(54) Title: CENTRAL CAVITY PERFUSION CALCULATION

(57) Abstract: A system, method and non-transitory computer readable storage medium for monitoring a perfusion of a patient. The system, method and computer readable storage medium receive an indication of a voltage applied across a chest of the patient via a first electrode, receive a measurement of a current across the chest of the patient, resulting from the applied voltage via a second electrode, generate an impedance-based respiratory rate waveform based on the applied voltage and the measured current, generate a Fourier Transform of the respiratory rate waveform relative to a heartbeat of the patient, isolate cardiac artifacts in the Fourier Transform and generate a perfusion waveform indicating a perfusion of a chest cavity of the patient based on the isolated cardiac artifacts.

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CENTRAL CAVITY PERFUSION CALCULATION

Background

[0001]   Perfusion of the central cavity (e.g., thorax) and changes in this perfusion in a patient is highly useful information in evaluating the cardiovascular state of a patient. There have been numerous attempts at quantifying the perfusion of the central cavity. However, existing systems and methods for quantifying the perfusion of the central cavity are inefficient, cumbersome and/or invasive. For example, a thoracic electrical impedance method requires the placement of extra sensors along with straps/cables on the patient. A Doppler flowmetry method may also be used to quantify the perfusion of the central cavity, but does not provide a continuous measurement, as the equipment if bulky, expensive, and requires hands-on use by a clinician. One can also use central venous pressure (CVP) measurements to calculate perfusion and cardiac output information, but this involves the use of an invasive catheter.

Brief Description of the Drawings

[0002]   Fig. 1 shows a schematic drawing of a system according to an exemplary embodiment of the present invention.

[0003]   Fig. 2 shows a flow diagram of a method according to an exemplary embodiment of the present invention.

[0004]   Fig. 3 shows a graph of an exemplary impedance-based respiratory rate waveform of a patient.

[0005]   Fig. 4 shows an exemplary Fourier transform of the respiratory rate waveform of Fig. 3.

[0006]   Fig. 5 shows a graph of an exemplary perfusion waveform based on cardiac artifacts identified via the Fourier Transform of Fig. 4.

Detailed Description

[0007]   The exemplary embodiments include a method for monitoring a perfusion of a patient. The method includes receiving an indication of a voltage applied across a chest of the patient via a first electrode, receiving a measurement of a current across the chest of the patient resulting from the applied voltage via a second electrode, generating an impedance-based respiratory rate waveform based on the applied voltage and the measured current, generating a Fourier Transform of the respiratory rate waveform relative to a heartbeat of the patient, isolating cardiac artifacts in the Fourier Transform and generating a perfusion waveform indicating a perfusion of a chest cavity of the patient based on the isolated cardiac artifacts.

[0008]   The exemplary embodiments also include a system for monitoring a perfusion of a patient. The system includes a first electrode applying a voltage across a chest of the patient, a second electrode measuring a current across the chest of the patient resulting from the applied voltage and a processor generating an impedance-based respiratory rate waveform based on the applied voltage and the measured current, generating a Fourier Transform of the respiratory rate waveform relative to a heartbeat of the patient, isolating cardiac artifacts in the Fourier Transform and generating a perfusion

waveform indicating a perfusion of a chest cavity of the patient based on the isolated cardiac artifacts.

[0009]   The exemplary embodiments further include a non-transitory computer-readable storage medium including a set of instructions executable by a processor. The set of instructions, when executed by the processor, cause the processor to perform operations, including receiving an indication of a voltage applied across a chest of the patient via a first electrode, receiving a measurement of a current across the chest of the patient resulting from the applied voltage via a second electrode, generating an impedance-based respiratory rate waveform based on the applied voltage and the measured current, generating a Fourier Transform of the respiratory rate waveform relative to a heartbeat of the patient, isolating cardiac artifacts in the Fourier Transform; and generating a perfusion waveform indicating a perfusion of a chest cavity of the patient based on the isolated cardiac artifacts.

