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(54) Title: SYSTEM AND METHOD FOR BREATHING RATE MEASUREMENTS

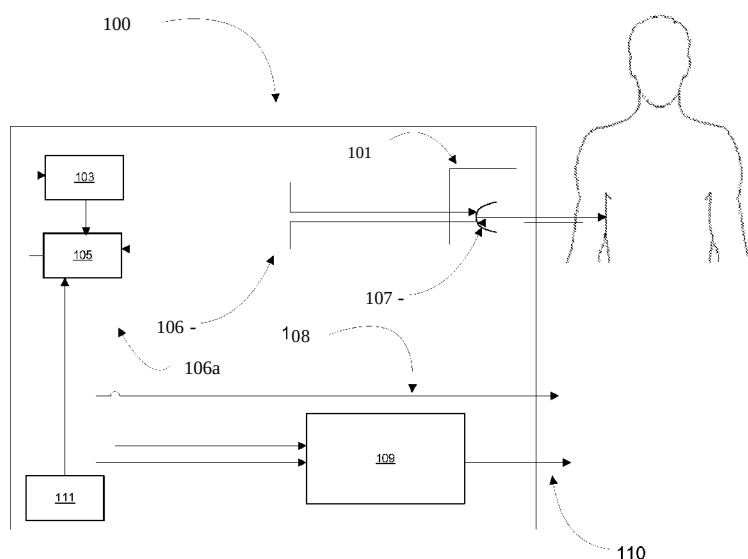


Fig. 1

(57) Abstract: A device (100) for monitoring a subject's breathing rate is disclosed. A transducer (107) radiates energy towards the chest of a subject and receives the reflected energy. An analyzer (105) receives a signal corresponding to the reflected energy. The reflected energy would have undergone Doppler frequency shifts due to the motion of the chest of the subject due to breathing, with reference to the transducer. The analyzer (105) analyzes the signal to calculate the breathing rate by measuring at least one of a periodicity of the signal and a number of cycles per unit time of the signal. In a preferred embodiment the transducer (107) is disposed in or on a sphygmomanometer cuff to radiate energy towards the chest of the subject and receive the energy reflected by the chest of the subject.

System and method for breathing rate measurements

FIELD OF THE INVENTION

This invention belongs to the field of measurement and monitoring of breathing rate of a human subject.

5

BACKGROUND OF THE INVENTION

A number of physiological parameters are measured to estimate the state of health of a person. In the case of a patient in a hospital and especially in an intensive care unit (ICU) physiological parameters are measured on a continuous basis to monitor variations in the state of health of the patient. This is done to ensure timely medical intervention in case of deterioration in the state of health, especially when the deterioration is likely to endanger life.

10

One of the important parameters measured is the breathing rate, also called the respiratory rate. The most commonly used method in low acuity settings is to observe the rise and fall of the patient's chest during breathing and counting the number of inhalation and exhalation cycles, timed with a clock. This is problematic when the patient has irregular or shallow breaths due to breathing distress.

15

Devices and methods to automatically measure the breathing rate are known in the field, using different types of transducers. Some of those methods are impedance plethysmography, capnography (mainly used in ICUs) and inductive thoracic plethysmography (Respiband TM) in sleep studies (polysomnography). All these methods require the positioning of the sensor on the patient's body or elsewhere by a trained person.

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The published patent application US20 100222687, assigned to the same assignee as that of the present application discloses a method of using a plurality of Doppler radars disposed on the seat belt or integrated into the seat belt for monitoring vital body signs of a person seated in a seat of a motor vehicle. The disclosed method unobtrusively monitors vital body signs like heart rate and respiration rate of the person seated in the motor vehicle.

25

SUMMARY OF THE INVENTION

There exists a need for a device for and a method of measuring the breathing rate of a patient for overcoming or mitigating one or more of the problems in the state of the art. The need is addressed with a device for measuring the breathing rate of a subject defined in claim 1.

