A method of estimating blood pressure of a user, the method including the steps of: injecting current into the user's body via a pair of current injection electrodes affixed to the user's upper body, receiving an electrocardiogram (ECG) signal from an ECG electrode affixed to the user's upper body, receiving at least one pulse signal related to pulse wave velocity (PWV) of a pressure pulse generated by a cardiac contraction, determining, from the ECG signal, instances of electrical stimulation of the user's heart; determining, from the least one pulse signal, corresponding instances of arrival at the user's carotid artery of a pulse wave; computing the pulse arrival time (PAT) from the instances of electrical stimulation and one or more corresponding instances of pulse wave arrival from the least one pulse signal; and estimating the blood pressure from the computed PAT.
CUFFLESS BLOOD PRESSURE MONITORING SYSTEM

Field of the Invention

[0001] The present invention relates generally to a method and system for monitoring blood pressure, and in particular to blood pressure monitoring systems and methods that do not involve the use of an inflatable cuff positioned about a user's arm for inflation by health practitioner.

Background

[0002] Abnormally high blood pressure (BP) or hypertension contributes to cardiovascular diseases (CVD) such as heart disease, stroke and kidney failure which lead to premature death and disability. With one in three adults worldwide having high BP and more people dying from CVDs, hypertension is recognized by the World Health Organization (WHO) as a global public health issue. Since the first ambulatory BP measurements (ABPM) were carried out 50 years ago, strong evidence has emerged in several long-term studies that mean BP levels as well as BP variations over 24 hours or longer are more sensitive and reliable predictors of CV risks than conventional measurements in the presence of a physician.

[0003] Methods of estimating BP without a cuff are known, and are based on determining Pulse Transit Time (PTT) or Pulse Arrival Time (PAT), which is related to pulse wave velocity (PWV). A pressure pulse is generated by a cardiac contraction (at the point of the aortic valve opening) which propagates along the entire arterial tree. PWV refers to the velocity of propagation with typical values ranging from 4 to 5m/s in larger, central and more elastic arteries, to 15 m/s in peripheral, muscular arteries such as the femoral artery.

[0004] Several proposed methods based on pulse wave velocity (PWV) or pulse transit time (PTT) are summarised in the following publication: D. Buxi et al., "A survey on signals and systems in ambulatory blood pressure monitoring using pulse transit time," Physiological Measurement, vol. 36, no. 3, pp. R1-R26, 2015. However, many of the methods rely on measurement of the arterial pulse at the radial artery or the finger, which not only undergoes vasomotion, but is also surrounded by muscular tissue. Both these factors influence PTT adversely, reducing the accuracy of prior BP-PTT calibrations.
It would therefore be desirable to provide a method and system of monitoring blood pressure without the use of a cuff that is accurate, enables the use of a compact monitoring device to be employed and is well adapted to both ambulatory and sedentary activities.

It would also be desirable to provide a blood pressure monitoring system and method that ameliorates and/or overcomes one or more disadvantages of known blood pressure monitoring methods and systems.

**Summary of the Invention**

According to a first aspect of the present invention, there is provided a method of estimating blood pressure of a user, the method including the steps of:

- injecting current into the user's body via a pair of current injection electrodes affixed to the user's upper body,
- receiving an electrocardiogram (ECG) signal from an ECG electrode affixed to the user's upper body,
- receiving at least one pulse signal related to pulse wave velocity (PWV) of a pressure pulse generated by a cardiac contraction,
- determining, from the ECG signal, instances of electrical stimulation of the user's heart;
- determining, from the least one pulse signal, corresponding instances of arrival at the user’s carotid artery of a pulse wave;
- computing the pulse arrival time (PAT) from the instances of electrical stimulation and one or more corresponding instances of pulse wave arrival from the least one pulse signal; and
- estimating the blood pressure from the computed PAT.

In one or more embodiments, the step of determining instances of electrical stimulation of the user's heart includes:

- determining instances of R-peaks in a QRS complex of the ECG signal.

