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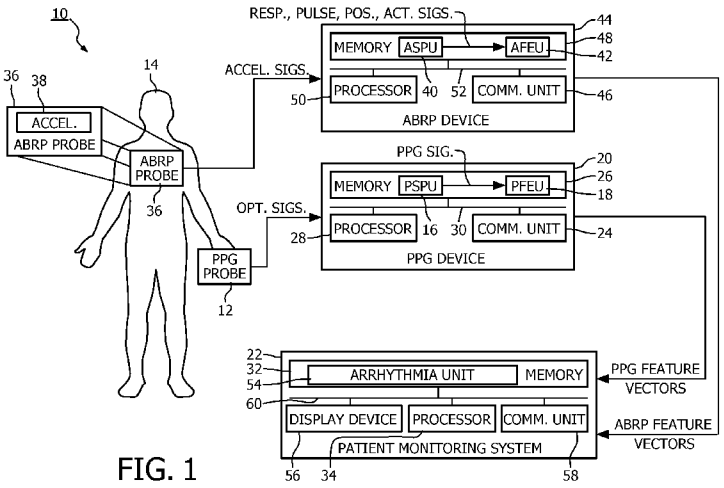

FIG. 1

(57) Abstract: A medical system (10) and method detect arrhythmi cevents. 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) anda pulse signal generated using an accelerometer (38)positioned on or within the patient (14) 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.

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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 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), 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 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.

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 signal to PPG feature vectors, extract features from the pulse signal to pulse feature vectors, 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.

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 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 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 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 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.

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 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.

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 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**.

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** 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 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 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 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 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 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.

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 **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** 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 reliable 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.

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 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** 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 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 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.

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 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 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 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 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 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 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 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** 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.

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 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 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.

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 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.

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, 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 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 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 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 embodiments. Modifications and alterations may occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be constructed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

CLAIMS:

1. A medical system **(10)** for detecting arrhythmic events, said system **(10)** comprising:

at least one processor **(28, 34, 50)** programmed to:

receive a photoplethysmogram (PPG) signal generated using a PPG probe **(12)** positioned on or within a patient **(14)**;

receive a pulse signal generated using an accelerometer **(38)** positioned on or within the patient **(14)**;

extract features from the PPG signal to PPG feature vectors;

extract features from the pulse signal to pulse feature vectors;

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.

2. The medical system **(10)** according to claim 1, 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 of a last predetermined number of pulses.

3. The medical system **(10)** according to either one of claims 1 and 2, wherein the at least one processor **(28, 34, 50)** is further programmed to:

receive a respiration signal generated using the accelerometer **(38)** positioned on or within the patient **(14)**;

extract features from the respiration signal to respiration feature vectors;

correlate the PPG feature vectors with the respiration feature vectors; and

evaluate correlated respiration feature vectors to detect arrhythmic events.

4. The medical system **(10)** according to claims 3, wherein features are extracted from the pulse and respiration signals when both a signal quality index (SQI) of the pulse

signal exceeds a predetermined threshold and an SQI of the respiration signal exceeds a predetermined threshold.

5. The medical system **(10)** according to any one of claims 1-4, wherein correlating the PPG feature vectors with the pulse feature vectors includes:

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

6. The medical system **(10)** according to any one of claims 1-5, wherein the at least one processor **(28, 34, 50)** is further programmed to:

receive a position signal, and an activity signal, generated using the accelerometer **(38)**;

extract features from the position and activity signals to 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.

7. The medical system **(10)** according to any one of claims 1-6, wherein features are extracted from the PPG signal in parallel with, and independent of, extraction of features from the pulse signal.

8. The medical system **(10)** according to any one of claims 1-7, wherein evaluating the correlated PPG feature vectors and the correlated pulse feature vectors to detect the arrhythmic events includes at least one of:

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 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.