Such a device may have the advantage that it may not need a skilled person to measure the breathing rate manually. Further, it may not need a skilled person to position a sensor proximate to the patient. Since the device measures the breathing rate, the data may be stored, or transmitted to a system for further processing or used along with the other measured parameters for making decisions or for issuing alarms.

Further, the need for such a method of measuring the breathing rate of a subject is addressed by a method as defined in claim 14.

Normally, patient monitors used in ICUs use a sphygmomanometer cuff to measure the subject's BP, among other things. Thus the disclosed method may offer the advantage that it makes it convenient to dispose the transducer in the cuff and once the cuff is worn by the subject, the measurement of the breathing rate of the subject is enabled without any additional positioning of a separate transducer.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the disclosed device and the disclosed method are described in detail with reference to the following figures, wherein:

Fig. 1 is a schematic diagram of the disclosed device;

Fig. 2 is a diagrammatic representation of the disclosed method; and

Fig. 3 is a representation of the disclosed device in use.

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 is a schematic diagram of the disclosed device 100. A transducer 107 radiates energy towards the chest of a subject. The transducer 107 also receives the energy reflected by the chest of the subject. Since the chest of the subject is moving due to the subject's breathing the frequency of the reflected energy undergoes Doppler shift. The analyzer 105 receives a signal 106 (to be called transducer signal here after) corresponding to the reflected energy received by the transducer 107. The analyzer 105 analyzes the transducer signal 106 and determines the breathing rate of the subject.

To give a better picture of the device and its process, an oscillator 103 produces energy at a predetermined frequency and drives the transducer 107. The transducer is preferably an antenna that converts high frequency energy into corresponding electromagnetic radiation and *vice versa* or an ultrasound transducer that converts electrical energy into ultrasound energy of a predetermined frequency and *vice versa*. In the description hereafter only one of them, viz, electromagnetic waves, will be referred to for ease of description. It is to be understood that *mutatis mutandis*, the description applies to ultrasound waves also. However, if there are exceptions, the differences with reference to the two forms of energy will be stated at appropriate places.

With a stationary transducer, if the energy is reflected by a stationary object, there is no information in it to be demodulated. However in the present case the reflecting surface is the surface of the chest of the subject that moves in synchronism with the breathing of the subject, at least a part of the movement will be in a direction parallel to the direction of radiation. Thus the frequency of the reflected energy experiences Doppler shifts. The analyzer 105 may demodulate the transducer signal 106. The transducer signal 106 or demodulated signal 106a exhibits a complex dependency on the motion velocity, the motion amplitude and the distance between the chest and sensor. By using appropriate state-of-the-art signal processing, the subject's breathing rate can be obtained from the transducer signal 106 or demodulated signal 106a.

The analyzer 105 analyzes the signal to determine a pattern corresponding to a complete breathing cycle, in the demodulated signal 106a. It identifies at least the beginning and end of each complete cycle comprising one inhalation and one exhalation.

The analyzer 105 determines the time period for each cycle or a time period and amplitude of a pattern within each cycle or counts the number of complete cycles in a given period of time. The pattern within the cycle may correspond to the inhalation phase, exhalation phase and pauses, if any, between them. As is well known, to measure low frequencies the method of calculating the time period of each cycle is more accurate. The reciprocal of the period when multiplied by sixty yields the breathing rate of the subject in number of breaths per minute which is the most common unit for breathing rate. The breathing rate and other values determined by the analyzer 105 are outputted appropriately 108.

In one embodiment, analyzer 105 calculates the breathing rate by Fourier analysis of the transducer signal 106 or the demodulated transducer signal 106a. This may be advantageous for accurate measurements as the effect of noise could be eliminated or

suppressed, eliminating the need for determining the start or end points of a cycle and thereby reducing or even eliminating the ambiguity therein.

