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

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
14 July 2016 (14.07.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/110781 A1

(51) International Patent Classification:
A61B 5/024 (2006.01) *A61B 5/021* (2006.01)
A61B 5/022 (2006.01) *A61B 5/11* (2006.01)
A61B 5/0225 (2006.01) *A61B 5/029* (2006.01)
A61B 5/00 (2006.01) *A61B 17/135* (2006.01)

(21) International Application Number:
PCT/IB2016/000075

(22) International Filing Date:
7 January 2016 (07.01.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
62/101,186 8 January 2015 (08.01.2015) US

(71) Applicant: **CNSYSTEMS MEDIZINTECHNIK AG** [AT/AT]; Reininghausstrasse 13, A-8020 Graz (AT).

(72) Inventor: **FORTIN, Jurgen**; Pfeifferhofweg 200, A-8043 Graz (AT).

(74) Agent: **BABELUK, Michael**; Florianigasse 26/3, A-1080 Wien (AT).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

(54) Title: WEARABLE HEMODYNAMIC SENSOR

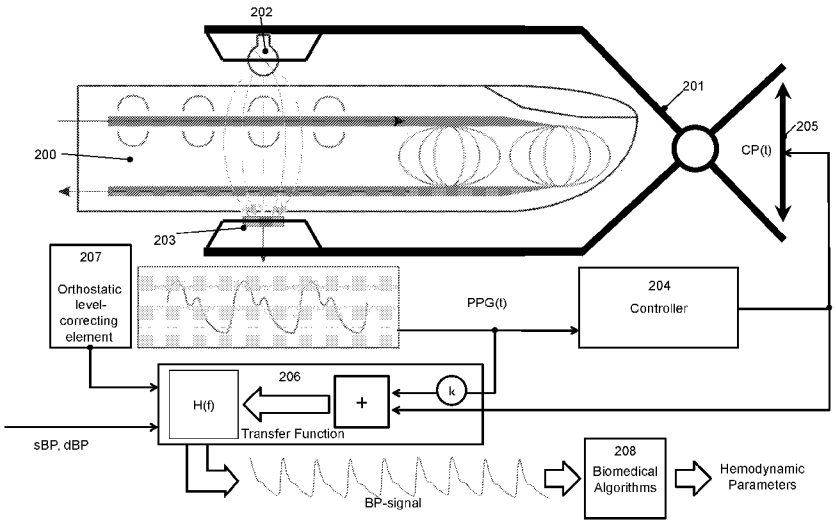


Figure 2

(57) Abstract: A wearable device and the accompanying method for the determination of continuous pulsatile BP are described. The absolute values can be obtained in the initial phase and how a transfer function can transform the BP-signal obtain at the finger or wrist to correct BP- values corresponding to the brachial artery and at heart level. The wearable device contains an orthostatic level-correcting element, which can measure the vertical distance between heart level and finger/wrist level, where the actual measurement takes places. The wearable device may be in the form of a ring, a watch, or a bracelet. Further, the wearable device has elements for wirelessly transmitting signals to host devices such as a smart phone, tablet or other computers.

WO 2016/110781 A1

SPECIFICATION

TITLE

WEARABLE HEMODYNAMIC SENSOR

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a non-provisional of U.S. provisional patent application no. 62/101,186 filed January 8, 2015, the entire contents of which are incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The application relates generally to a sensor system of measuring blood pressure and further derived hemodynamic parameters, as well as to a method of how continuous hemodynamic readings can be measured with the sensor system. The sensor system is further configured to be wearable.

BACKGROUND

[0003] A common modality in medicine is Photoplethysmograpy (PPG), where light from one or more LED's with possibly different wavelengths is transmitted though or reflected from a part of a body and detected by light receivers, such as photo diodes. The photo current is amplified and typically converted into digital signals, whereas the resulting light signal corresponds primarily to blood flow. This PPG-signal is a surrogate of blood pressure, but a translation into blood pressure values with a clinical acceptable accuracy is difficult. The signal is interfered with by noise, especially coming from changes of blood volume caused by vasomotor activity of the arteries. Thus, PPG-based wearable devices usually only measure heart rate, pulse oximetry, or are the second (mostly distal) point of measurement for propagation time methods.

[0004] Current wearable BP devices use a method where different sensors measure the propagation time of blood pulses from a proximal body part to a distal body part. This propagation time, which is also called "Pulse Transit Time" (PTT), "Pulse Arrival Time, (PAT)" or other commercially used names, is inversely related to blood pressure. Those PTT-methods and devices do not produce a true pulsatile continuous BP signal, as such devices can only measure one PTT episode per beat. Thus, the BP-signal from those devices cannot be used for further determination of hemodynamic parameters using biomedical algorithms

like Pulse Contour Analysis and other pulse related methods. The BP signal measured from those devices needs further calibration with an intermittent upper-arm sphygmomanometer, also called non-invasive BP device (NBP), in a relatively short calibration interval. The calibration interval is dramatically shortened by vasomotoric influences, e.g. thermoregulation, stress or drugs.

[0005] Contrary to PTT-methods, WO 2013178475 describes an apparatus and method for the continuous, non-invasive determination of blood pressure (BP) by means of a photoplethysmographic (PPG) system, where the contact pressure of the PPG-system is modified according to the mean arterial pressure (mBP) in the finger. With this method, the true pulsatile BP in the finger or wrist can be obtained by adding the pulsatile PPG-signal PPG(t) multiplied with a calibration factor to the measured contact pressure CP(t) that equals to the mBP.

[0006] This method of continuous hemodynamic monitoring according to WO 2013178475 has several limits and cannot be used as a wearable sensor with clinical acceptable accuracy. For example, the system from WO 2013178475 does not allow for the measurement of absolute BP-values and needs persistent NBP calibration. For a wearable device, the permanent use of a NBP on the upper arm is not appropriate.

[0007] The system from WO 2013178475 is further influenced by orthostatic pressure difference between heart level and the actual finger level. For a correct use of WO2013178475, the finger or wrist has to be constantly kept on heart level, which is not appropriate for a wearable system.

SUMMARY

[0008] In one embodiment, a method for the continuous non-invasive measurement of hemodynamic parameters within a wearable device is disclosed. The method includes measuring a photoplethysmographic signal PPG(t) disposed on a body part containing an artery using a photoplethysmographic system having at least one light source, and at least one light detector generating the photoplethysmographic signal. The contact pressure of the photoplethysmographic system can be varied by an actuator, and the movement of the actuator and the contact pressure is controlled by a control system using at least a part of the photoplethysmographic signal. The true pulsatile BP-signal and further calculated hemodynamic parameters are derived from the contact pressure and the photoplethysmographic signal and from a transfer function and further hemodynamic parameters can be calculated using biomedical algorithms.

[0009] In another embodiment, a wearable device for measuring hemodynamic parameters is disclosed. The wearable device includes a photoplethysmographic system having one or more light sources, one or more light detectors that generate the photoplethysmographic signal, a mounting element for attaching the photoplethysmographic system to a body part containing an artery having an actuator, a control system for controlling the actuator and the contact pressure of the photoplethysmographic system and an orthostatic level-correcting element, e.g. an accelerator, motion sensor or fluid-filled hose, placed next to the photoplethysmographic system used for heart level correction.