[0010]   The exemplary embodiments may be further understood with reference to the following description and the appended drawings, wherein like elements are referred to with the same reference numerals. The exemplary embodiments relate to a system and method for assessing the cardiovascular state of a patient. In particular, the exemplary embodiments describe quantifying a perfusion of the central cavity of the patient to determine the cardiovascular state of the patient. Although exemplary embodiments show and describe using electrodes to determine a respiratory rate of a patient, it will be understood by those of skill in the art that the system and method of the

present invention may utilize other devices for determining the
respiratory rate such as, for example,

[0011]   As shown in Fig. 1, a system 100 according to an
exemplary embodiment of the present disclosure measures a
perfusion of a central cavity of a patient. The system 100
comprises a processor 102, a user interface 104, a display 106
and a memory 108. The system 100 also comprises a first
electrode 110 and a second electrode 112, each of which are
connected (directly or indirectly) to the processor 102 so that
a voltage applied by the first electrode 110 and a current
measured by the second electrode 112 can be detected and
monitored via the processor 102. The first and second electrode
110, 112 may be adhered to a chest of a patient and controlled
via the user interface 104 which may include, for example, input
devices such as a keyboard, a mouse and/or a touch display on
the display 106. The first electrode 110 may be an EKG
electrode that applies a small, high frequency voltage across
the chest and the second electrode 112 may be a second EKG
electrode measuring a resulting current across the chest.
Impedance-based respiratory rate measurement is based on the
fact that the chest impedance changes with the inspiration and
exhalation of air. Since air is a poor conductor, the thorax
becomes less conductive as air enters the lungs. This is
reflected by an increased impedance across the chest as air is
exhaled. Once the voltage is applied and the resulting current
across the chest is measured, the processor 102 calculates the
impedance by dividing the voltage across the chest with the
resulting current. The first and second electrodes 110, 112 may
continuously apply a voltage and measure the resulting current,
respectively, so that the processor 102 determines the
continuous respiratory rate of the patient. Basic impedance is

on the order of several hundred ohms, which is relatively
stationary, and the respiratory impedance is around, for
example, 2 ohms. Another detectable oscillating impedance,
however, is that caused by blood being pumped into and out of
the thorax by the heart. This impedance change is on the order
of half an ohm. This impedance is observable particularly when
lungs are emptied after an exhalation. This information may be
used to estimate the amount of blood entering the central
cavity.

[0012]   In particular, the processor 102 takes a continuous
respiratory waveform and resamples it over a new time domain,
for which the heart is the clock and for which the distance
between any two heartbeats is equivalent. The information about
heartbeats is collected by the associated EKG. The respiratory
signal is then interpolated over this new heartbeat-based time
domain. At this point, the processor 102 takes the Fourier
transform of the respiratory rate waveform of the patient, the
x-axis being 1/Heartbeat rather than 1/s. The result is a
transform that highlights the cardiac artifact measured by the
impedance – e.g., the impedance across the chest caused by blood
being pumped into and out of the thorax. The processor 102 then
isolates the cardiac artifacts and inverts the Fourier transform
of the cardiac artifacts to generate a waveform representing an
amount of blood being pumped into and out of the thorax. This
new signal is resampled back into the original time via
interpolation. Changes in amplitude of the resulting waveform
may be analyzed to determine the perfusion of the chest cavity,
giving clinicians an idea of the hemodynamic state of the
patient. The resulting perfusion waveform may be displayed on
the display 106. It will be understood that the resulting
perfusion waveform along with any associated data such as the

continuous respiratory rate and Fourier transforms may be stored
to the memory 108.

[0013]   Fig. 2 shows an exemplary method by which the system
100 generates a waveform representing the perfusion of a
patient, for analysis. As discussed above in regard to the
system 100, the first and second electrodes 110, 112 are adhered
to a chest of the patient. The first and second electrodes 110,
112 may be positioned along the chest and adhered thereto in a
manner known to those of skill in the art. In a step 210, the
first electrode 110 applies a continuous small, high frequency
voltage across the chest of the patient. In a step 220, the
second electrode 210, measures the current across the chest of
the patient resulting from the applied voltage. The applied
voltage and the measured current may be monitored by the
processor 102 such that, in a step 230, the processor 102
generates a impedance-based respiratory rate waveform resulting
from dividing the applied voltage by the resulting current as
shown, for example, in Fig. 3. This respiratory rate waveform
may be stored to the memory 108 and/or displayed on the display
106. In a step 240, the processor 102 takes the respiratory
rate waveform and resamples it in a new time domain in which the
heart acts as the clock. A distance between two heartbeats may
be equivalent. The respiratory signal is then interpolated over
this new heartbeat-based time domain. In a step 250, the
processor 102 then takes the Fourier Transform of the resampled
respiratory rate waveform, the x-axis being 1/Heartbeat rather
than 1/s, for example, in Fig. 4. In particular, the Fourier
Transform may be stretched and/or condensed over time so that
each patient heartbeat is equally spaced from one another. It
will be understood by those of skill in the art that the DC
component may also be removed to normalize the signal shown in

Fourier Transform. Cardiac artifacts may be shown in the
Fourier Transform as narrow spikes at the frequency of one
heartbeat.

