming regular, fast, and persistent and the activity level being below the predetermined threshold and PPG signal amplitude dropping.

10 8. The medical system according to any one of claims 1-7, further including

a photoplethysmogram (PPG) device generating the PPG signal using the PPG probe positioned on or within the patient; and

an accelerometer based respiration and pulse (ABRP) device generating the pulse signal using the accelerometer positioned on or within the patient.

14

1/3

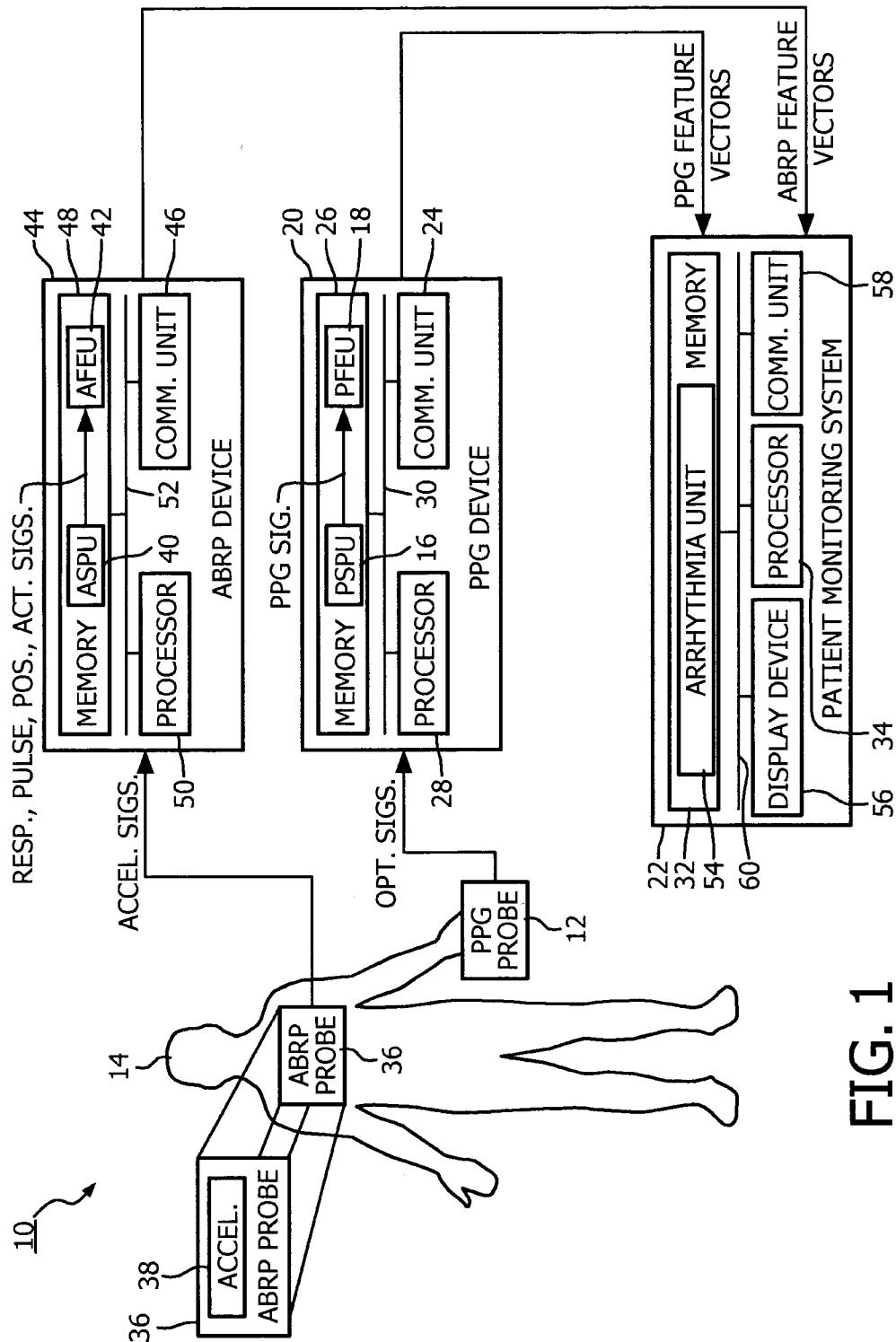


FIG. 1

2/3

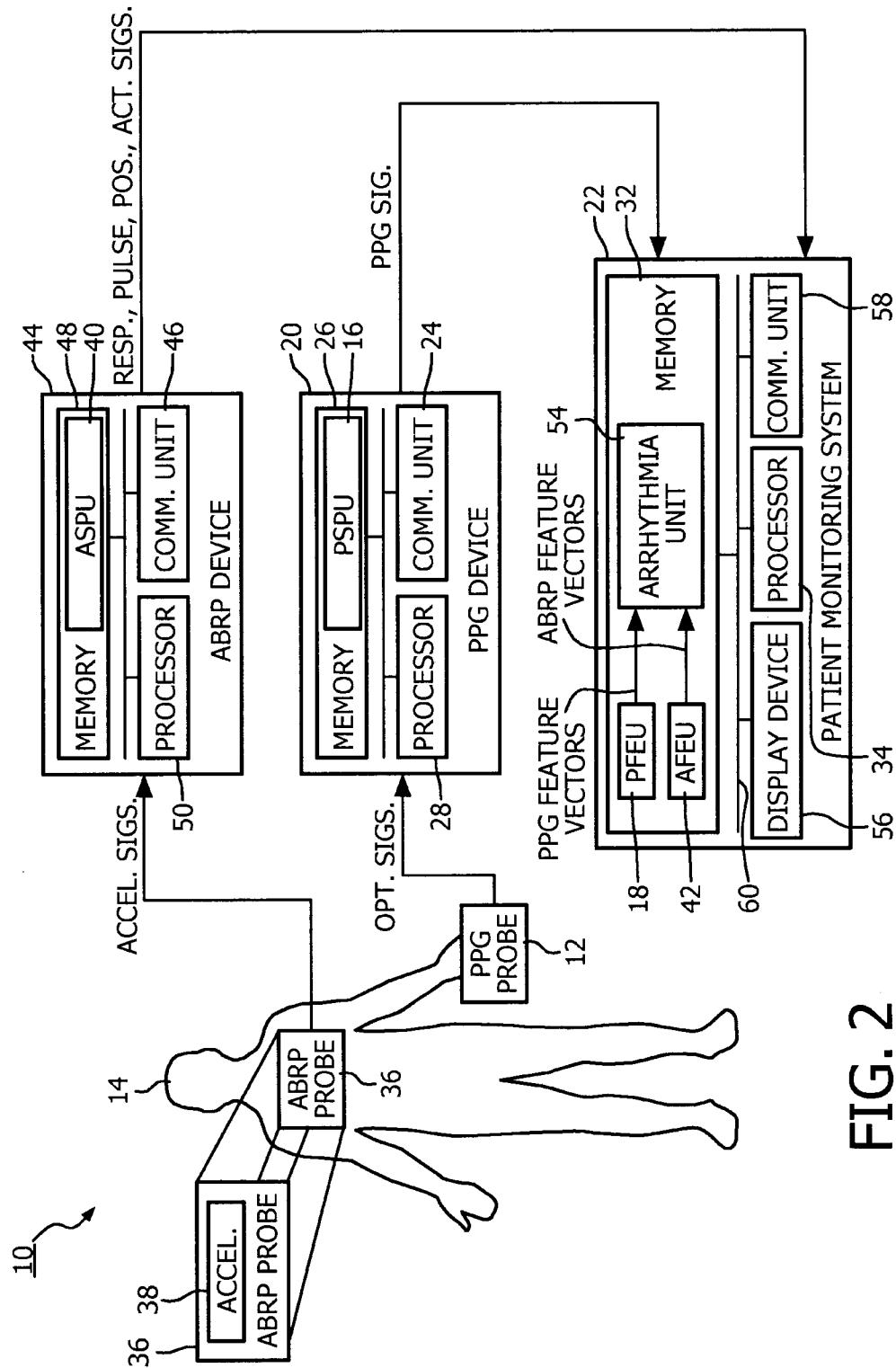


FIG. 2