BRIEF DESCRIPTION OF THE FIGURES

[0010] An exemplary embodiment of the present invention is described herein with reference to the drawings, in which:

[0011] Figure 1 shows the prior art method of measuring continuous, non-invasive pressure (BP) by means of a photoplethysmographic (PPG) system;

[0012] Figure 2 shows a method of continuous non-invasive measurement of hemodynamic parameters within a wearable device of the present application;

[0013] Figure 3 shows the general block diagram and the hardware elements of the present application;

[0014] Figure 4 is a flowchart showing the different operating modes of the system of the present application;

[0015] Figure 5 shows an example embodiment of a wearable device of the present application;

[0016] Figure 6 shows another example embodiment of a wearable device of the present application; and

[0017] Figure 7 shows the present application in use with another device.

DETAILED DESCRIPTION

[0018] A wearable device and the accompanying method for the determination of continuous pulsatile BP are disclosed. Absolute values can be obtained in the initial phase and how a transfer function can transform the BP-signal obtained at the finger or wrist to true BP-values corresponding to the brachial artery and at heart level. A one-time calibration method with NBP in order to determine the transfer function is disclosed.

[0019] The wearable device contains an orthostatic level-correcting element, for example an accelerator or motion sensor, which can measure the vertical distance between

heart level and finger/wrist level, where the actual measurement takes places. The orthostatic pressure difference can be calculated and the BP-signal can be corrected to heart level pressure values, which is used for regular BP-measurement.

[0020] The wearable device has different operating modes. One mode is for the continuous measurement of hemodynamic parameters. In this mode, the contact pressure CP(t) is adaptively changed to mean arterial blood pressure (mBP) or a fraction of mBP.

[0021] Another mode is the initialization mode, where systolic, diastolic and mean arterial BP (sBP, dBP, mBP) is determined. Mean arterial BP (mBP) is the starting point for the continuous BP-measurement. sBP and dBP are used for the correct determination of the transfer function in order to correct the BP-signal obtained at the finger/wrist to central values. This is used for a correct clinical interpretation of BP. With this special initialization mode where actual sBP, dBP and mBP can be determined, the need for a calibration to NBP is eliminated or at least reduced to a one-time personalization of the transfer function to central BP-values before using the device.

[0022] A further mode may be an idle mode, where the contact pressure is reduced to 30 – 40mmHg. The PPG-signal is still measured and can be used for heart rate detection. The system can be automatically switched into initialization and further to measurement mode by the motion sensor, when a fall of the patient is detected. Another trigger for switching into initialization and further measurement mode can be an unexpected increase or drop in heart rate or different timed intervals.

[0023] Further, the wearable device has elements for wirelessly transmitting signals to host devices like smart phone, tablet or other computers. The wearable device can be in the form of a ring or a watch or bracelet, for example.

[0024] Figure 1 shows a prior art system **101** placed on a finger **100**. The system **101** includes one or more light sources **102**, preferably LEDs, and one or more light receivers **103**, which generates a photoplethysmographic (PPG) signal PPG(t). PPG(t) is the input for a controller **104**. The controller 104 is altering the contact pressure CP(t) of the PPG-system using an actuator **105**. The altering contact pressure CP(t) follows true mBP with the help of the controller **104**.

[0025] Figure 2 shows the system of the present application including the measurement of clinical relevant BP. Elements **200** to **205** are analogous to Fig. 1. In order to obtain clinical useful BP-values and a true continuous BP-signal, the finger BP is corrected to central values by using a mathematical transfer function **206**. For that transfer function, PPG(t) is generated by the one or more light receivers **203,** and CP(t) applied from the

actuator **205** are used. Further, initial values of the transfer function **206**, for example individual systolic and diastolic BP, may be obtained in an initial phase and/or during a one-time calibration to individual values of the patient before starting using the device. The transfer function **206** may be implemented in software that runs on a microcontroller or other computer.

[0026] For clinical use, BP must be measured at heart level or must be corrected to that level, if the location of the BP-sensor differs. In the daily use, the point of measurement of the sensor typically differs from heart level. In order to continuously correct the BP-signal obtained from the present sensor at the finger or wrist to heart level, an orthostatic level-correcting element **207** is used. This orthostatic level-correcting element **207** is in general measuring or calculating the pressure (orthostatic) difference between heart level and the point of measurement.

[0027] For this correction, the transfer function **206** receives information from the orthostatic level-correcting element **207**, for example an accelerator or motion sensor, which can continuously measure the vertical distance between heart level and finger/wirst level, where the actual measurement takes places. The orthostatic BP difference can be calculated using the known blood density and the vertical distance. Thus, the BP-signal can be corrected to heart level pressure values, which is important for regular BP-measurement.

[0028] In a further embodiment, the orthostatic level-correcting element **207** could be a fluid-filled hose between the PPG-system and heart level is used as orthostatic level-correcting element (not shown). The hose is filled with a fluid having a density similar to that of blood. Otherwise a correction factor c must be used, where c is the fraction of the density of blood to the density of the fluid used. One end is closed with a freely floating membrane and the other end with a standard pressure sensor. The value obtained from this heart level pressure sensor multiplied with correction factor c equals to orthostatic BP difference and can be used for heart level correction.

[0029] Further hemodynamic parameters could be obtained from the pulsatile BP-signal using mathematical biomedical algorithms **208**. One type of biomedical algorithms **208** could be a Pulse Contour Analysis method for the determination of cardiac output, stroke volume, peripheral resistance etc. Other parameters, especially parameters for the assessment of the autonomic nervous systems may be calculated by using further mathematical methods known from the art. The biomedical algorithms **208** may be implemented in software that runs on a microcontroller or other computer.

[0030] Preferably, the calculation of the BP-signal using the transfer function **206**, the correction to heart level **207,** as well further biomedical algorithms **208** takes place in one or more microcontrollers or computers (μCs) using software. These μCs can be placed either in the system **201** and/or on a smart phone, tablet or other computer connected to the Internet (see for further explanation Figure 7).

[0031] Figure 3 shows the general block diagram and the hardware elements of the system. The system **301** is connected to a finger **300** and includes one or more light transmitters **302**, preferably LED's with different wavelengths, and one or more light receivers **303** generating a PPG-signal PPG(t). The PPG-signal is sent to a controller unit **304** preferable a microcontroller or other type of computer using software. For example, the microchip AS7000 (ams AG, Unterpremstaetten, Austria) is a combined optical light receiver with a digital processor that may be used for measuring PPG(t) and further controlling the contact pressure CP(t) with an actuator **305**.

[0032] In a basic embodiment, the microcontroller μC **304** controls contact pressure CP(t) using the actuator **305**, measures the contact pressure CP(t) by using a pressure sensor **306**, controls the one or more light transmitters LED's **302** and receives the PPG-signal PPG(t) from the one or more light receivers **303**.

[0033] A pressure sensor **306** is used in combination with the actuator **305**. The pressure sensor **306** will directly measure CP(t) and thus increase accuracy of the CP(t) measurement, which is a major input to the final BP-signal. In an alternative embodiment, the contact pressure CP(t) could be derived from the control signal of the actuator **305**.

[0034] The actuator **305** could be a step motor, piezo element, or a "new material" that alters its dimension by applying an electrical signal to its surface. Ideally, no energy should be needed for "holding" the pressure. As mentioned above, the pressure sensor **306** is included for an accurate measurement of CP(t).