In one embodiment, the device may output the demodulated signal 106a in a manner suitable for being displayed on a monitor 109. In another preferred embodiment, limiting values for the various measured values, such as breathing rate, or time for one breath (a complete cycle), time for each inhalation and each exhalation and so on may be input to the device through a suitable user interface 111 and whenever the individual values cross the limiting values, an indication or alarm 110 may be issued by the device. It is to be understood that the indication may be an audio or visual or audio-visual alarm. In one embodiment, the one or more outputs such as the breathing rate, the duration and amplitude of the phases of breathing, etc., may be outputted in a wired or wireless manner, to a central monitoring unit or a bedside unit or a central repository for storing a record of the monitored values or incidents when an alarm was issued.

Since breathing is a natural biological phenomenon, there may be large variations in the time per cycle between cycles. Thus, if the breathing rate calculated as described above is displayed as is, the display on the monitor 109 may change fairly rapidly and hence may be confusing or difficult to read. Thus, the output 108 may be a running average of a predetermined number of breathing cycles for the display unit to display. Alternatively, both the cycle by cycle breathing rate and the running average may be displayed. Once in a while, subjects take a longer breath than normal voluntarily or involuntarily. In one embodiment, when such events occur, such very long cycles may be dropped from the calculation of the average.

In one embodiment, the transducer 107 is disposed on a sphygmomanometer cuff 101 as shown in Fig. 1. The transducer may be releasably coupleable to the cuff, for example using hook-and-loop fasteners. Even though the cuff is shown at a distance from the upper arm of the diagrammatic representation of the subject, it is to be understood that the cuff 101 is wrapped or suitably placed on the upper arm of the subject, as prescribed. The transducer 107 is disposed on the cuff so that in use, when the cuff is worn by the subject as prescribed, the direction of radiation of the energy is substantially towards the chest of the subject. When the radiated energy encounters the chest of the subject, at least part of the energy is reflected by the chest and at least a part of the reflected energy is sensed by the transducer 107.

Fig. 3 shows the cuff 101, the transducer 107 disposed on the cuff 101 worn by a subject, as prescribed. In this embodiment, the breathing rate measurement device and a

sphygmomanometer cuff based blood pressure measurement device may be two independent instruments. In one embodiment, the device according to claim 1 and the blood pressure measurement device are housed in the same enclosure. It may have a display that displays both the blood pressure and the breathing rate. In such a case, the antenna maybe advantageously disposed in the cuff, to be worn by the subject to be monitored so that no special care is needed in positioning the transducer in relation to the chest of the subject.

Now the disclosed method 200 is described in detail with reference to Fig. 2. The method comprises the steps as follows. In a disposing step 213, a transducer is disposed on the arm of the subject. In an analyzing step 215 the signal received from the transducer is analyzed to determine the breathing rate of the subject.

Since, when the subject breathes, the chest expands and contracts in synchronism with the breathing, the chest moves away from the transducer or towards it during exhalation and inhalation respectively. The movement produces shifts in the frequency of the radiated energy. The frequency shift, the Doppler shift, is negative - frequency lower than the radiated frequency - during exhalation and the shift is positive during inhalation. The magnitude of the shift is proportional to the rate of movement of the chest in relation to the transducer.

In an analyzing step 215, at least one temporal pattern in the signal is determined. This could mean that the part of the signal that represents the inhalation phase or exhalation phase and the pauses, if any, between them may be determined. At least complete cycles of breathing maybe determined. This means that the start and end points of a complete breathing cycle may be determined. This could also mean that the starting points of two consecutive breathing cycles may be determined.

Alternatively the breathing rate could also be calculated by Fourier Analysis of the received signal. This may be advantageous for accurate measurements as the effect of noise could be eliminated more easily, reducing the ambiguity in determining the start or end of a cycle.

The time duration of the complete cycle determined is measured. The reciprocal of this measured time, when multiplied by sixty, yields the breathing rate in breaths per minute. Normally, higher frequencies are measured by counting the number of cycles in a certain period of time and the frequency in Hz is calculated. But for slow or long duration phenomenon, it is preferable to measure the time duration of each cycle and calculate the frequency in a suitable unit - Hz or cycles per minute, for instance.