In one or more embodiments, the at least one pulse signal includes a bioimpedance (BioZ) signal from a BioZ electrode affixed to the user's upper body.
In one or more embodiments, the pair of current injection electrodes are positioned on the user's upper body across the common carotid arteries.

In one or more embodiments, one or both of the ECG and BioZ electrodes are also positioned on the user's upper body across the common carotid and / or subclavian arteries.

In one or more embodiments, the method further includes:

receiving a reflected wave signal from a continuous wave radar device, the device including two or more antennae affixed to the user's upper body, and wherein the at least one pulse signal includes a radar signal (RDR), derived from the reflected wave signal, that varies in accordance with the periodic motion of the user's heart or aorta.

In one or more embodiments, the RDR signal is linearly correlated with the periodic motion of the user's heart or aorta.

In one or more embodiments, the two antennas are positioned across the user's heart or aorta.

In one or more embodiments, the step of receiving at least one pulse signal includes receiving two or more pulse signals related to pulse wave velocity (PWV) of a pressure pulse generated by a cardiac contraction, and wherein the step of computing the pulse arrival time (PAT) includes comparing the instances of electrical stimulation and to instances of pulse wave arrival from the two or more pulse signals, the method further including the step of: computing the Pulse Transition Time (PTT) by comparing the PATs from the two or more pulse signals; and estimating the blood pressure from the computed PTT.

In one or more embodiments, the at least one pulse signal includes a bioimpedance (BioZ) signal from a BioZ electrode affixed to the user's upper body.

In one or more embodiments, the method further includes:

receiving a reflected wave signal from a continuous wave radar device, the device including two or more antennae affixed to the user's upper body, and wherein the at least one pulse signal includes a radar signal (RDR), derived from the reflected wave signal, that varies in accordance with the periodic motion of the user's heart or aorta.
According to a second aspect of the present invention, there is provided a device for estimating blood pressure of a user, comprising:

- inputs for receiving signals from the electrodes mounted to a user’s upper body; and
- a processing unit and associated memory for storing computer program instructions to cause the processing unit to perform a method as described hereabove.

According to a third aspect of the present invention, for estimating blood pressure of a user, comprising:

- inputs for receiving signals from electrodes and antennae mounted to a user’s upper body; and
- a processing unit and associated memory for storing computer program instructions to cause the processing unit to perform a method as described hereabove.

Brief Description of the Drawings

The invention will now be described in further detail by reference to the accompanying drawings. It is to be understood that the particularity of the drawings does not supersede the generality of the preceding description of the invention.

Figure 1 is a schematic diagram showing one embodiment of a system for estimating blood pressure of a user;

Figures 2 and 3 are diagrams showing the attachment to a user of electrodes and antennae forming part of the system of Figure 1;

Figures 4 and 5 are respectively a flow chart depicted processing steps carried out by the processing unit forming part of a first variant to the system of Figure 1 and signals received or derived by the processing unit forming part of the first variant to the system of Figure 1;

Figures 6 and 7 are respectively a flow chart depicted processing steps carried out by the processing unit forming part of the system of Figure 1 and signals received or derived by the processing unit forming part of the system of Figure 1;

Figures 8 and 9 are respectively a flow chart depicted processing steps carried out by the processing unit forming part of a second variant to the
system of Figure 1 and signals received or derived by the processing unit forming part of the second variant to the system of Figure 1;

[0026] Figures 10 and 11 are graphical representation of test results of the system shown in Figure 1;

[0027] Figures 12 and 13 are diagrams showing the extraction of respiration related data from pulse signals received by the system of Figure 1; and

[0028] Figure 14 is a schematic diagram the device of Figure 1 interconnected to a network of communication devices.