[0014]   In a step 260, the cardiac artifacts may be isolated,
removing other unnecessary signals resulting from, for example,
a movement and breathing of the patient. In a step 270, the
processor 102 may take the inverse Fourier Transform of these
isolated cardiac artifacts to generate a waveform representing
an amount of blood being pumped into and out of the chest
cavity, as shown, for example in Fig. 5. In a step 280, the
inverse Fourier Transform is resampled back into the original
time via interpolation to generate a perfusion waveform. This
perfusion waveform may be stored to the memory 108 and/or
displayed on the display 106. The perfusion waveform may be
analyzed, in a step 290, to determine a cardiac state of the
patient. Changes in an amplitude of the perfusion waveform
indicate changes in the amount of blood being circulated in the
chest cavity and is a good indicator of how the patient's body
is handling its blood supply and how well perfused the patient's
body is. For example, a decrease in amplitude over time may
indicate that the patient is not well perfused and may have
hypotension. Thus, analysis of the perfusion waveform may
include determining changes in amplitude of the perfusion
waveform. When, for example, a decrease in amplitude exceeds a
predetermined threshold value or is within a predetermined range
of values, the processor 102 may generate a warning to a user
(e.g., the clinician) indicating that the patient is not well
perfused and may be experiencing hypotension. The warning may
be auditory and/or may be displayed on the display 106. It will
be understood by those of skill in the art that the

predetermined threshold values and predetermined range in values may be changed or updated by a user of the system via the user interface 104. It will also be understood by those of skill in the art that the perfusion waveform may be analyzed along with other available information such as, for example, the amount of blood in peripheral sites of the patient's body, as measured by photoplethysmography, to better understand the hemodynamic state of the patient's body.

[0015]   It will be understood by those of skill in the art that the perfusion waveform may be generated for a given period of time or may be a continuous waveform generated for as long as the first and second electrodes 110, 112 are applying voltage and measuring current, respectively. Each heartbeat may include a number of amplitudes so that it may be beneficial to be able to view the perfusion waveform in smaller increments of time. For example, the user may be able to select a window or frame, via the user interface 104, which may be moved over portions of the perfusion waveform to better view changes of amplitude within a smaller window of time.

[0016]   It is noted that the claims may include reference signs/numerals in accordance with PCT Rule 6.2(b). However, the present claims should not be considered to be limited to the exemplary embodiments corresponding to the reference signs/numerals.

[0017]   Those skilled in the art will understand that the above-described exemplary embodiments may be implemented in any number of manners, including, as a separate software module, as a combination of hardware and software, etc. For example, generation of the perfusion waveform may be implanted by

programs containing lines of code that, when compiled, may be executed on a processor.

[0018]   It will be apparent to those skilled in the art that various modifications may be made to the disclosed exemplary embodiment and methods and alternatives without departing from the spirit or scope of the disclosure. Thus, it is intended that the present disclosure cover the modifications and variations provided that they come within the scope of the appended claims and their equivalents.

What is claimed is:

1.   A method for monitoring a perfusion of a patient,
      comprising:

            receiving an indication of a voltage applied across a
      chest of the patient via a first electrode;

            receiving a measurement of a current across the chest
      of the patient resulting from the applied voltage via a
      second electrode;

            generating an impedance-based respiratory rate
      waveform based on the applied voltage and the measured
      current;

            generating a Fourier Transform of the respiratory rate
      waveform relative to a heartbeat of the patient;

            isolating cardiac artifacts in the Fourier Transform;
      and

            generating a perfusion waveform indicating a perfusion
      of a chest cavity of the patient based on the isolated
      cardiac artifacts.

2.   The method of claim 1, further comprising:
            analyzing the perfusion waveform by identifying
      changes in amplitude to assess the cardiac state of the
      patient.