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

a photoplethysmogram (PPG) device **(20)** generating the PPG signal using the PPG probe **(12)** positioned on or within the patient **(14)**;

an accelerometer based respiration and pulse (ABRP) device **(440)** generating the pulse signal using the accelerometer **(38)** positioned on or within the patient **(14)**;

10. A medical method for detecting arrhythmic events, said method comprising:

receiving a PPG signal generated using a PPG probe **(12)** positioned on or within a patient **(14)**;

receiving a pulse signal generated using an accelerometer **(38)** positioned on or within the patient **(14)**;

extracting features from the PPG signal to PPG feature vectors;

extracting features from the pulse signal to pulse feature vectors;

correlating the PPG feature vectors with the pulse feature vectors; and,

evaluating correlated PPG feature vectors and correlated pulse feature vectors to detect arrhythmic events.

11. The medical method according to claim 10, 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 of a last predetermined number of pulses.

12. The medical method according to either one of claims 10 and 11, further including:

receiving a respiration signal generated using the accelerometer **(38)** positioned on or within the patient **(14)**;

extracting features from the respiration signal to respiration feature vectors;

correlating the PPG feature vectors with the respiration feature vectors; and

evaluating correlated respiration feature vectors to detect arrhythmic events.

13. The medical method according to claim 12, further including:

extracting features from the pulse and respiration signals when both a signal quality index (SQI) of the pulse signal exceeds a predetermined threshold and an SQI of the respiration signal exceeds a predetermined threshold.

14. The medical method according to any one of claims 10-13, wherein correlating the PPG feature vectors with the pulse feature vectors includes:

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

15. The medical method according to any one of claims 10-14, further including:

receiving a position signal, and an activity signal, generated using the accelerometer **(38)**;

extracting features from the position and activity signals to position feature vectors and activity feature vectors, respectively;

evaluating the correlated PPG feature vectors and the correlated pulse feature vectors to detect the arrhythmic events using the position and activity feature vectors.

16. The medical method according to any one of claims 10-15, wherein features are extracted from the PPG signal in parallel with, and independent of, extraction of features from the pulse signal.

17. The medical method according to any one of claims 10-16, wherein evaluating the correlated PPG feature vectors and the correlated pulse feature vectors to detect the arrhythmic events includes at least one of:

detecting onset of atrial fibrillation (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 A-Fib in response to IPI trend going from irregularly 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.

18. A non-transitory computer readable medium carrying software which contains one or more processors **(28, 34, 50)** to perform the method according to any one of claims 10-17.

19. A medical system **(10)** for detecting arrhythmic events, said system **(10)** comprising:

a first feature unit receiving and/or extracting features from a PPG signal to PPG feature vectors, the PPG signal generated using a PPG probe **(12)** positioned on or within a patient **(14)**;

a second feature unit receiving and/or extracting features from a pulse signal and a respiration signal to pulse feature vectors and respiration feature vectors, respectively, the pulse and respiration signals generated using an accelerometer **(38)** positioned on or within the patient **(14)**;

an arrhythmia unit **(54)** configured to:

correlate the PPG feature vectors with the pulse and respiration feature vectors; and,

evaluate correlated PPG feature vectors and correlated pulse and respiration feature vectors to detect arrhythmic events.

20. The medical system according to claim 19, further including:

at least one program memory **(26, 32, 48)** including processor executable instructions embodying at least one of the first feature extraction unit **(18)**, the second feature extraction unit **(42)**, and the arrhythmia unit **(54)**; and,

at least one processor **(28, 34, 50)** executing the processor executable instructions.