**Detailed Description**

[0029] Referring firstly to Figure 1, there is shown generally a cuffless blood pressure monitoring system 10 including a continuous wave radar device 12, current injection module 14, analog to digital converters 16 to 22, together with a microcomputer 24, input/output module 26 and communications module 28. The continuous wave radar device 12 includes a pair of antennae 30 and 32 affixed to the upper body of a user 34 coupled to a radar signal generating and receiving module 36.

[0030] The microcomputer 24 includes a processing unit 38 and associated memory 40 for storing computer program instructions to cause the processing unit 38 to perform the various functions described herein, together with a further memory 42 for storing data required in the performance of those operations.

[0031] The system 10 further includes an antenna or other data receiving and/or transmitting means 54 coupled to the communications module 28.

[0032] In addition, the system 10 includes electrodes 44 and 46 coupled to the current injection module 14 as well as corresponding electrodes 48 and 50 for respectively receiving an electrocardiogram (ECG) signal and bioimpedance (BioZ) signal generated by the user's body 34. The electrodes 48 and 50 are respectively coupled to the inputs of the analog to digital converters 16 and 18.

[0033] In this exemplary embodiment, system 10 further includes an optional phonocardiographic (PCG) sensor 52 coupled to the input of the analog to digital converter 22.

[0034] As can be best seen in Figures 2 and 3, the current injection electrodes 44 and 46 (here respectively referenced 2b and 2a) are affixed to the upper body of a user and preferably around the left and right common carotid
\[ T_{CW}(t) = E_0 \cos(\omega t + \varphi(t)) \]  
\[ R_{CW}(f) = E_\perp \cos(mt + \varphi(t) - 2d_0/c) - \frac{4\pi d_0}{\lambda} \frac{4\pi m(t)}{k} + \theta_0 \]
\[ \frac{1}{2} \cdot (t) = E_0 \cos(\Omega t + \phi(t)) \]  
(1)

\[ R_{CW}(t) = E_1 \cos(\Omega t + \phi_1(t - 2d_0/c) - \frac{4\pi d_0}{\lambda} - \frac{4\pi m(t)}{\lambda} + \theta_0) \]  
(2)

[0039] Amplification, filtering and demodulation of RCW \((t)\) with a homodyne quadrature mixer will yield in-phase and quadrature baseband signals. Neglecting amplitude values, these signals are expressed as:

\[ I(t) = \cos\left(\phi - \phi_1(t - \frac{d_0}{c}) + \theta_0 + \frac{4\pi d_0}{\lambda} + \frac{4\pi m(t)}{\lambda}\right) \]  
(3)

\[ Q(t) = \sin\left(\phi - \phi_1(t - \frac{d_0}{c}) + \theta_0 + \frac{4\pi d_0}{\lambda} + \frac{4\pi m(t)}{\lambda}\right) \]  
(4)

[0040] In order to overcome non-linearities produced by null-points, an arctangent of \(RDR(t) = Q(t) + \delta\), where \(\delta\) is an arbitrary constant, is calculated by the processing unit 26 to produce a signal that is linearly correlated with \(m(t)\).

[0041] The BioZ signal is the impedance measured across the common carotid arteries. The RDR signal arises from changes in the carotid arterial and venous blood volumes.

[0042] In this exemplary embodiment, the RDR signal is acquired at 1GHz using patch antennas 30 and 32. However, in other embodiments, the frequency of the radar signal can vary and can be any suitable high frequency RF or microwave signal.

[0043] The injected bioimpedance current is 4mA rms at 50kHz, however in other embodiments the injected bioimpedance current can be different values and different waveform shapes (not just sinusoidal).

[0044] Computer program instructions stored in the memory 40 cause the processor to analyse the ECG signal so as to determine instances of electrical stimulation of the user’s heart. The processing unit 38 also acts to analyse the BioZ and RDR signals to determine corresponding instances of arrival at the users carotid artery of the pulse wave generated by an aortic valve opening.