[0035] The μC **304** could further calculate the above mentioned mathematical transfer function **206** as well as the biomedical algorithms **208** like a pulse contour analysis for stroke volume and cardiac output measurement and further biomedical calculations e.g. for the assessment of the autonomic nervous system.

[0036] The μC **304** could be further connected with a power supply and power management unit **307**, which receives and manages the power from a preferably loadable battery **308**. The power received from the battery **308** can therefore optimized depending on the energy needs in different operation modes. This unit is also responsible for loading the battery **308**.

[0037] For clinical use, BP must be measured at heart level and thus an orthostatic level-correcting element **309** is connected to the µC **304**. In one embodiment, the orthostatic level-correcting element **309** could be the previously described fluid-filled hose.

[0038] In another embodiment, the orthostatic level-correcting element **309** could be an accelerator or motion sensor. For example, the microchips LIS3DH (STMicroelectronics) or the FXLS8471QFS (Xtrinsic) represent such accelerators or motion sensors which could be used for continuous calculating the vertical difference between heart and location of the sensor.

[0039] For zeroing the accelerator or motion sensor, a push button **310** is connected to the µC **304**. During the zeroing procedure, the sensor is held at heart level and the button **310** is pushed to indicate zero orthostatic difference. Ideally, a short press or double press on the button indicates zeroing, as long presses may switch the sensor on and off. The µC **304** stores the actual vertical value of the accelerator or motion sensor **309** and can then continuously calculate the difference between the stored value and the new actual vertical value. Thus, the orthostatic pressure can be calculated from the vertical difference and the density of blood. In another embodiment, as BP is measured in Millimeters of Mercury (mmHg), the scaling factor between mmHg and centimeter water column (cmH_20) can be used for the calculation of the orthostatic pressure, when the difference in cm is known. The resulting value must be corrected with the relative density of blood.

[0040] The accelerator or motion sensor **309** can detected heavy motion artifacts and disturbed signals could be marked. A further zeroing procedure will be needed, which could be indicated on the host device. A further indicator for re-zeroing could be an alternating swing of the contact pressure CP(t).

[0041] For the transmission of the BP-signal to a smart phone, tablet or another computer preferable connectable to the Internet, a signal transmitter **311** is connected to the µC **304**. This transmitter could be WLAN or Bluetooth or any other available sender. This unit may also receive information from the host.

[0042] Figure 4 is a flow chart showing the different operation modes of the system. After switching the sensor on, the device will be in idle mode **401**. The sensor (ring, watch, or bracelet) can be placed on the finger or wrist respectively, as the contact pressure CP(t) is in idle position. It should be at a normal value for PPG-systems, which is about 30-40 mmHg. The system starts measuring the PPG-signal, which is now used for heart rate monitoring. A press on the button, a detected fall, immediately increase or decrease of heart rate or the host device will start the measurement beginning with the initial phase **402**.

[0043] In the initial phase **402**, CP(t) is adjusted by the control system and the actuator to different pressure levels. PPG(t) is measured, especially the PPG-amplitude is compared at different CP-levels. mBP can now be determined at the optimal contact pressure CP_{OPT}, where coevally the highest amplitude of the photoplethysmographic signal is measured. This mBP multiplied by a constant factor can now be used as the starting point CP_{Start} for the measurement mode **403**.

[0044] In addition to mBP, systolic and diastolic blood pressure sBP and dBP can be estimated using the distribution of the amplitude of PPG(t) versus the applied CP. Typically the distribution of the PPG-amplitudes is according to an envelop-curve, where the width of the envelope corresponds to Pulse Pressure (sBP minus dBP). sBP and dBP can be estimated according to this so-called oscillometric method.

[0045] In measurement mode **403**, the PPG-signal is measured and the controller calculates the so-called VERIFI criteria (as described in WO 2013178475) for continuously altering CP(t) to mBP. If VERIFI indicates vasomotoric changes and/or mBP changes, CP(t) is adapted accordingly. The transfer function is applied to PPG(t) and to the current CP(t) in order to achieve the continuous BP. Either the resulting BP-signal is send to the host device and/or the underlying components PPG(t), CP(t) and the continuous vertical difference between heart level and sensor level. Biomedical algorithms are further calculating hemodynamic parameters from the true pulsatile BP-signal.

[0046] The device can be switched back to a further idle mode **404** by decreasing CP(t) again to about 30-40 mmHg. The PPG-signal can still be measured for heart rate monitoring or the ring/watch can be removed from finger/wrist. Power management can reduce energy for a longer battery life.

[0047] In this idle mode **404**, the system works also as a surveillance monitor. The previously described accelerator or motion sensor may detect falls of the patient and switches first to the initialization mode **402** and afterwards to measurement mode **403**. When the BP signal is submitted to a smart phone, an emergency may be called for a patient's safety. Zeroing the orthostatic level-correcting element will be not as important as it can be assumed that the patient lies on the floor and thus the sensor is likely on heart level.

[0048] Figure 5 shows the sensor configured as a ring **501** worn on a finger **500,** preferably on the index, middle or ring finger. The ring placed on the first phalanx is likely the most artifact free implementation. A ring can easily alter its CP by changing its circumference using, for example, actuators **505**, such as a step motor in a "hose clamp" mechanic, a piezo element changing the circumference, or "new material" changes the

circumference. This "new material" is able to change its dimensions by applying an electrical signal to its surface. The actuators **505** are placed on fixators **507**. The contact pressure CP(t) is measured using a pressure sensor **506**.

[0049] The other electronic **504** elements like μC, motion sensor, wireless transmitter, power manager, battery etc. shall be place inside the ring according to the Figure 5. One push button **511** for start/stop and heart level adjustment should be added.

[0050] A "jewel" **508** may indicate correct placement for PPG-sensors especially the light sensors **502** and **503**. As can be seen in Figure 5, the finger **500** contains two digital arteries **509**, which are palmar/volar sided to the finger bone **510**. The best PPG-signal can be obtained, when the light sensors **502** and **503** are placed left and right to the finger according to Figure 5 and the "jewel" **508** is therefore in the correct dorsal direction.

[0051] Figure 6 shows the sensor configured as a bracelet or watch **601** worn on the wrist **600**. On a wrist, simply changing the diameter cannot alter CP(t) to the radial artery **612**. Instead, a U-shaped band **608** connected to fixations **607** is part of the bracelet or watch **601**. The bracelet or watch **601** should be placed in such a way that the U-shaped band **608** is at the location, where the radial artery pulse can be palpated. This radial pulse is generated in the radial artery **612** and amplified by the reflection at the radius **613**. The system **601** can alter the depth of its 'U' with an actuator **605** - when the actuator **605** constricts, the depth of the U-shaped band **608** increases and CP(t) increases too.

[0052] The pressure sensor **606** may be placed on the trough of the U-shaped band **608**. Further, there must be space for the PPG-elements **602** and **603,** which then receive the light signals reflected on the radius. The PPG signal will help with finding the correct placement of the sensor. The other electronic elements **604** like μC, motion sensor, wireless transmitter, power manager, battery etc. shall be place in the "more rigid shell" **609**. With that configuration, a free blood flow in the ulna artery **614** beside the ulna **615** is guaranteed. The embodiment as a watch will further allow for user interaction on the watch display **610**. A push button **611** for start/stop and heart level adjustment should be added.