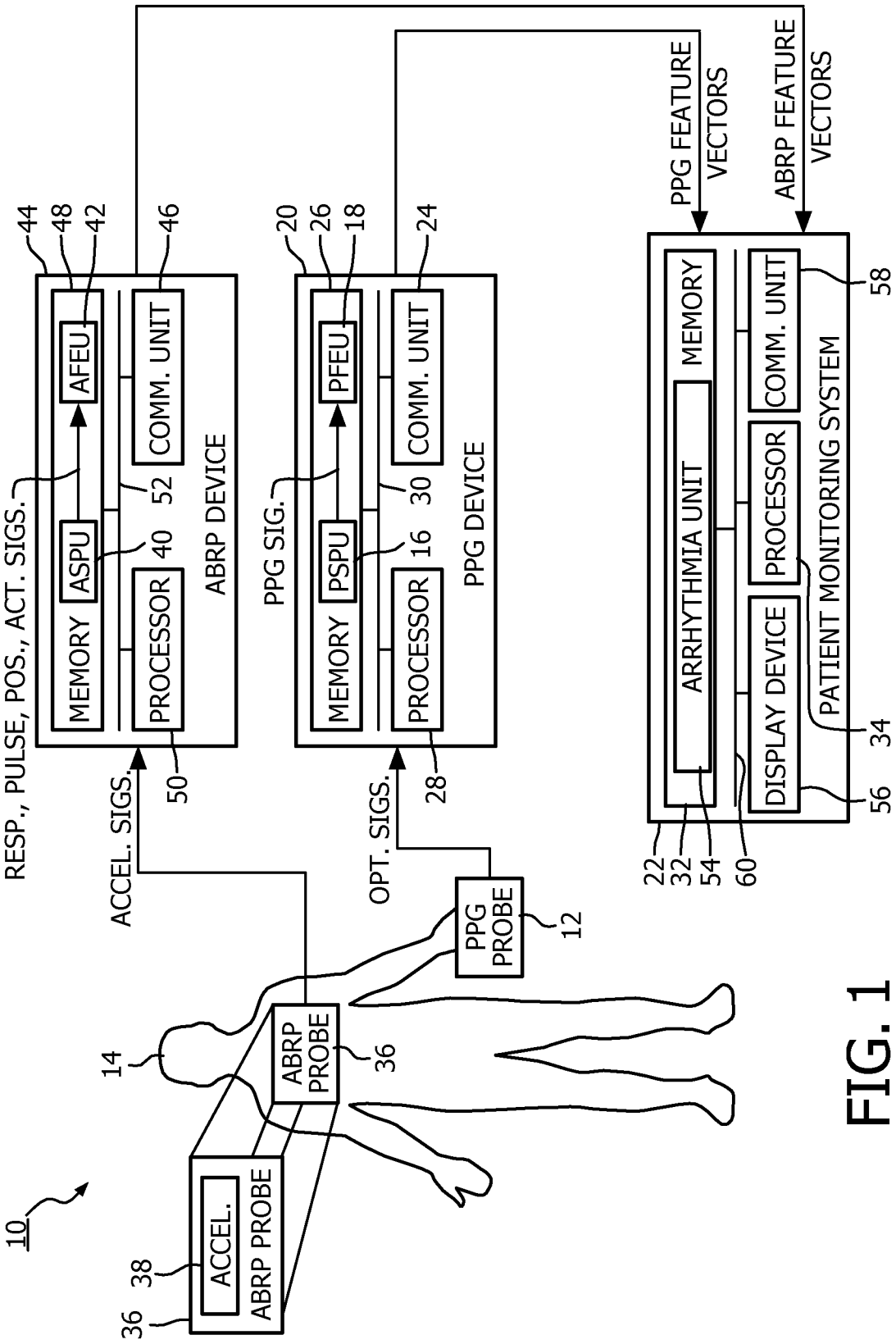
10
ABRP PROBE
ACCEL.
38
36
14
ABRP PROBE
36
PPG PROBE
12
ACCEL. SIGS.
OPT. SIGS.
28
50
RESP., PULSE, POS., ACT. SIGS.
PPG SIG.
ABRP DEVICE
MEMORY
ASPU
AFEU
PROCESSOR
40
COMM. UNIT
52
46
42
48
44
PPG DEVICE
MEMORY
PSPU
PFEU
PROCESSOR
16
COMM. UNIT
30
24
18
26
20
PPG FEATURE VECTORS
ABRP FEATURE VECTORS
PATIENT MONITORING SYSTEM
ARRHYTHMIA UNIT
MEMORY
PROCESSOR
DISPLAY DEVICE
COMM. UNIT
58
34
56
22
32
54
60