The values measured or further values calculated based on those measurements are output suitably. The output could be displayed in the form of alphanumeric display, or with lights or audio-visual display and so on and combinations thereof and is not treated as a part of this description of the method.

5 The basic equations necessary to carry out the measurement using Doppler are explained below:

The Doppler signal for a single target, which is a good approximation of a subject's chest, is given by Equation 1 below as:

10
$$x(t) = a(t) \cdot \cos(\theta(t))$$

where the amplitude $a(t)$ can be assumed to be constant $a(t) = a_0$, since we consider only small distance changes ($\sim$ cm) due to breathing and the beating heart, disregarding large subject movements. The phase-term in the equation above can be expressed by Equation 2

15 below as:

$$D(t) = \frac{4\pi}{\lambda} \left(\Xi + \sum_{k=1}^4 \int_0^t v_k(t') dt' \right),$$

20 where λ is the wavelength of the transmitted waves, and Ξ is the sensor-chest distance for $t = 0$. The sum consists of 4 terms due to the breathing motion (amplitude A of 5 mm - 30 mm at 0.1 Hz - 0.8 Hz), due to the beating heart (typically < 5 mm at 0.5 Hz - 3 Hz), the patient's global motion and - if applicable - movement of the sensor itself.

For an ideal measurement situation with breathing motion only and a perfect estimation of the phase term, equation (2) reduces to:

25

$$D(t) = \frac{4\pi}{\lambda} (E + x(t))$$

wherein $s(t)$ is the displacement of the chest beginning from $t=0$.

30 In one variant of the method the breathing rate displayed is the running average of a predetermined number of previous cycles. In one variant both the present breathing rate based on the latest full cycle and the running average as mentioned above are

displayed together. In one variant the output includes an alarm when any of the measured or calculated parameters exceed or cross predetermined thresholds.

In one embodiment of the method, the transducer is disposed in a sphygmomanometer cuff. In one embodiment the transducer may be integrated into the cuff
5 as an integral part. Since the cuff has a predefined position and orientation of application on the arm of the subject, the transducer may be so coupled or integrated into it, such that when the cuff is applied to the subject's arm properly, the transducer is in the appropriate position relative to the subject's chest for the measurement of the breathing rate.

The method has hitherto been described as a combination of the cuff based
10 sphygmomanometer and the breathing rate. However it is to be understood that the method may be employed or practiced as an adjunct to or within a monitoring device or system which monitors various other parameters of a subject, for instance in an ICU or any other care facility. The parameters normally measured and monitored in that way are, but not limited to, blood pressure, Blood Oxygen Saturation (SpO₂), heart rate and body temperature and so on.

In one embodiment, electromagnetic waves are used. Though other
15 frequencies may be used, it is found that reliable results are obtained with a frequency of at least 1 GHz. Preferably, the frequency is between 20 GHz and 30 GHz and most preferably the frequency has a nominal value of 24 GHz. In another embodiment, ultrasound energy is employed with a frequency of at least 40 kHz. In other words the device and method may use
20 the principle of Doppler RADAR or ultrasound based Doppler Sonar, also called Acoustic Doppler Sonar, using Ultrasound.

While the embodiments have been described in detail in the drawings and description, such drawings and description are to be considered exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Wherever electrical
25 connections or communication is referred to, it is to be understood that it could be effected in a wired or wireless manner. For instance, instead of displaying measured values of the duration of each phase of the breathing cycle, one or more of them may be displayed as a ratio of the duration of the phase and the duration of the whole breathing cycle and so on. Units described as distinct may in practice be realized in the same physical unit. The units
30 may be built using any one or more devices of various technologies such as microcontrollers, microprocessors, digital signal processors (DSP's), programmable logic devices and so on. The distinction made here is for the ease of understanding and the implementation of the units and the practice of the steps may be varied by skilled persons to advantage.

