



(11) **EP 3 366 203 B1**

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention
of the grant of the patent:
25.12.2019 Bulletin 2019/52

(51) Int Cl.:
A61B 5/021 ^(2006.01) **A61B 5/0456** ^(2006.01)
A61B 5/024 ^(2006.01) **A61B 5/00** ^(2006.01)

(21) Application number: **18156830.4**

(22) Date of filing: **15.02.2018**

(54) **METHOD AND SYSTEM FOR CUFFLESS BLOOD PRESSURE ESTIMATION USING
PHOTOPLETHYSMOGRAM FEATURES AND PULSE TRANSIT TIME**

VERFAHREN UND SYSTEM ZUR MANSCHETTENLOSEN BLUTDRUCKSCHÄTZUNG UNTER MIT
PHOTOPLETHYSMOGRAMMMERKMALEN UND PULSLAUFEIT

PROCÉDÉ ET SYSTÈME D'ESTIMATION DE LA PRESSION ARTÉRIELLE SANS BRASSARD
FAISANT APPEL AUX CARACTÉRISTIQUES DU PHOTOPLÉTHYSMOGRAMME ET AU TEMPS DE
TRANSIT DU POULS

(84) Designated Contracting States:
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**

(30) Priority: **23.02.2017 IN 201721006574**

(43) Date of publication of application:
29.08.2018 Bulletin 2018/35

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(56) References cited:
WO-A1-2013/036718

- **BOSE S SREE NIRANJANAA ET AL: "Improving the performance of continuous non-invasive estimation of blood pressure using ECG and PPG", 2015 ANNUAL IEEE INDIA CONFERENCE (INDICON), IEEE, 17 December 2015 (2015-12-17), pages 1-5, XP032887408, DOI: 10.1109/INDICON.2015.7443297 [retrieved on 2016-03-29]**
- **GHOSH SHRIMANTI ET AL: "Continuous blood pressure prediction from pulse transit time using ECG and PPG signals", 2016 IEEE HEALTHCARE INNOVATION POINT-OF-CARE TECHNOLOGIES CONFERENCE (HI-POCT), IEEE, 9 November 2016 (2016-11-09), pages 188-191, XP033032082, DOI: 10.1109/HIC.2016.7797728 [retrieved on 2016-12-27]**

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DescriptionTECHNICAL FIELD

5 **[0001]** The present application generally relates to the field of non-invasive blood pressure estimation. More particularly, but not specifically, the invention provides a system and method for estimation of blood pressure of a person using photoplethysmogram and pulse transit time.

BACKGROUND

10 **[0002]** Measurement of various physiological parameters, such as blood pressure of a person is typically performed in a clinical setting. Blood pressure is one of the important signs about the person's physical attributes and usefully indicates cardiovascular diseases. Therefore, the measurement/estimation of blood pressure has gained increasing attention. One can measure blood pressure in one of the two ways, that is, invasive and non-invasive methods. Although
15 the accuracy of invasive method is high, it carries great risks and thus is restricted to a hospital setting in critical care. The most popular non-invasive blood pressure measurement techniques are auscultatory and oscillometric. These two methods involve occlusion of blood flow using an inflatable cuff. The sphygmomanometer is an auscultatory technique. As the auscultatory method is non-invasive, easy, and safe, it is well supported and has been accepted as standard method for clinical measurement despite the inaccuracy due to both observer errors and methodological errors. However,
20 rather than using a stethoscope, a calibrated electronic pressure transducer is used to monitor the pressure oscillations within the cuff. Since it is also non-invasive, easy, safe, and furthermore eliminates the mercury column, the oscillometric technique is used primarily in automated non-invasive blood pressure devices. Common limitations of measurement include the reliance on blood flow and selection of an inappropriate cuff size and position.