FIG. 1

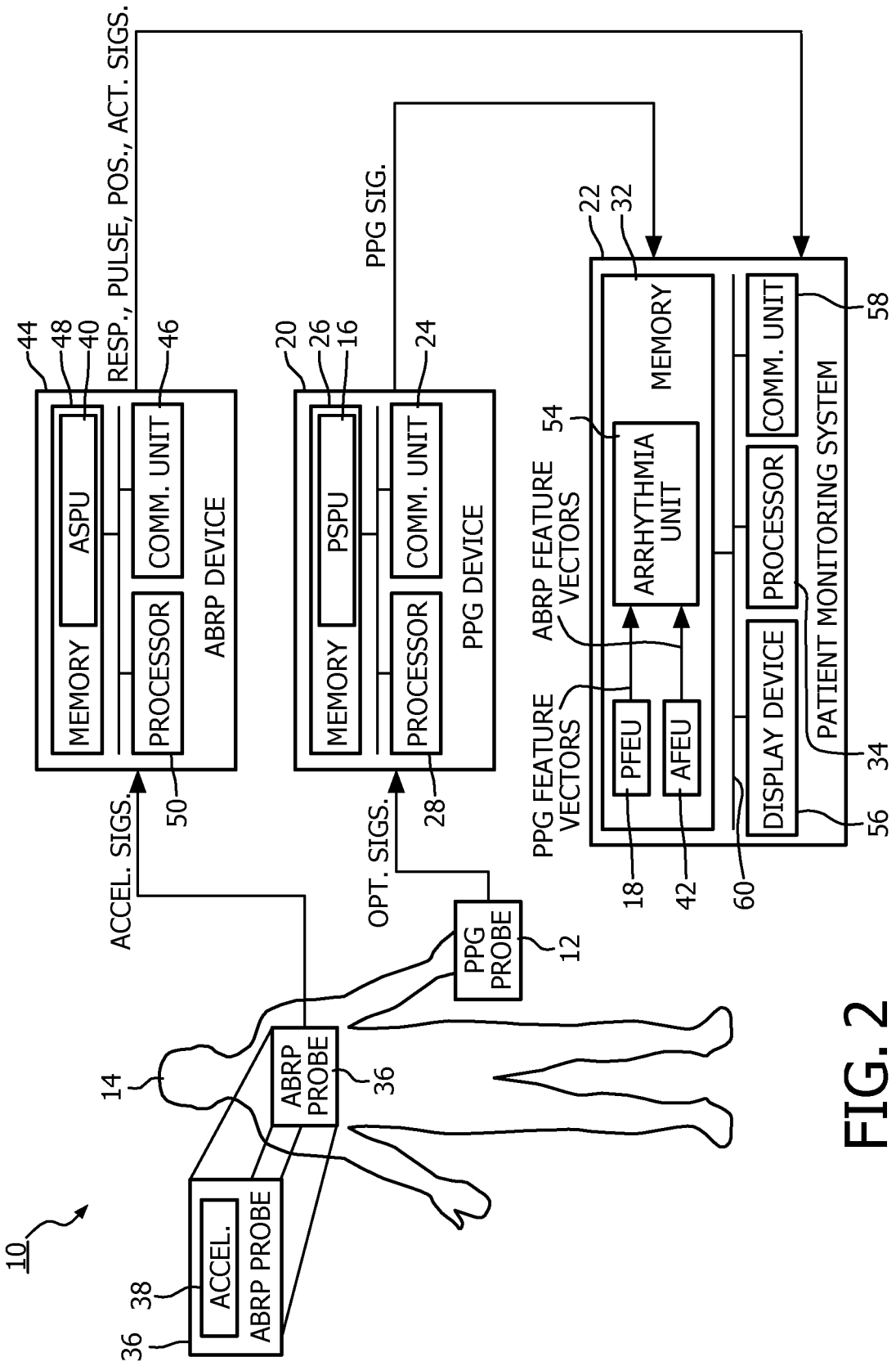
10
ACCEL.
ABRP PROBE
38
36
ABRP PROBE
36
14
PPG PROBE
12
ACCEL. SIGS.
OPT. SIGS.
50
28
ABRP DEVICE
MEMORY
ASPU
PROCESSOR
COMM. UNIT
PPG DEVICE
MEMORY
PSPU
PROCESSOR
COMM. UNIT
RESP., PULSE, POS., ACT. SIGS.
PPG SIG.
44
48
40
46
20
26
16
24
22
32
54
58
34
56
PATIENT MONITORING SYSTEM
MEMORY
ARRHYTHMIA UNIT
PFEU
AFEU
PROCESSOR
DISPLAY DEVICE
COMM. UNIT
ABRP FEATURE VECTORS
PPG FEATURE VECTORS
18
42
60