Other variations to the disclosed embodiments can be understood and effected by those skilled in the art, in practicing the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude elements or steps other than those mentioned, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or other unit may fulfill the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

CLAIMS:

1. A device (100) for monitoring respiration of a subject, the device comprising:
a transducer (107) arranged to be worn on an arm of the subject, the transducer
being arranged for radiating energy towards the chest of the subject and receiving the energy
reflected by the chest of the subject;

5 an analyzer (105) operatively coupled to the transducer (107), the transducer
(107) being arranged for radiating energy under control of the analyzer, the analyzer being
arranged for processing a signal received from the transducer, for determining a respiration
rate of the subject in dependence on the Doppler frequency shifts in the reflected energy
received by the transducer.

10 2. The device (100) of claim 1 wherein the transducer (107) comprises an
ultrasound transducer or an antenna.

3. The device (100) of claim 1 further comprising a sphygmomanometer cuff
15 (101) for monitoring a blood pressure of the subject, the cuff (101) being mechanically
coupleable to the transducer (107).

4. The device (100) of claim 3 wherein the transducer (107) is integrated into the
sphygmomanometer cuff (101).

20 5. The device of claim 3 or 4 wherein the sphygmomanometer cuff (101) is
further electrically coupleable to the analyzer (105), the sphygmomanometer cuff (101) being
arranged for monitoring a blood pressure of the subject in response to a further signal
received from the analyzer (105).

25 6. The device (100) of claim 5 wherein the analyzer (105) is further arranged to
receive data on the monitored blood pressure from the sphygmomanometer cuff (101).

7. The device (100) according to any one of claims 3 to 6 wherein the analyzer (105) is arranged for wireless communication with the transducer (107) or the cuff (101) or both to allow remote monitoring of the subject.

5 8. The device (100) of claim 1, wherein the analyzer (105) is further configured for identifying at least one breathing phase from the transducer signal and for calculating at least one of a duration and an amplitude of the identified phase.

9. The device (100) of claim 1, wherein the analyzer (105) is further configured
10 for averaging at least one of the periodicity of respiration, the number of cycles of respiration per unit time, the duration of the phase, and the amplitude of the phase over at least one of a predetermined time period and a predetermined previous number of cycles.

10. The device (100) of claim 9, wherein the analyzer (105) is further configured
15 for using a current value within predetermined upper and lower limiting values or values that are within a predetermined multiple of a current average value, for calculating a subsequent average value.

11. The device (100) of claim 10 wherein the analyzer (105) is configured for
20 comparing at least one of the periodicity, the number of cycles per unit time, the duration of one or more phases and the amplitude of one or more phases with at least one threshold value for each of those values for generating an alarm signal.

12. The device (100) of claim 2, wherein the radiated energy has a frequency of at
25 least 1 GHz, preferably between 20 GHz and 30 GHz and most preferably in the order of 24 GHz.

13. The device (100) of claims 2, wherein the radiated energy is ultrasound energy
with a frequency of at least 40 kHz.

30 14. A method (200) of monitoring the respiratory rate of a subject, the method comprising the steps of:

a disposing step (213) of disposing a transducer on an arm of a subject for radiating energy towards the chest of the subject and receiving the energy reflected by the

chest of the subject;

an analyzing step of (215) of analyzing a signal received from the transducer, for determining a respiration rate of the subject in dependence on the Doppler frequency shifts in the transducer signal.

5

15. The method (200) of claim 14, wherein the disposing is by mechanically coupling to or integrating the transducer into a sphygmomanometer cuff.