[0053] Figure 7 shows the transmission of the BP-signal and/or its components like PPG-signal, contact pressure, and vertical distance from the wearable device **701** to a smart phone, tablet or other computer **702** that may be connected to the Internet. An APP is further calculating hemodynamic and other parameters as well as software for displays, reimbursement models and other functionality. The functionality of the APP is shown in Figure 7.

[0054] The APP performs the following functions:

- receives unfiltered BP-signal and its components from sensor;
- sends control information to the sensor;
- allows for software-update of the sensor;
- calculates further hemodynamic, autonomic and vascular parameters;
- has possibilities for displaying these further hemodynamic, autonomic and vascular parameters in a user-friendly and self-explanatory way;
- transmits and stores information;
- allows for different business models;
- supports reimbursement from health care system;

[0055] As mentioned above, the system further includes a transfer function **208**. This transfer function includes different parts. The first part is the contact pressure CP(t), which adaptively changed to mBP or a constant factor c_1 multiplied with mBP (as described in to WO 2013178475). Thus, mBP in a distal part of the body typically at the finger or wrist is measured using CP(t) or CP(t)/c_1.

[0056] The next part is the pulsatile PPG(t) that can be used for the continuous BP-signal. The PPG(t) must be amplified by a gain factor k. The resulting finger BP-signal is:

$$BP_f(t) = CP(t) / c_1 + k * PPG(t)$$

where k can be estimated from the sBP and dBP values measured during initial mode. PPG_{sys} and PPG_{dia} are the corresponding PPG(t) values to sBP and dBP:

$$k = (sBP - dBP) / (PPG_{sys} - PPG_{dia})$$

[0057] The finger BP-signal must then be corrected to heart level by using the previously described vertical distance d_v and the converting factor of [mmHg] to [cmH_2O], which is 0.73556 as well as to the relative density of blood ρ_{Blood} which is 1.0506 (95% confidence interval: 1.0537-1.0475) at 37 °C.

$$BP_f(t) = CP(t) / c_1 + k * PPG(t) + 0.73556 * d_v * \rho_{Blood}$$

[0058] When the fluid-filled hose is used for heart level correction, the true orthostatic pressure difference $p_o(z)$ is measured.

$$BP_f(t) = CP(t) / c_1 + k * PPG(t) + p_o(z)$$

[0059] BP changes along the arterial pathway and peripheral BP_f measurements need to be transferred to values that are comparable to standard values obtained at the brachial

artery. This part of the transfer function **206** is typically a shift of frequency components H(f) and there are well known concepts out using a general transfer function.

[0060] This general transfer function H(f) of **206** may be personalized with a calibration performed before the first use. Upper arm cuff BP-values shall be obtained while the initial mode calculates finger sBP and dBP. These values, upper arm cuff sBP and dBP as well as finger sBP and dBP, can be used for a personalized general transfer function H(f) to get a proximal BP-signal.

[0061] The transfer function **206** in general as well as all parts of this transfer function **206** may be implemented in software that runs either on the microcontroller **304** or in the APP on the smart phone, tablet or other computer **702**.

[0062] A further embodiment is the additional use as a pulse oximeter. Typically the system will work at the isosbestic point of oxyhemoglobin and desoxyhemoglobin at wavelength λ_{CNAP} = 805 nm. When the LED's are exchanged by bi-color LED's working at pulsoxy wavelength (λ_{red} = 660 nm, λ_{IR} = 910 nm), the sensor can work as SpO_2 ring or watch too by using a state-of-the-art pulse oximeter method.

[0063] While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize that still further modifications, permutations, additions and sub-combinations thereof of the features of the disclosed embodiments are still possible. It is therefore intended that the following appended claims and claims hereafter introduced are interpreted to include all such modifications, permutations, additions and sub-combinations as are within their true spirit and scope.

CLAIMS

1. A method for the continuous non-invasive measurement of hemodynamic parameters within a wearable device comprising:

measuring a photoplethysmographic signal disposed on a body part containing an artery using a photoplethysmographic system having:

at least one light source; and

at least one light detector generating the photoplethysmographic signal;

wherein the contact pressure of the photoplethysmographic system can be varied by an actuator;

wherein the movement of the actuator and the contact pressure is controlled by a control system using at least a part of the photoplethysmographic signal;

wherein the true pulsatile BP-signal and further calculated hemodynamic parameters are derived from the contact pressure and the photoplethysmographic signal; and

wherein the hemodynamic parameters are further derived from a transfer function.

2. The method of claim 1 wherein contact pressure is measured by a pressure sensor.

3. The method of claim 1 or 2 wherein the hemodynamic parameters are corrected to heart level using an orthostatic level-correcting element.

4. The method of claim 3 wherein the orthostatic level-correcting element comprises a fluid filled hose between the photoplethysmographic system and heart level;

wherein the hose is filled with a fluid having a density similar to that of blood;

wherein the hose is closed on one end with a freely floating membrane;

wherein the hose is closed on the other end with a pressure sensor; and

wherein the pressure obtained from this heart level pressure sensor is used for heart level correction.

5. The method of claim 3 wherein the orthostatic level-correcting element comprises an accelerometer or motion sensor;

wherein the accelerometer or motion sensor is placed next to the photoplethysmographic system;

wherein the movement in the same direction as gravity is used for calculating

orthostatic distance between heart level and the location of the photoplethysmographic system; and

wherein the correcting procedure can be zeroed by simultaneously placing the wearable device on heart level.

6. The method according to any of claims 1-5 wherein the transfer function is a general transfer function valid for humans.

7. The method according to any of claims 1-6 wherein the transfer function is personalized by using the individual systolic and diastolic blood pressure of a patient.

8. The method according to any of claims 1-7 wherein different modes of operation are implemented.

9. The method of claim 8 wherein a mode for continuous measurement of hemodynamic parameters is used,

wherein the contact pressure is adjusted by the control system and the actuator according to mean arterial pressure multiplied by a constant factor; and

wherein the transfer function is applied to the photoplethysmographic signal and the contact pressure.

10. The method of claim 8 wherein a mode for the initialization of the continuous measurement of hemodynamic parameters is used

wherein the contact pressure is adjusted by the control system and the actuator to different pressure levels;

wherein the amplitude of the photoplethysmographic signal is determined;

wherein mean blood pressure is determined at the contact pressure, where coevally the highest amplitude of the photoplethysmographic signal is measured; and

wherein the mean blood pressure multiplied by a constant factor is used as the starting point for the measurement modus.

11. The method of claim 10 wherein systolic and diastolic blood pressure is estimated using the distribution of the amplitude of the photoplethysmographic signal versus the applied contact pressure; and

wherein systolic and diastolic blood pressure is used for the calibration of the

transfer function.

12. The method of claim 8 wherein an idle mode is used

wherein the contact pressure is adjusted to a constant pressure around 30 – 40 mmHg; and

wherein the system waits for user interaction in order to bring the system in initialization and further into the measuring mode; and

wherein the photoplethysmographic signal is measured for obtaining heart rate;

wherein the system can be further brought in initialization and thereafter into the measuring mode if heart rate increases over or decreases under a predefined threshold.

13. The method according to any of claims 5 or 8-12 wherein the accelerator detects falls of the patient and initiates or re-initiates the initialization mode.

14. The method according to any of claims 1-13 wherein some of the hemodynamic parameters are calculated by using biomedical algorithms applied to the photoplethysmographic signal, the contact pressure and the transfer function.