FIG. 2

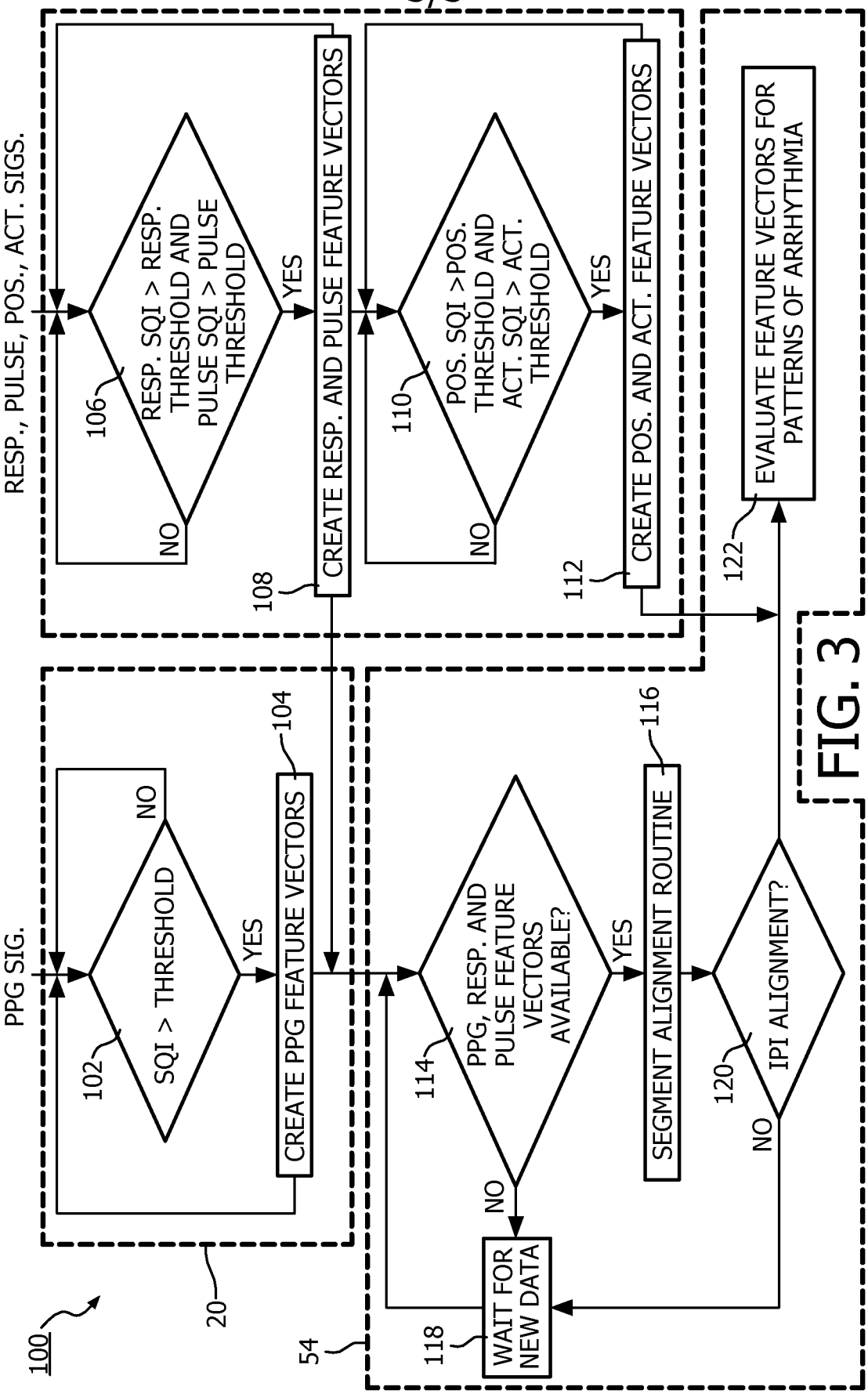
100
20
54
PPG SIG.
RESP., PULSE, POS., ACT. SIGS.
102
SQI > THRESHOLD
NO
YES
104
CREATE PPG FEATURE VECTORS
106
RESP. SQI > RESP. THRESHOLD AND PULSE SQI > PULSE THRESHOLD
NO
YES
108
CREATE RESP. AND PULSE FEATURE VECTORS
110
POS. SQI >POS. THRESHOLD AND ACT. SQI > ACT. THRESHOLD
NO
YES
112
CREATE POS. AND ACT. FEATURE VECTORS
114
PPG, RESP. AND PULSE FEATURE VECTORS AVAILABLE?
NO
YES
116
SEGMENT ALIGNMENT ROUTINE
118
WAIT FOR NEW DATA
120
IPI ALIGNMENT?
NO
122
EVALUATE FEATURE VECTORS FOR PATTERNS OF ARRHYTHMIA