3.   The method of claim 2, wherein analyzing the perfusion
      waveform includes identifying a decrease in the amplitude.

4.   The method of claim 3, further comprising:
            initiating a warning signal to a user when the
      decrease in amplitude exceeds a predetermined threshold
      value.

5.   The method of claim 4, wherein the warning signal is one of an auditory signal and a visual signal.

6.   The method of claim 1, wherein generating the Fourier Transform includes removing a DC component.

7.   The method of claim 1, wherein generating the perfusion waveform includes taking an inverse Fourier Transform of the isolated cardiac artifacts.

8.   The method of claim 1, further comprising:
        storing one of the respiratory rate waveform and the perfusion waveform in a memory.

9.   The method of claim 1, further comprising:
        displaying the perfusion waveform on a display.

10.   The method of claim 9, further comprising:
        selecting a portion of the displayed perfusion waveform to view the portion of the perfusion waveform within a predetermined window of time.

11.   A system for monitoring a perfusion of a patient, comprising:
        a first electrode applying a voltage across a chest of the patient;
        a second electrode measuring a current across the chest of the patient resulting from the applied voltage;
        a processor generating an impedance-based respiratory rate waveform based on the applied voltage and the measured current, generating a Fourier Transform of the respiratory rate waveform relative to a heartbeat of the patient,

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isolating cardiac artifacts in the Fourier Transform and generating a perfusion waveform indicating a perfusion of a chest cavity of the patient based on the isolated cardiac artifacts.

12.   The system of claim 11, wherein the processor analyzes the perfusion waveform by identifying changes in amplitude to assess the cardiac state of the patient.

13.   The system of claim 12, wherein the processor analyzes the perfusion waveform by identifying a decrease in the amplitude.

14.   The system of claim 13, wherein the processor initiates a warning signal to a user when the decrease in amplitude exceeds a predetermined threshold value.

15.   The system of claim 11, wherein generating the Fourier Transform includes removing a DC component.

16.   The system of claim 11, wherein generating the perfusion waveform includes taking an inverse Fourier Transform of the isolated cardiac artifacts.

17.   The system of claim 11, further comprising:
            a memory storing one of the respiratory rate waveform and the perfusion waveform.

18.   The system of claim 11, further comprising:
            a display displaying the perfusion waveform on a display.

19. The system of claim 18, further comprising:

a user interface permitting a user to select a portion of the displayed perfusion waveform to view the portion the perfusion waveform within a predetermined window of time.

20. A non-transitory computer-readable storage medium including a set of instructions executable by a processor, the set of instructions, when executed by the processor, causing the processor to perform operations, comprising:

receiving an indication of a voltage applied across a chest of the patient via a first electrode;

receiving a measurement of a current across the chest of the patient resulting from the applied voltage via a second electrode;

generating an impedance-based respiratory rate waveform based on the applied voltage and the measured current;

generating a Fourier Transform of the respiratory rate waveform relative to a heartbeat of the patient;