15. A wearable device for measuring hemodynamic parameters comprising:

a photoplethysmographic system having:

one or more light sources;

one or more light detectors that generate the photoplethysmographic signal;

a mounting element for attaching the photoplethysmographic system to a body part containing an artery having an actuator;

a control system for controlling the actuator and the contact pressure of the photoplethysmographic system; and

an accelerator or motion sensor placed next to the photoplethysmographic system used for heart level correction.

16. The wearable device of claim 15 wherein the control system can be switched into different operating modes.

17. The wearable device of claim 15 or 16 wherein the contact pressure is measured by a pressure sensor.

18. The wearable device of any of claims 15-17 further comprising a transmitter for sending the resulting hemodynamic parameters to a host device that is connected to the Internet.

19. The wearable device of any of claims 15-18 wherein at least two or more light sources or wavelengths are used;

wherein the least one light detector generates two or more photoplethysmographic signals corresponding to the at least two or more light sources or wavelengths; and

further comprising means for calculating oxygen saturation by using the at least two different photoplethysmographic signals.

20. The wearable device of any of claims 15-19 wherein the elements of the device are placed into a ring, wherein the circumference of the ring can be altered by the actuator.

21. The wearable device of any of claims 15-19 wherein the elements of the device are placed in a bracelet or watch, wherein the actuator changes the contact pressure of the bracelet or watch at the wrist, where the radial artery can be palpated.

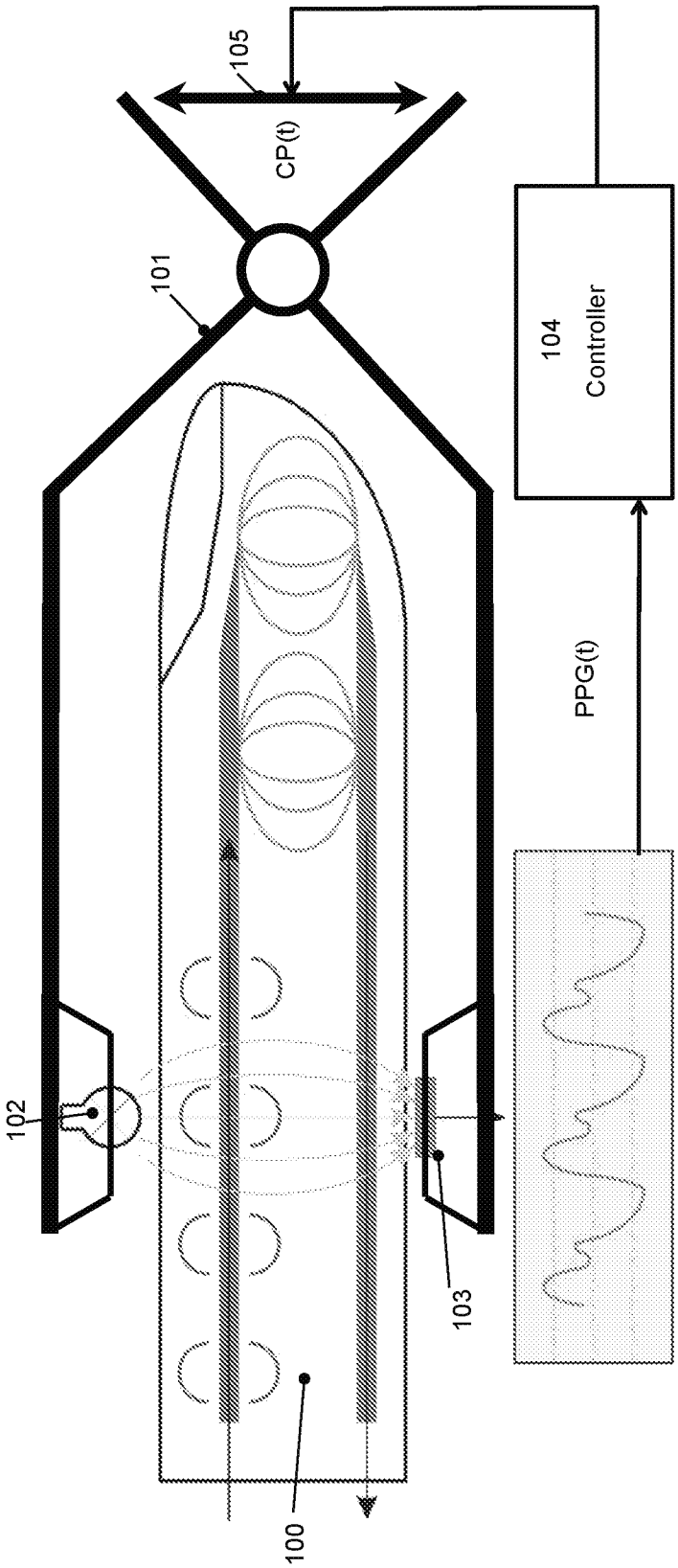


Figure 1
(prior art)