[0045] In the embodiment shown in Figures 4 and 5, the three antennae 4a, 4b and 4c are positioned across the heart. A fiducial point detection computing unit 60 is employed by the processing unit 38 detects the ECG R-peak in the
ECG signal 62 using the Pan-Tompkins algorithm. It will be appreciated that the R-peak (referenced 64 in Figure 5) is simply one characteristic of the ECG wave that could be detected. The R-peak is a prominent portion of a QRS complex of the ECG signal and is therefore convenient to monitor, but in another embodiments of the invention another portion of the signal may be monitored.

[0046] The Pulse Arrival Time (PAT) of the BioZ signal 66 received from the electrode 48 and the two RDR signals 68 and 78 received respectively from antennae 4a and 4c are determined by PAT detection computing units 72, 74 and 76. Each of the PAT detection computing units determines a maximal peak in the first order derivative of their respective input signals, and then determines the respective PAT (PAT1, PAT2, PAT3) from the time lag between the R-peak of the ECG signal and that maximal peak.

[0047] The Pulse Transit Time (PTT) of the RDR signal 68 is computed by the PTT1 computation unit 78 by comparing the PAT of the RDR signal 68 to the PAT of the BioZ signal 66, whereas the Pulse Transit Time (PTT) of the RDR signal 70 is computed by the PTT2 computation unit 80 by comparing the PAT of the RDR signal 70 to the PAT of the BioZ signal 66.

[0048] Those skilled in the art will appreciate that the pulse wave velocity (PWV) is the ratio of the distance Z between the two pulse wave measurement points and the PTT. Distance Z in meters is measured according to known methods described in Laurent, S., et al. (2006). "Expert consensus document on arterial stiffness: methodological issues and clinical applications." European Heart Journal 27(21): 2588-2605.

\[ PWV = \frac{Z}{PTT} \]

[0049] The two PTT values computed by the PTT1 computation units 78 and 80 are then provided to a Blood Pressure Computing Unit 82 where the Blood Pressure values are averaged. It will be appreciated that in other embodiments the two PTT values may be combined in a different manner.

[0050] A Recalibration Unit 84 is used to update the values of PTTWo, SBPo and DBPo (described below) to account for physiological changes in the body's arteries. The update can be done with or without the reference cuff pressure.
Figures 6 and 7 depict another embodiment in which the two antennae 1a and 1b are positioned on the sternum across the user's aortic arch. Once again, a fiducial point detection computing unit 100 is employed by the processing unit 38 detects the ECG R-peak in the ECG signal 102 using the Pan-Tompkins algorithm.

The Pulse Arrival Time (PAT) of the BioZ signal 104 received from the electrode 48 and the RDR signal 106 received respectively from antenna 1b are determined by PAT detection computing units 108 and 110. Each of the PAT detection computing units determines a maximal peak in the first order derivative of their respective input signals, and then determines the respective PAT (PAT1, PAT2) from the time lag between the R-peak of the ECG signal and that maximal peak.

The Pulse Transit Time (PTT) of the RDR signal 106 is computed by the PTT1 computation unit 112 by comparing the PAT of the RDR signal 106 to the PAT of the BioZ signal 104.

Blood pressure values are then estimated from the PTT value by a Blood Pressure Computing Unit 114. A Recalibration Unit 116, functionally identical to the Recalibration Unit 84, is also provided.

In some cases, a patient's blood volume distribution will not change, for example, in case of monitoring during sleep. In such cases, the measurement of PAT using ECG and BioZ signals only is sufficient to estimate blood pressure. The radar unit can either be switched off or need not be placed on the body. Figures 8 and 9 depict such an embodiment in which no antennae need be positioned on the user's body.

Once again, a fiducial point detection computing unit 130 is employed by the processing unit 38 detects the ECG R-peak in the ECG signal 132 using the Pan-Tompkins algorithm.

The Pulse Arrival Time (PAT) of the BioZ signal 134 received from the electrode 48 is determined by PAT detection computing units 136, which determines a maximal peak in the first order derivative of its respective input signal, and then determines the respective PAT (PAT1) from the time lag between the R-peak of the ECG signal and that maximal peak.
Blood pressure values are then estimated from the PAT value by a Blood Pressure Computing Unit 138. A Recalibration Unit 140, functionally identical to the Recalibration Unit 84, is also provided.