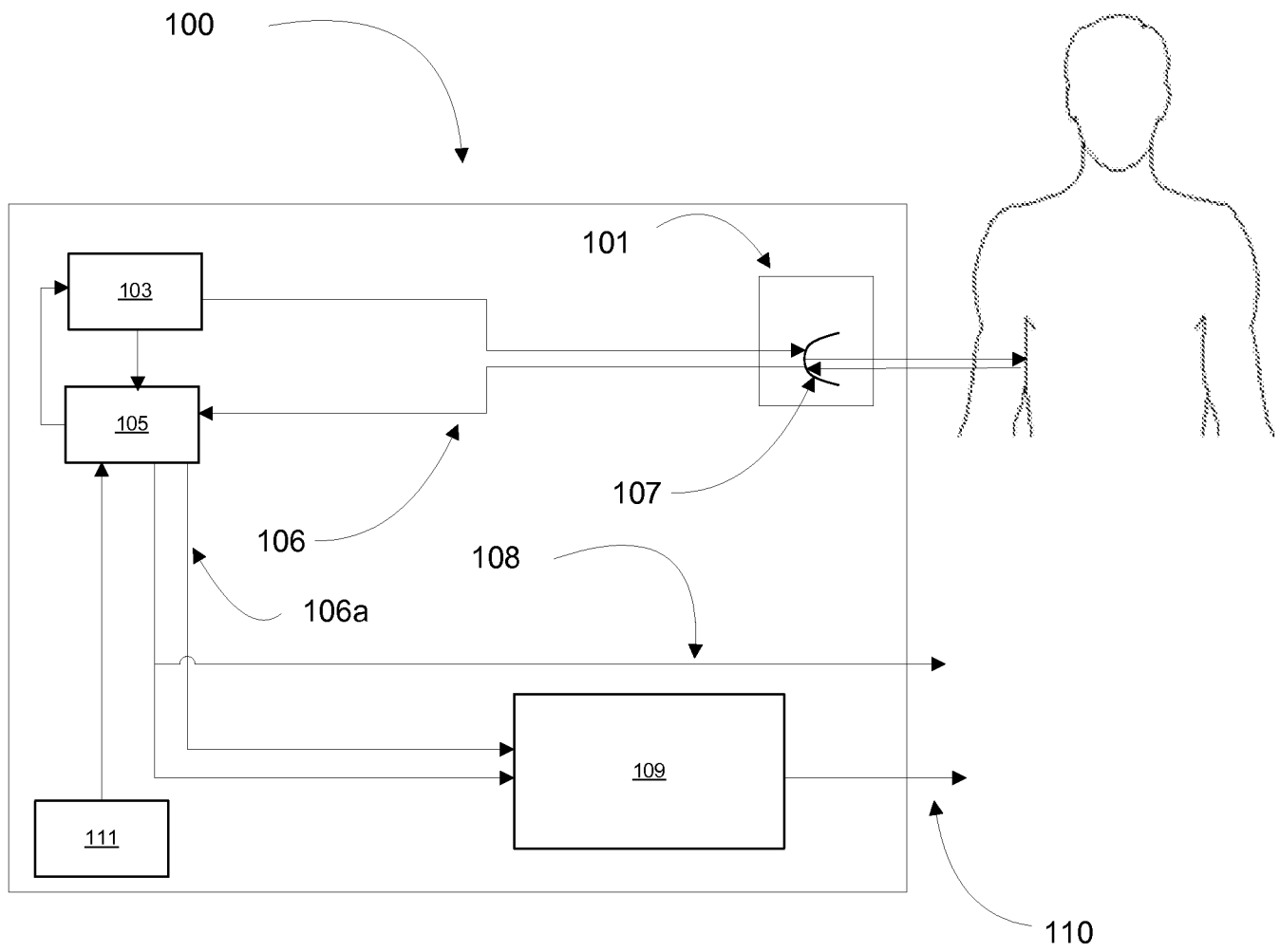


Fig. 1