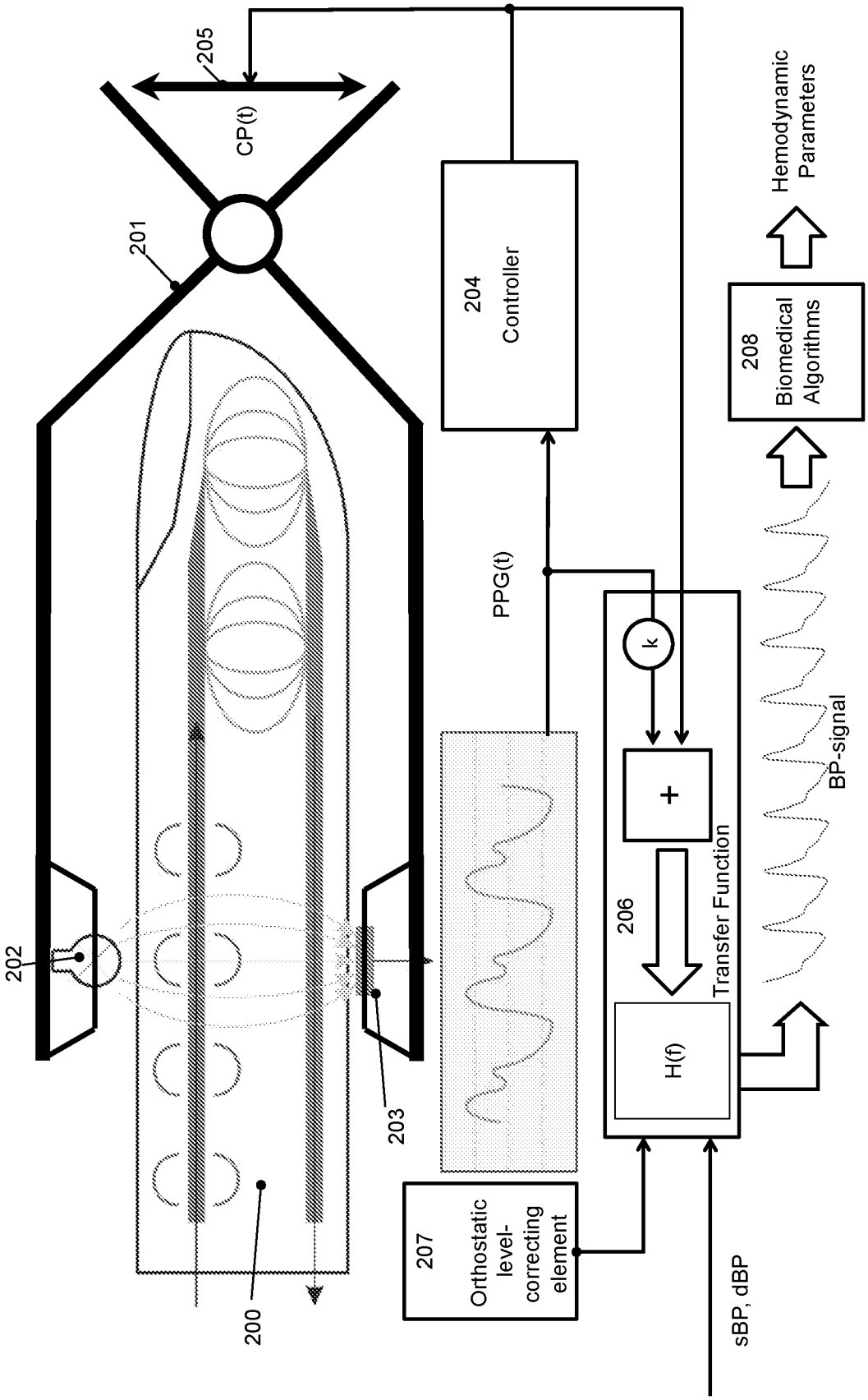

205
CP(t)
201
202
200
203
204
Controller
PPG(t)
207
Orthostatic level-correcting element
sBP, dBP
206
Transfer Function
H(f)
+
k
BP-signal
208
Biomedical Algorithms
Hemodynamic Parameters

Figure 2

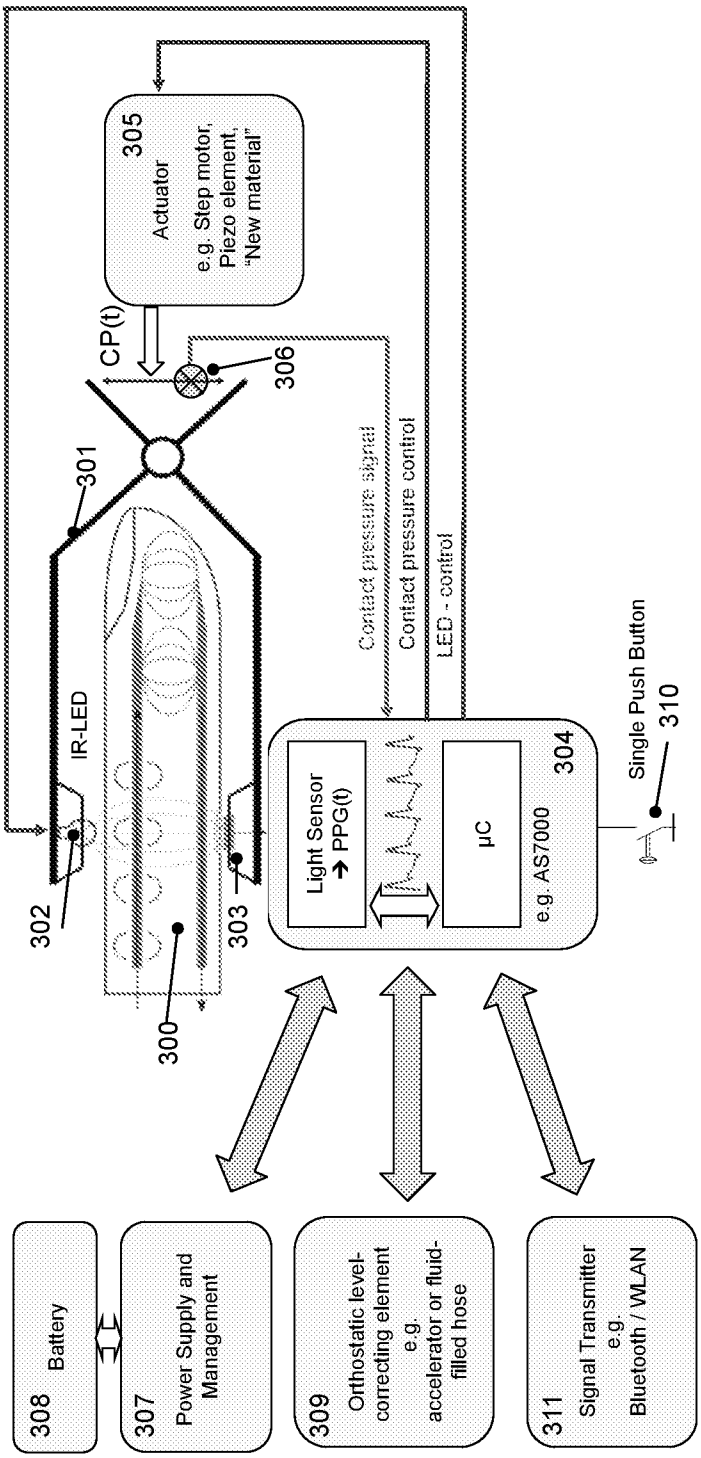

305
Actuator
e.g. Step motor, Piezo element, "New material"
CP(t)
306
301
IR-LED
Contact pressure signal
Contact pressure control
LED - control
302
303
300
Light Sensor → PPG(t)
µC
e.g. AS7000
304
Single Push Button
310
308 Battery
307 Power Supply and Management
309 Orthostatic level-correcting element e.g. accelerator or fluid-filled hose
311 Signal Transmitter e.g. Bluetooth / WLAN