The processing unit 38 performs the PAT and/or PTT computations in order to determine estimated blood pressure values. Either the PAT or PTT can be used to compute Systolic Blood Pressure (SBP), Mean Blood Pressure (MBP) and Diastolic Blood Pressure (DBP).

By way of example only, the following computations using PTT values may be performed by the processing unit 38:

\[
DBP = \frac{SBP_o}{3} + \frac{2DBP_o}{3} + A\ln\left(\frac{PTT_o}{PTT}\right) - \frac{SBP_o - DBP_o}{3}\left(\frac{PTT_o}{PTT}\right)^2
\]

\[
SBP = DBP + (SBP_o - DBP_o)\left(\frac{PTT_o}{PTT}\right)^2
\]

where DBPo and SBPo are the cuff-based blood pressure values during calibration and PTT0 is the transit time value during calibration. PTT is mapped onto SBP and DBP using the calibration values in the equation above. The mean blood pressure MBP is given by \(\frac{1}{3}\) * SBP + \(\frac{2}{3}\) * DBP.

Alternatively, and by way of example only, the following computations using PAT values may be performed by the processing unit 38:

\[
DBP = \frac{SBP_o}{3} + \frac{2DBP_o}{3} + A\ln\left(\frac{PAT_o}{PAT}\right) - \frac{SBP_o - DBP_o}{3}\left(\frac{PAT_o}{PAT}\right)^2
\]

\[
SBP = DBP + (SBP_o - DBP_o)\left(\frac{PAT_o}{PAT}\right)^2
\]

where DBPo and SBPo are the cuff-based blood pressure values during calibration and PAT0 is the arrival time value during calibration. PAT is mapped onto SBP and DBP using the calibration values in the equation above. The mean blood pressure MBP is given by \(\frac{1}{3}\) * SBP + \(\frac{2}{3}\) * DBP.

In order to confirm the effectiveness of the above described system 10, a series of experiments were conducted on test subjects. In order to vary the blood pressure due to physical load, the experimental protocol was as follows:
1) Measure all signals for one minute as well as reference BP at 'rest'. Conduct two measurements with interval of 2.5 minutes in-between to allow brachial artery to rest.

2) 2.5 minutes cycling at speed of 15-18km/h.

3) Measure signals at 'moderate' BP as per item 1.

4) 2.5 minutes cycling at speed of 25-30km/h.

5) Measure signals at 'high' BP as per item 1.

[0063] The analysis of the signals was carried out as follows. The signals were high and low-pass filtered using FIR filters at 0.3Hz and 400Hz respectively. Using the Pan-Tompkins algorithm, ensemble averaging of all signals over 10 cardiac beats was carried out to increase SNR. For each 1 minute recording, the mean PAT and PTT were computed from all ensemble averages. From the total of six measurements per subject, a linear regression using Matlab's polyfit function was carried out between PAT-SBP and PTT-Mean BP (MBP), where MBP = 2/3 DBP + 1/3 SBP with DBP standing for diastolic BP. The mean and standard deviation of the difference between the PAT-estimated SBP and actual SBP were then calculated for all subjects. The same was done for PTT-estimated and reference MBP.

[0064] The scatter plots 160 and 162 of the PAT and PTT versus the reference SBP shown in Figures 10 and 11, as well as Table 1 below, indicate that there is moderate to strong correlation between PAT and SBP for all subjects.

<table>
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<tr>
<th>PAT</th>
<th>PAT-SBP</th>
<th>PTT-SBP</th>
<th>PAT-MBP</th>
<th>PTT-MBP</th>
<th>PAT-DBP</th>
<th>PTT-DBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>-0.66 (0.001)</td>
<td>-0.48 (0.0029)</td>
<td>-0.39/ (0.038)</td>
<td>-0.49/ (0.002)</td>
<td>-0.40 / (0.04)</td>
<td>-0.33/ (0.048)</td>
</tr>
</tbody>
</table>

Table 1: Pearson correlation coefficients for individual subjects.