isolating cardiac artifacts in the Fourier Transform; and

generating a perfusion waveform indicating a perfusion of a chest cavity of the patient based on the isolated cardiac artifacts.
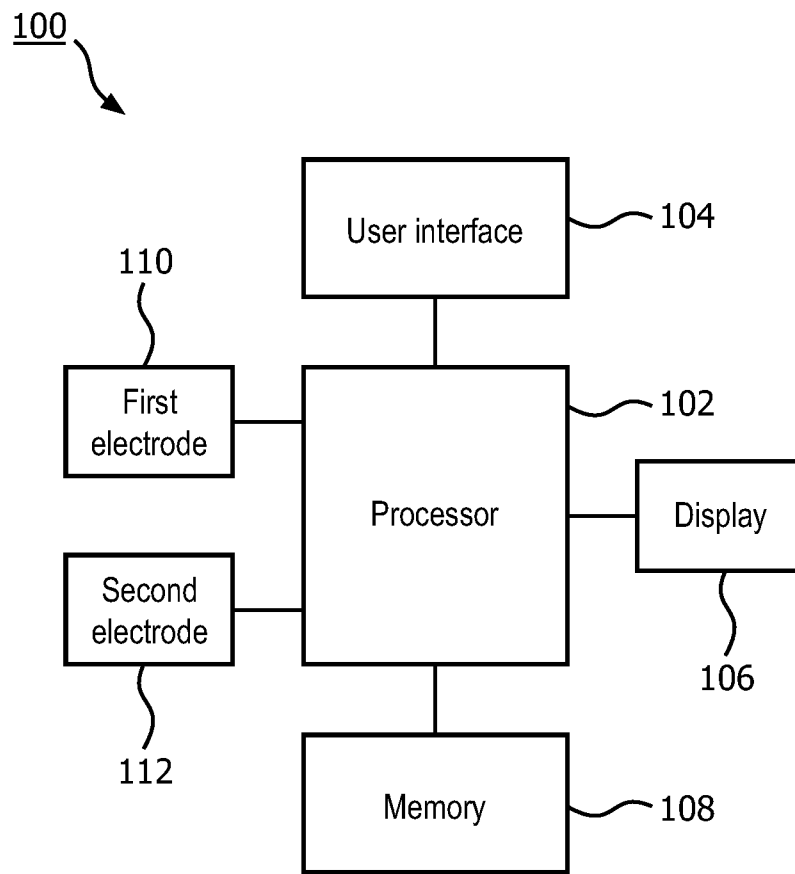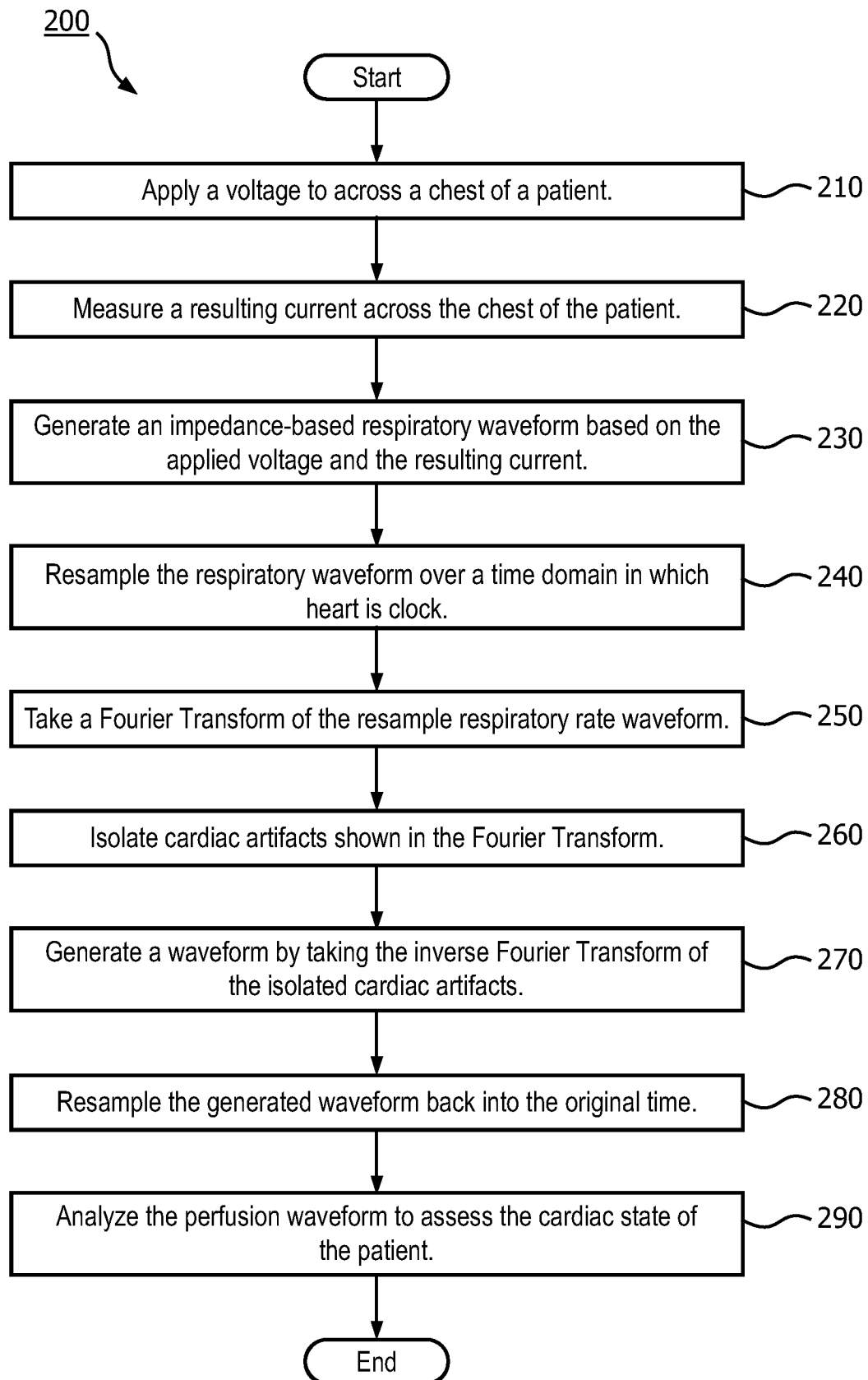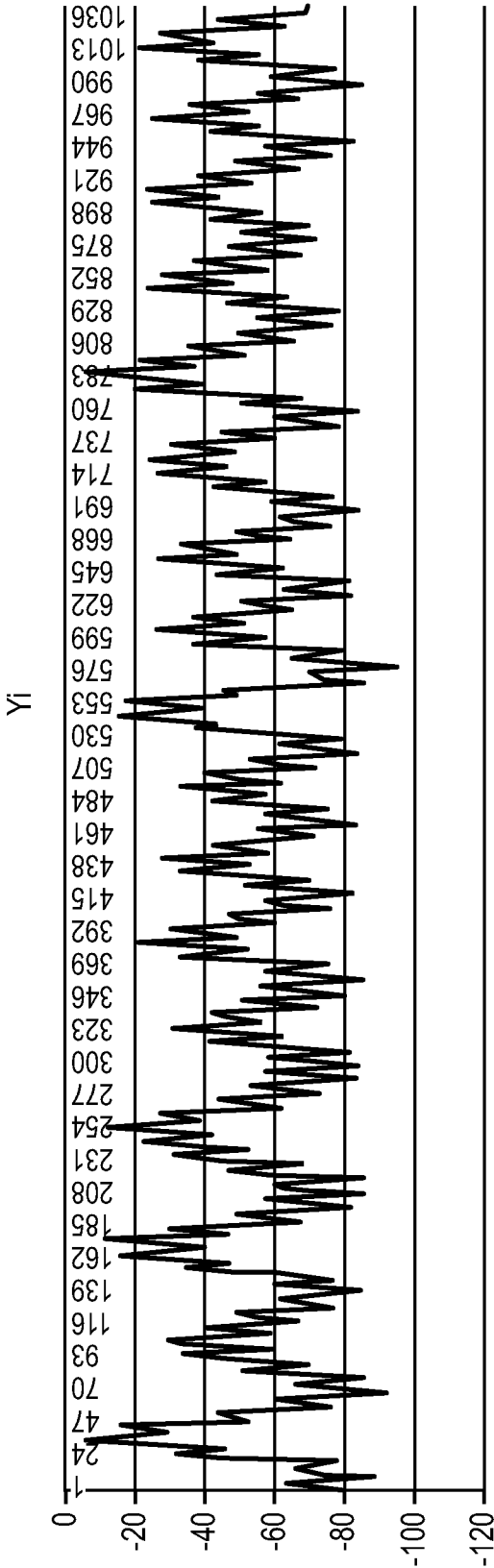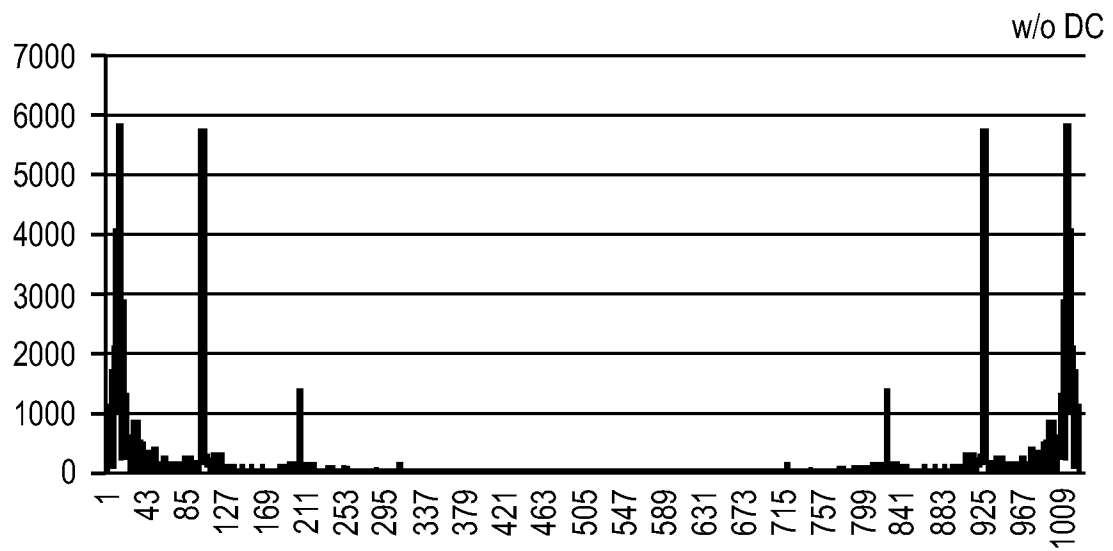
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100