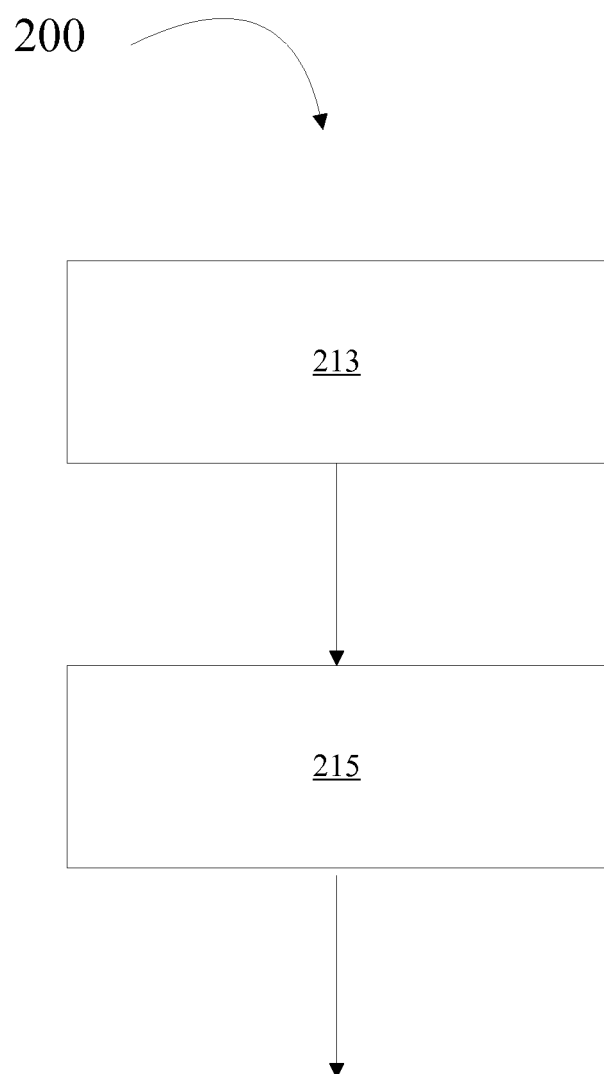
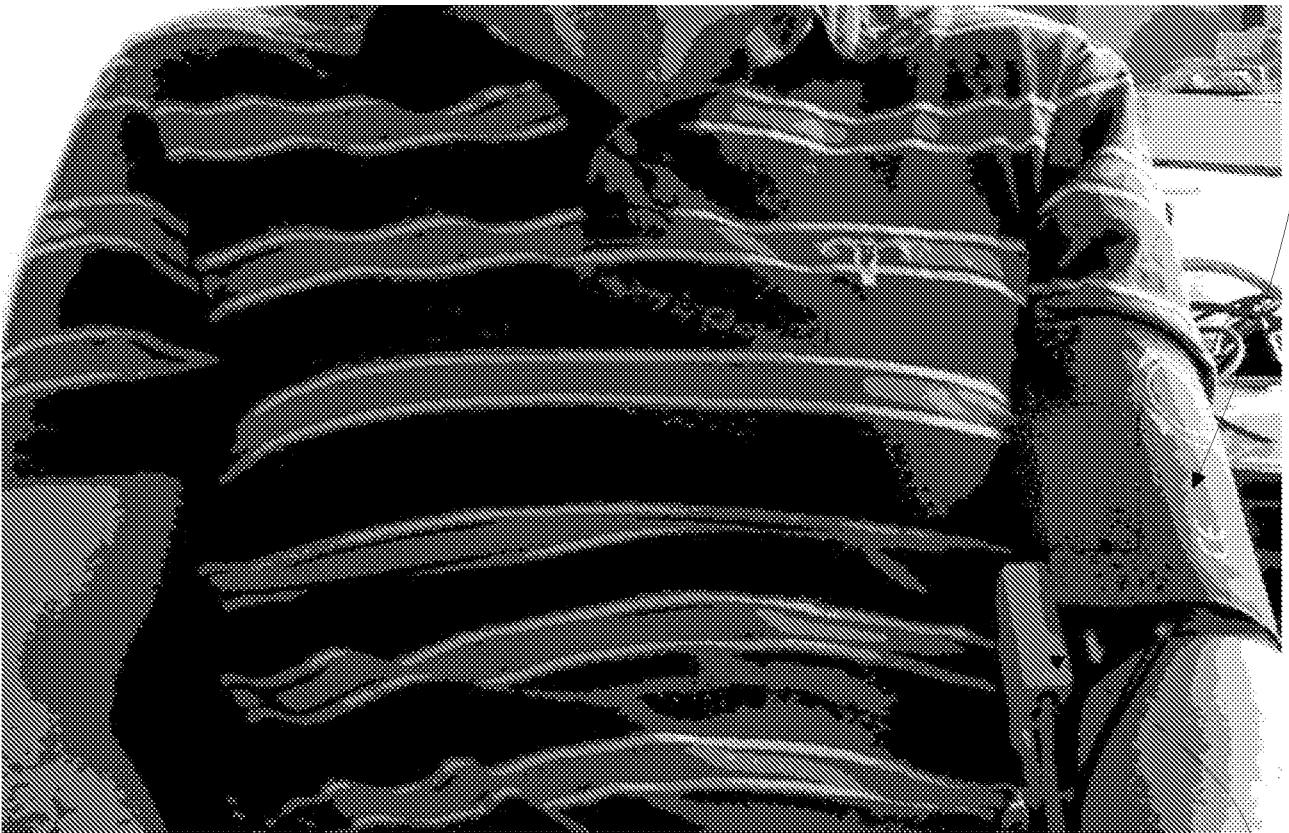