[0065] In one or more embodiments, the RDR and BioZ signals 164 seen in Figure 12 can be low pass filtered with a low pass finite impulse or infinite impulse response filter to produce signals 166 seen in Figure 13 containing respiration related information. Time or frequency domain algorithms can be used by the processing unit 38 to extract the mean respiration rate. The BioZ
signal's output is proportional to lung volume, and hence the two phases of a respiration cycle (inspiration = breathing in and expiration = breathing out) can be calculated by the processing unit 38.

[0066] As seen in Figure 14, the system 10 may be configured to communicate with a smart phone 200 or other communications device by means of the communications module 28 and corresponding antenna 54. In this exemplary embodiment, a Bluetooth communication link 212 is established between the system 10 and the smart phones 200. Software can be downloaded to the system 10 over the link 212, and blood pressure information and other data can be uploaded across the link 212 to the smart phone 200.

[0067] The data uploaded to the smart phone 200 may be used by the smart phone itself, for example for use by an app or other piece of resident software, and/or may be uploaded from the smartphone 200 to a remote database server 214 via a communications network such as the internet 216. Data from a number of devices can therefore be aggregated at the data base server 214 and an analysis of that data performed remotely via a user terminal 218. The data aggregated at the data base server 214 may include blood pressure data and other measurements performed by the system 10 and may additionally include user specific data, such as health data acquired by fitness apps and like wearable devices, the user's age, weight and various other types of user specific or demographic data. In this way, the analysis of the aggregated data maintained in the data base server 214 can be used to improve or chance the data or software instructions downloaded to the system 10 for future use by the user 34.

[0068] The system 10 is well suited to the continuous monitoring of a user's blood pressure, for example during sleep or during sports (e.g. cycling) where an athlete's heart rate and blood pressure performance may be monitored continuously.

[0069] While the invention has been described in conjunction with a limited number of embodiments, it will be appreciated by those skilled in the art that many alternative, modifications and variations in light of the foregoing description are possible. Accordingly, the present invention is intended to embrace all such alternative, modifications and variations as may fall within the spirit and scope of the invention as disclosed.
Claims

1. A method of estimating blood pressure of a user, the method including the steps of:
   - injecting current into the user's body via a pair of current injection electrodes affixed to the user's upper body,
   - receiving an electrocardiogram (ECG) signal from an ECG electrode affixed to the user's upper body,
   - receiving at least one pulse signal related to pulse wave velocity (PWV) of a pressure pulse generated by a cardiac contraction,
   - determining, from the ECG signal, instances of electrical stimulation of the user's heart;
   - determining, from the least one pulse signal, corresponding instances of arrival at the user's carotid artery of a pulse wave;
   - computing the pulse arrival time (PAT) from the instances of electrical stimulation and one or more corresponding instances of pulse wave arrival from the least one pulse signal; and
   - estimating the blood pressure from the computed PAT.

2. A method according to claim 1, wherein the step of determining instances of electrical stimulation of the user's heart includes:
   - determining instances of R-peaks in a QRS complex of the ECG signal.

3. A method according to either one of claims 1 or 2, wherein the at least one pulse signal includes a bioimpedance (BioZ) signal from a BioZ electrode affixed to the user's upper body.

4. A method according to any one of the preceding claims, wherein the pair of current injection electrodes are positioned on the user's upper body across the common carotid arteries.

5. A method according to claim 4, wherein one or both of the ECG and BioZ electrodes are also positioned on the user's upper body across the common carotid and/or subclavian arteries.
6. A method according to claim 1, wherein the method further includes:
   receiving a reflected wave signal from a continuous wave radar device, the device including two or more antennae affixed to the user's upper body, and wherein
   the at least one pulse signal includes a radar signal (RDR), derived from the reflected wave signal, that varies in accordance with the periodic motion of the user's heart or aorta.