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/060707

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/024 A61B5/0205 A61B5/11 A61B5/021 A61N1/05
A61N1/365
ADD. A61B5/00
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 A61N

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.
Y	US 2010/145201 A1 (WESTBROOK PHILIP R [US] ET AL) 10 June 2010 (2010-06-10) abstract; figures 1a-2,5-7 paragraphs [0008] - [0015], [0024] - [0026], [0031] - [0033]	1-9, 18-20
Y	US 7 794 406 B2 (REISFELD DANIEL [IL] ET AL) 14 September 2010 (2010-09-14) abstract; figures 1-3A column 3, lines 26-40 column 5, line 15 - column 7, line 6 column 7, line 43 - column 10, line 25	1-9, 18-20

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 March 2014	13/03/2014

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lahorte, Philippe

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2013/060707

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.: 10-17
because they relate to subject matter not required to be searched by this Authority, namely:

Rule 39.1(iv) PCT - Method for treatment of the human or animal body by surgery as well as diagnostic method practised on the human or animal body.

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

[ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2013/060707

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	JOHANSSON A: "NEURAL NETWORK FOR PHOTOPLETHYSMOGRAPHIC RESPIRATORY RATE MONITORING", MEDICAL AND BIOLOGICAL ENGINEERING AND COMPUTING, SPRINGER, HEILDELBERG, DE, vol. 41, no. 3, 1 May 2003 (2003-05-01), pages 242-248, XP001047246, ISSN: 0140-0118, DOI: 10.1007/BF02348427 abstract; figures 1, 2, 4 paragraphs [0001], [02.1], [0004] - [0005]	1-9, 18-20
Y	EP 1 908 401 A1 (ETA SA MFT HORLOGERE SUISSE [CH]) 9 April 2008 (2008-04-09) abstract; figures 1, 3 paragraphs [0003] - [0004], [0010] - [0014]	1-9, 18-20
Y	JANIS SPIGULIS ET AL: "<title>Wearable wireless photoplethysmography sensors</title>", PROCEEDINGS OF SPIE, vol. 6991, 25 April 2008 (2008-04-25), pages 699120-699120-7, XP055105393, ISSN: 0277-786X, DOI: 10.1117/12.801966 abstract; figures 1, 3, 6 paragraphs [001.], [002.]	1-9, 18-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2013/060707

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2010145201 A1	10-06-2010	US 2008081961 A1	03-04-2008
		US 2010145201 A1	10-06-2010
		WO 2007147069 A2	21-12-2007
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		US 2006111635 A1	25-05-2006
		US 2007213620 A1	13-09-2007
		US 2007213621 A1	13-09-2007
		US 2007213622 A1	13-09-2007
		US 2007213624 A1	13-09-2007
		WO 2006054306 A2	26-05-2006
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		TW 200833297 A	16-08-2008
		WO 2008040735 A1	10-04-2008