Fig. 2

101



107

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No

PCT/IB2013/059091

A. CLASSIFICATION OF SUBJECT MATTER

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ADD.

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.
A	US 2006/100530 AI (KLIOT MICHEL [US] ET AL) 11 May 2006 (2006-05-11) paragraphs [0046] , [0049] , [0051] figures 1-3 -----	1-15
A	US 2012/197128 AI (PALTI YORAM [IL]) 2 August 2012 (2012-08-02) paragraphs [0004] , [0037] , [0048] -----	1-15
A	US 2006/074283 AI (HENDERSON LESLIE G [US] ET AL) 6 April 2006 (2006-04-06) paragraphs [0044] , [0073] figures 3-6 -----	1-15
A	US 3 527 197 A (WARE RAY W ET AL) 8 September 1970 (1970-09-08) figures 1-4 -----	1-15



Further documents are listed in the continuation of Box C.



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

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"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

24 January 2014

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Authorized officer

Worms , Georg

INTERNATIONAL SEARCH REPORT

Information on patent family members

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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专利名称(译)	用于呼吸速率测量的系统和方法		
公开(公告)号	EP2906104A1	公开(公告)日	2015-08-19
申请号	EP2013785655	申请日	2013-10-03
[标]申请(专利权)人(译)	皇家飞利浦电子股份有限公司		
申请(专利权)人(译)	皇家飞利浦N.V.		
当前申请(专利权)人(译)	皇家飞利浦N.V.		
[标]发明人	MUHLSTEFF JENS		
发明人	MÜHLSTEFF, JENS		
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CPC分类号	A61B5/0205 A61B5/022 A61B5/0816 A61B5/6824 A61B5/7278 A61B8/08		
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摘要(译)

公开了一种用于监测受试者呼吸速率的装置 (100)。换能器 (107) 向对象的胸部辐射能量并接收反射的能量。分析器 (105) 接收与反射能量相对应的信号。参考换能器, 由于呼吸引起的受试者胸部的运动, 反射的能量将经历多普勒频率偏移。分析器 (105) 通过测量信号的周期性和信号的每单位时间的周期数中的至少一个来分析信号以计算呼吸率。在优选实施例中, 换能器 (107) 设置在血压计袖带中或血压计袖带上, 以朝向受试者的胸部辐射能量, 并接收由受试者的胸部反射的能量。