7. A method according to claim 6, wherein the RDR signal is linearly correlated with the periodic motion of the user's heart or aorta.

8. A method according to either one of claims 6 or 7, wherein the two antenna are positioned across the user's heart or aorta.

9. A method according to claim 1, wherein the step of receiving at least one pulse signal includes receiving two or more pulse signals related to pulse wave velocity (PWV) of a pressure pulse generated by a cardiac contraction, and wherein
   the step of computing the pulse arrival time (PAT) includes comparing the instances of electrical stimulation and to instances of pulse wave arrival from the two or more pulse signals,
   the method further including the step of:
   computing the Pulse Transition Time (PTT) by comparing the PATs from the two or more pulse signals; and
   estimating the blood pressure from the computed PTT.

10. A method according to claim 9, wherein the at least one pulse signal includes a bioimpedance (BioZ) signal from a BioZ electrode affixed to the user's upper body.

11. A method according to either one of claims 9 or 10, wherein the method further includes:
receiving a reflected wave signal from a continuous wave radar device, the device including two or more antennae affixed to the user's upper body, and wherein

the at least one pulse signal includes a radar signal (RDR), derived from the reflected wave signal, that varies in accordance with the periodic motion of the user's heart or aorta.

12. A device for estimating blood pressure of a user, comprising:

inputs for receiving signals from the electrodes mounted to a user's upper body; and

a processing unit and associated memory for storing computer program instructions to cause the processing unit to perform a method according to any one of claims 1 to 5.

13. A device for estimating blood pressure of a user, comprising:

inputs for receiving signals from electrodes and antennae mounted to a user's upper body; and

a processing unit and associated memory for storing computer program instructions to cause the processing unit to perform a method according to any one of claims 6 to 11.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

A61B 5/021 (2006.01)

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)

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)


GOOGLE PATENTS, GOOGLE SCHOLAR, ESPACENET: A61B5/02125, A61B5/6801 and keywords: cuffless, blood pressure, ECG, bioimpedance signal, electrode, pulse, antenna, position, compute, carotid artery, pulse arrival time, pulse transition time, and like terms.

APPLICANT/INVENTOR SEARCH in EPODOC. Applicant(s)/Inventor(s) name searched in internal databases provided by IP Australia.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

<table>
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<td>X</td>
<td>Further documents are listed in the continuation of Box C</td>
<td>X See patent family annex</td>
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"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 15 November 2016

Date of mailing of the international search report 15 November 2016

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Form PCT/ISA/210 (fifth sheet) (July 2009)
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<td>X</td>
<td>US 2014/0249443 A1 (BANET et al.) 04 September 2014 paragraph [0023], paragraph [0024], paragraph [0080] lines 1-4, paragraph [0086] lines 2-3 and 15-17, paragraph [0100] lines 2-4 and 8-13, paragraph [0101] lines 1-12 and 37-42, paragraph [0102] lines 8-10, paragraph [0115], figures 5-6 and 8-9 as above</td>
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<td>US 8428699 B2 (PINTER et al.) 23 April 2013 column 1 lines 15-21, column 6 lines 11-12 and 51-60, column 7 lines 4-5 and 8-12, column 8 lines 35-39, column 13 lines 50-55, figures 1 and 5</td>
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<td>US 9408542 B1 (KINAST et al.) 09 August 2016 abstract, column 3 line 29 - column 4 line 18, column 4 lines 33-52, column 5 line 62 - column 6 line 5, column 6 line 37 - column 8 line 54, column 10 lines 31-35, column 11 lines 19-21 and 28-44, column 12 lines 23-25, column 13 lines 51-56, column 13 line 66 - column 14 line 1, figures 4B, 5A-5B, 7, 9B</td>
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This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

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Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.
Form PCT/ISA/210 (Family Annex)(July 2009)