Figure 3

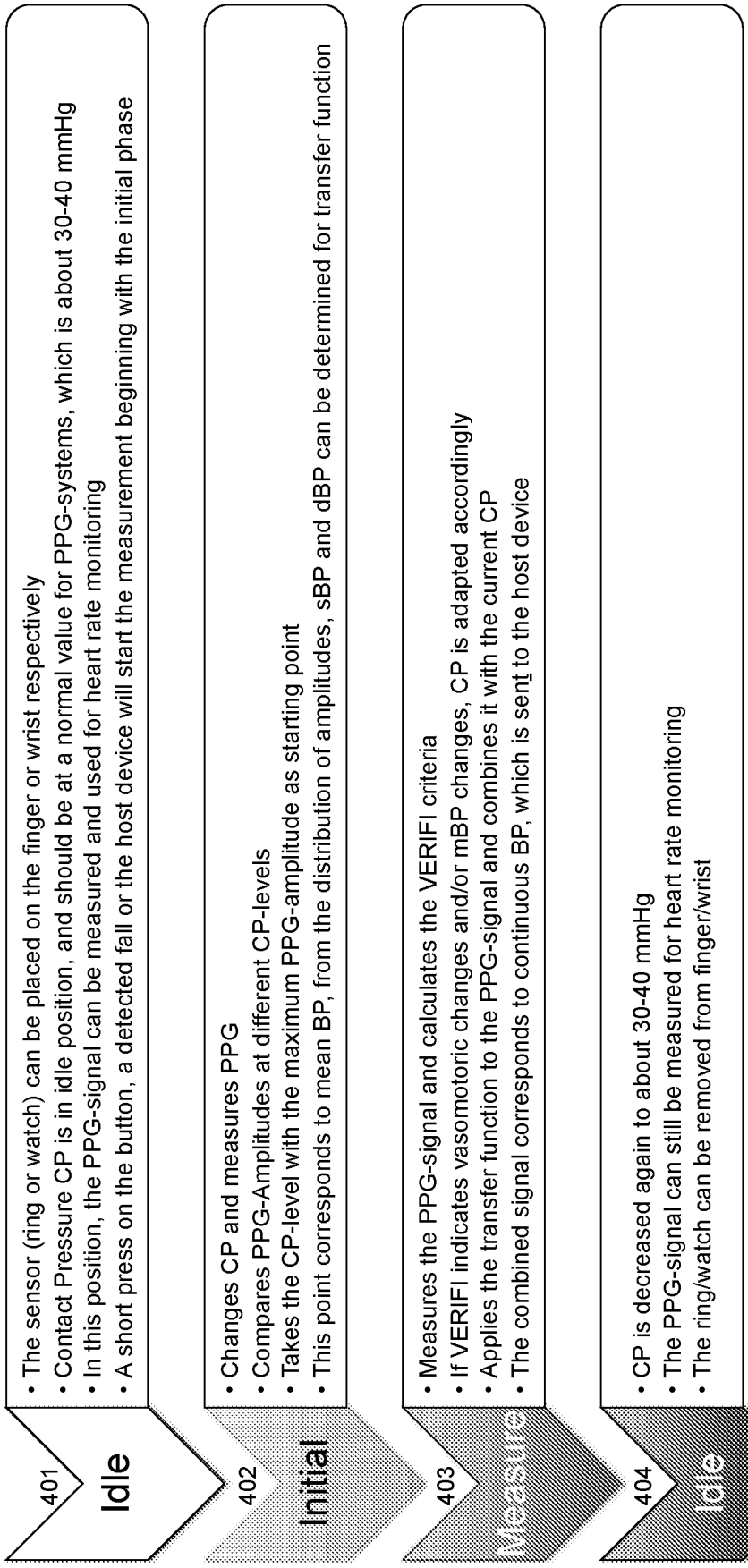

401
Idle
• The sensor (ring or watch) can be placed on the finger or wrist respectively
• Contact Pressure CP is in idle position, and should be at a normal value for PPG-systems, which is about 30-40 mmHg
• In this position, the PPG-signal can be measured and used for heart rate monitoring
• A short press on the button, a detected fall or the host device will start the measurement beginning with the initial phase
402
Initial
• Changes CP and measures PPG
• Compares PPG-Amplitudes at different CP-levels
• Takes the CP-level with the maximum PPG-amplitude as starting point
• This point corresponds to mean BP, from the distribution of amplitudes, sBP and dBP can be determined for transfer function
403
Measure
• Measures the PPG-signal and calculates the VERIFI criteria
• If VERIFI indicates vasomotoric changes and/or mBP changes, CP is adapted accordingly
• Applies the transfer function to the PPG-signal and combines it with the current CP
• The combined signal corresponds to continuous BP, which is sent to the host device
404
Idle
• CP is decreased again to about 30-40 mmHg
• The PPG-signal can still be measured for heart rate monitoring
• The ring/watch can be removed from finger/wrist

Figure 4

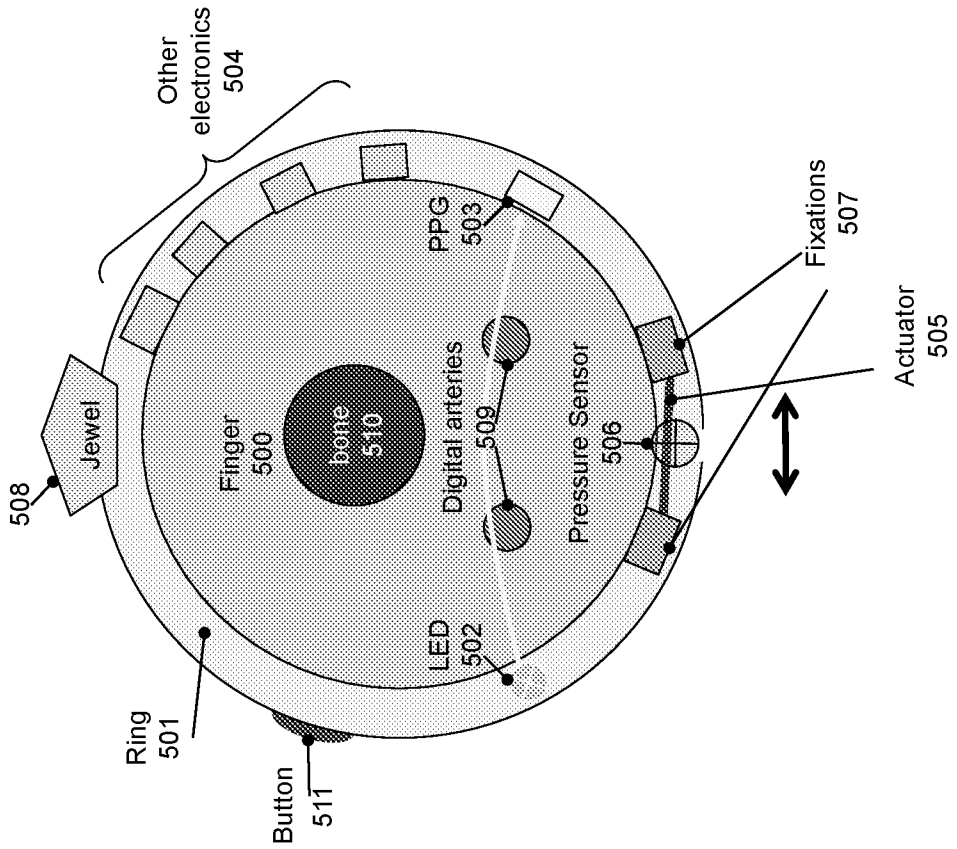

Other electronics 504
PPG 503
Fixations 507
Actuator 505
Jewel
508
Finger 500
bone 510
Digital arteries 509
Pressure Sensor 506
LED 502
Ring 501
Button 511