FIG. 1

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200

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                              ┌──────────┐
                              │  Start   │
                              └──────────┘
                                   │
                                   ▼
        ┌─────────────────────────────────────────────────┐
        │  Apply a voltage to across a chest of a patient.  │────── 210
        └─────────────────────────────────────────────────┘
                                   │
                                   ▼
        ┌─────────────────────────────────────────────────┐
        │  Measure a resulting current across the chest of  │────── 220
        │                  the patient.                     │
        └─────────────────────────────────────────────────┘
                                   │
                                   ▼
        ┌─────────────────────────────────────────────────┐
        │  Generate an impedance-based respiratory waveform │
        │  based on the applied voltage and the resulting   │────── 230
        │                    current.                       │
        └─────────────────────────────────────────────────┘
                                   │
                                   ▼
        ┌─────────────────────────────────────────────────┐
        │  Resample the respiratory waveform over a time    │
        │  domain in which heart is clock.                  │────── 240
        └─────────────────────────────────────────────────┘
                                   │
                                   ▼
        ┌─────────────────────────────────────────────────┐
        │  Take a Fourier Transform of the resample         │────── 250
        │  respiratory rate waveform.                       │
        └─────────────────────────────────────────────────┘
                                   │
                                   ▼
        ┌─────────────────────────────────────────────────┐
        │  Isolate cardiac artifacts shown in the Fourier   │────── 260
        │  Transform.                                       │
        └─────────────────────────────────────────────────┘
                                   │
                                   ▼
        ┌─────────────────────────────────────────────────┐
        │  Generate a waveform by taking the inverse        │
        │  Fourier Transform of the isolated cardiac        │────── 270
        │  artifacts.                                       │
        └─────────────────────────────────────────────────┘
                                   │
                                   ▼
        ┌─────────────────────────────────────────────────┐
        │  Resample the generated waveform back into the    │────── 280
        │  original time.                                   │
        └─────────────────────────────────────────────────┘
                                   │
                                   ▼
        ┌─────────────────────────────────────────────────┐
        │  Analyze the perfusion waveform to assess the     │────── 290
        │  cardiac state of the patient.                    │
        └─────────────────────────────────────────────────┘
                                   │
                                   ▼
                              ┌──────────┐
                              │   End    │
                              └──────────┘
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FIG. 2

FIG. 3

FIG. 4

Chart area IDFT (105)

FIG. 5

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/02   A61B5/0295   A61B5/00
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.
Y	US 5 178 154 A (ACKMANN JAMES J [US] ET AL) 12 January 1993 (1993-01-12) column 1, line 1 - column 2, line 63 column 3, line 33 - column 5, line 28 column 10, lines 28-68 figures	1-20
Y	US 2012/172730 A1 (DELOS JOHN B [US] ET AL) 5 July 2012 (2012-07-05) paragraphs [0006] - [0012] paragraphs [0027] - [0031] figure 6	1-20
A	US 2005/065554 A1 (KENKNIGHT BRUCE H [US] ET AL) 24 March 2005 (2005-03-24) paragraphs [0016], [0019], [0023], [0026], [0033]	1-20

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents :

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

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Date of the actual completion of the international search	Date of mailing of the international search report
12 June 2015	18/06/2015

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

Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
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