Figure 5

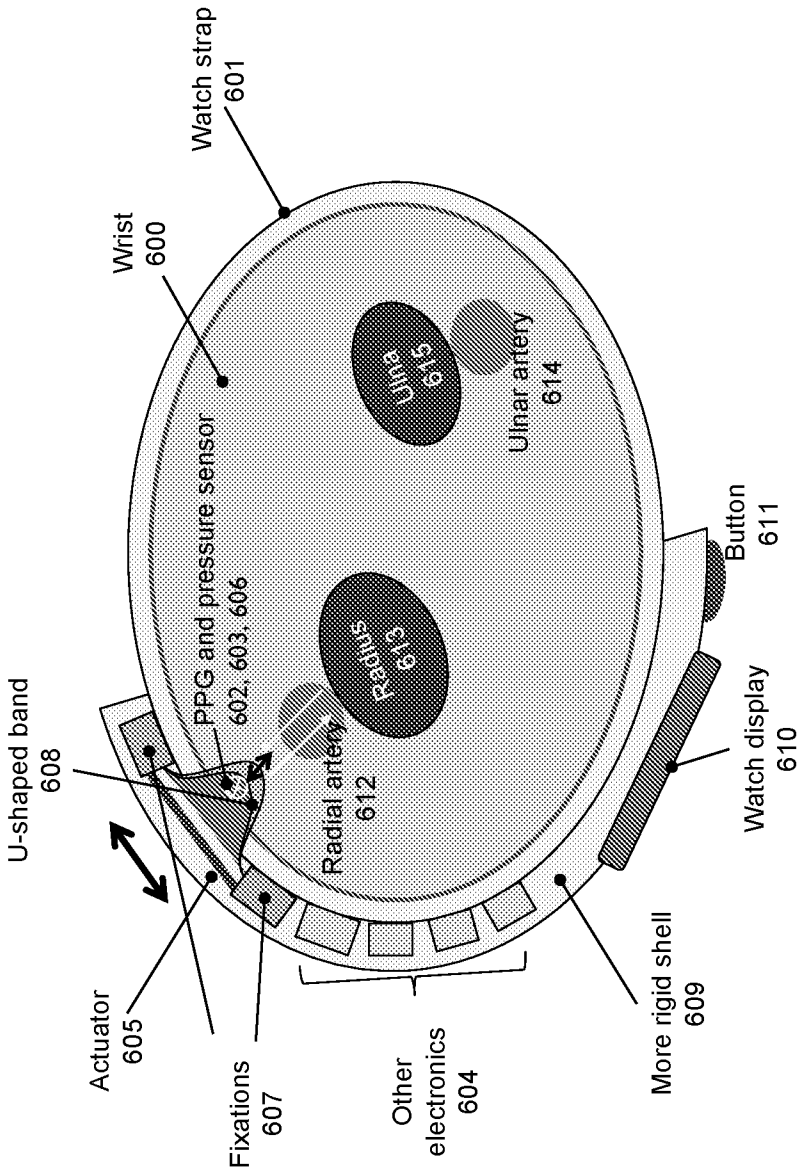
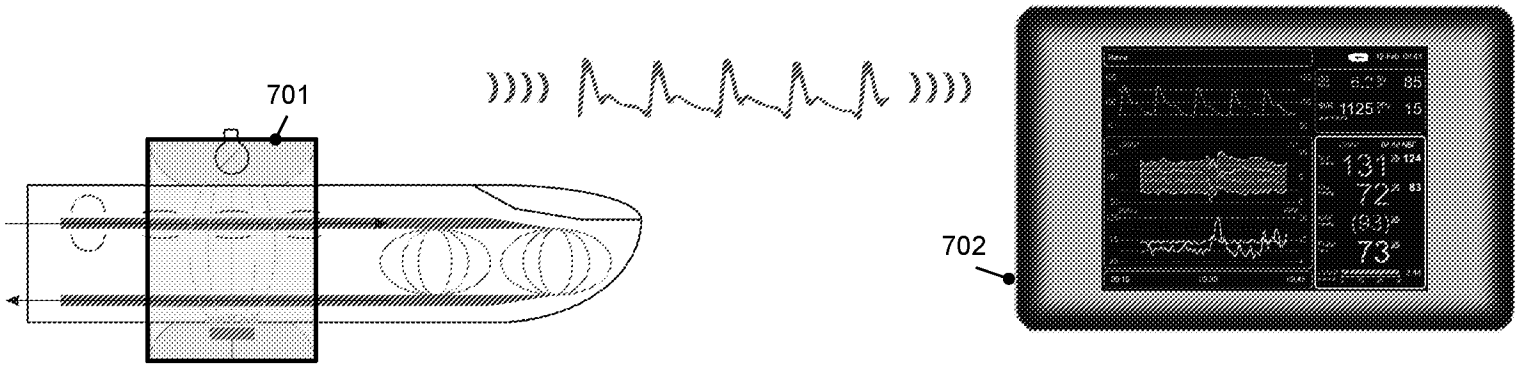

Watch strap
601
Wrist
600
PPG and pressure sensor
602, 603, 606
Ulna
619
Ulnar artery
614
Radius
619
Radial artery
612
Button
611
U-shaped band
608
Watch display
610
Actuator
605
Fixations
607
Other
electronics
604
More rigid shell
609

Figure 6



Wearable sensor measures BP-signal and its components and sends info to Tablet / Smartphone or other computer connected to the internet

1. APP receives BP-signal or BP-signal components
   - Optional: App transforms PPG-signal, contact pressure and vertical distance with transfer function to real BP-signal.
2. Applies further biomedical algorithms:
   - Basic PCA algorithms for:
     - Cardiac Output, Stroke Volume, Total Peripheral Resistance
     - Arterial Stiffness, Endothelic Function, Augmentation Index
   - Autonomic Function, Sympathetic/Parasympathetic Drive, Baroreflex sensitivity
3. Further APP functionality:
   - Application specific analysis and display
   - Pay-per-use business models
     - Allows for medical reimbursement
   - Possibility to collect biomedical data for further big-data analysis

Figure 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2016/000075

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B5/024 A61B5/022 A61B5/0225 A61B5/00
ADD. A61B5/021 A61B5/11 A61B5/029 A61B17/135

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.
X	US 2007/055163 A1 (ASADA HARUHIKO H [US] ET AL) 8 March 2007 (2007-03-08) paragraph [0063] - paragraph [0131]; claims; figures ----- US 2003/036685 A1 (GOODMAN JESSE B [CA]) 20 February 2003 (2003-02-20) paragraphs [0138], [0157], [0191], [0201], [0217] - [0245]; claims; figures ----- US 2011/054330 A1 (PFEIFFER ULRICH [DE] ET AL) 3 March 2011 (2011-03-03) paragraphs [0017], [0027], [0037], [0099] - [0124], [0143] - [0153], [0189] - [0209]; claims; figures ----- -/--	1-21 1-21 1-21

[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
20 April 2016	29/04/2016

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	Crisan, Carmen-Clara

1

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2016/000075

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2011/105917 A1 (FORTIN JUERGEN [AT] ET AL) 5 May 2011 (2011-05-05) paragraphs [0023] - [0046]; claims; figures	1-21
X	EP 2 502 555 A1 (BMEYE B V [NL]) 26 September 2012 (2012-09-26)	15-21
A	paragraphs [0026], [0032] - [0040]; claims; figures	1-14

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2016/000075

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2007055163 A1	08-03-2007	US 2007055163 A1	08-03-2007
		WO 2007024777 A2	01-03-2007
US 2003036685 A1	20-02-2003	US 6616613 B1	09-09-2003
		US 2003036685 A1	20-02-2003
US 2011054330 A1	03-03-2011	NONE	
US 2011105917 A1	05-05-2011	CN 102647940 A	22-08-2012
		CN 102791192 A	21-11-2012
		EP 2493370 A1	05-09-2012
		EP 2493373 A1	05-09-2012
		JP 2013509225 A	14-03-2013
		JP 2013509226 A	14-03-2013
		JP 2016025935 A	12-02-2016
		US 2011105917 A1	05-05-2011
		US 2011105918 A1	05-05-2011
		WO 2011051819 A1	05-05-2011
		WO 2011051822 A1	05-05-2011
EP 2502555 A1	26-09-2012	CN 103619242 A	05-03-2014
		EP 2502555 A1	26-09-2012
		EP 2713859 A1	09-04-2014
		JP 2014511719 A	19-05-2014
		US 2015080669 A1	19-03-2015
		WO 2012126798 A1	27-09-2012