[0003] With the rapid increase of cardiovascular diseases non-invasive cuff-less measurement methods are more
25 commonly required for routine examinations and monitoring. In this regard, a large number of studies have been conducted and it has been observed that the pulse transit time (PTT) is an important physiological parameter that it is closely related to arterial stiffness and can be used to estimate the blood pressure of the person. PTT can be determined as the time delay from the R wave peak of electrocardiogram (ECG) to a characteristic point of finger photoplethysmogram (PPG) in the same cardiac cycle.

30 **[0004]** However, one of the main problems in blood pressure estimation analysis is uncertainty. Some of the sources of this uncertainty include imprecision in computations and vagueness in class definition. Various methods in the prior arts have used PTT as a parameter for the estimation of blood pressure, but most fail to distinguish between extreme and normal BP values with high accuracy, therefore there is still scope for the improvement.

[0005] In BOSE S SREE NIRANJANAA ET AL: "Improving the performance of continuous non-invasive estimation of
35 blood pressure using ECG and PPG", 2015 ANNUAL IEEE INDIA CONFERENCE (INDICON), IEEE, 17 December 2015, blood pressure is estimated using linear regression on PTT, ECG and PPG data.

SUMMARY

40 **[0006]** In view of the foregoing, an embodiment herein provides a system for estimating blood pressure (BP) of a person. The system comprises an ECG sensor, a PPG sensor, a memory and a processor. The ECG sensor captures an electrocardiogram (ECG) signal of the person. The PPG sensor captures a photoplethysmogram (PPG) signal of the person. The PPG signal is synchronized with the ECG signal. The processor is in communication with the memory. The processor further comprises a preprocessor, pulse transit time estimation module, a feature extraction module, an input
45 module, a feature selection module, a classification module and a regression analysis module. The preprocessor pre-processes the ECG signal and PPG signal to remove a plurality of noises. The pulse transit time estimation module estimates a pulse transit time (PTT) using the ECG signal and PPG signal. The feature extraction module extracts a plurality of features of the PPG signal. The input module provides the PTT and the plurality of features to a feature selection module. The feature selection module applies a feature selection algorithm for selecting a set of features. The
50 set of features are selected to maximize the accuracy in classifying a low/normal BP class from a high BP class. The classification module classifies the data corresponding to ECG signal, PPG signal and PTT in to the high BP class and the low/normal BP class based on the selected set of features. The regression analysis module performs the regression analysis on the PPG features and the PTT corresponding to the low/normal BP class to estimate the blood pressure of the person.

55 **[0007]** Another embodiment provides a method for estimating a blood pressure (BP) of a person. Initially, an electrocardiogram (ECG) signal of the person is captured using an ECG sensor. And a photoplethysmogram (PPG) signal of the person is captured using a PPG sensor. The PPG signal is synchronized with the ECG signal. In the next step, the ECG signal and PPG signal are preprocessed to remove a plurality of noises. Further, a pulse transit time (PTT) is

estimated using the ECG signal and PPG signal, followed by the estimation of a plurality of features of the PPG signal. The PTT and the plurality of features are then sent to a feature selection module. In the next step, a feature selection algorithm is applied for selecting a set of features. The set of features are selected in a way as to maximize the accuracy in classifying a low/normal BP class from a high BP class. Then, the data corresponding to ECG signal, PPG signal and PTT is classified in to the high BP class and the low/normal BP class based on the selected set of features using a classification module. And finally the regression analysis is performed on the ECG signal, the PPG signal and the PTT corresponding to the low/normal BP class to estimate the blood pressure of the person.

[0008] In another embodiment, a non-transitory computer-readable medium having embodied thereon a computer program for estimating a blood pressure (BP) of a person. Initially, an electrocardiogram (ECG) signal of the person is captured using an ECG sensor. And a photoplethysmogram (PPG) signal of the person is captured using a PPG sensor. The PPG signal is synchronized with the ECG signal. In the next step, the ECG signal and PPG signal are preprocessed to remove a plurality of noises. Further, a pulse transit time (PTT) is estimated using the ECG signal and PPG signal, followed by the estimation of a plurality of features of the PPG signal. The PTT and the plurality of features are then sent to a feature selection module. In the next step, a feature selection algorithm is applied for selecting a set of features. The set of features are selected in a way as to maximize the accuracy in classifying a low/normal BP class from a high BP class. Then, the data corresponding to ECG signal, PPG signal and PTT is classified in to the high BP class and the low/normal BP class based on the selected set of features using a classification module. And finally the regression analysis is performed on the ECG signal, the PPG signal and the PTT corresponding to the low/normal BP class to estimate the blood pressure of the person.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The embodiments herein will be better understood from the following detailed description with reference to the drawings, in which:

Fig. 1 illustrates a block diagram of a system for estimating a blood pressure (BP) of a person using pulse transit time, in accordance with an embodiment of the present disclosure;

Fig. 2 is a graphical representation of PPG signal, ECG signal and pulse transit time, in accordance with an embodiment of the present disclosure; and

Fig. 3A-3B is a flowchart illustrating the steps involved in the estimation of blood pressure (BP) of a person using pulse transit time, in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION OF EMBODIMENTS

[0010] Referring now to the drawings, and more particularly to FIG. 1, where similar reference characters denote corresponding features consistently throughout the figures, there are shown preferred embodiments and these embodiments are described in the context of the following exemplary system and/or method.

[0011] According to an embodiment of the disclosure, a system 100 for estimating a blood pressure (BP) of a person is shown in Fig. 1. The system 100 provides a non-invasive cuff-less technique for the estimation of the blood pressure of the person. The disclosure uses pulse transit time (PTT) as one of most important parameter for the estimation of the blood pressure. The system 100 classifies the normal / low BP class with high BP class and estimates the blood pressure with higher accuracy.

[0012] According to an embodiment of the disclosure, the system 100 comprises an ECG sensor 102, a PPG sensor 104, a memory 106 and a processor 108 in communication with the memory 106. The processor 108 is configured to read a plurality of algorithms stored in the memory to perform various functions. The processor 108 further includes a plurality of modules such as a preprocessor 110, a pulse transit time estimation module 112, a feature extraction module 114, an input module 116, a feature selection module 118, a classification module 120 and a regression analysis module 122.

[0013] According to an embodiment of the invention, an ECG signal of the person is captured using the ECG sensor 102. It should be appreciated that the use of any kind of ECG sensor 102 is well within the scope of this disclosure. The ECG signal is a graphic recording or display of the time variant voltages produced by the myocardium during the cardiac cycle. The P, Q, R, S and T reflect the rhythmic electrical depolarization and re-polarization of the myocardium associated with the contraction of the atria and ventricles.

[0014] According to an embodiment a PPG signal is captured using the PPG sensor 104. The PPG signal is based on the determination of the optical properties of a selected skin area. For this purpose nonvisible infrared light is emitted into the skin. More or less light is absorbed, depending on the blood volume. Blood volume changes can then be

determined by measuring the reflected/transmitted light. It should be appreciated that the captured PPG signal is synchronized with the captured ECG signal. Generally the captured ECG signal and the PPG signals contain a plurality of noises. Therefore the ECG signal and the PPG signal are preprocessed using the preprocessor 110. The preprocessor 110 uses various pre-processing techniques like baseline and topline corrections and histogram based cycle selection strategies etc.

[0015] According to an embodiment of the disclosure, the processor 108 further calculates the pulse transit time (PTT) for the person using the pulse transit time estimation module 112. PTT is the time taken by a pulse wave to propagate from heart of the person to a specified point on the body where the reading is taken, normally the finger or ear lobe. PTT is defined as the time duration from a reference point of time, for the pulse pressure wave to travel to any specified point on the periphery. Blood pressure changes, heart rate and the compliance of the arterial walls, and so on influence the PTT. The stiffness and tension in the arterial walls are the principle factors determining the speed of transmission of the pulse wave, and this in turn depends to a large extent on blood pressure. An increase in BP increases arterial wall tension and stiffness, thus shortening PTT; and conversely, a drop in BP lessens the stiffness and tension in the arterial walls, thus lengthening PTT. In an embodiment of the disclosure PTT is calculated as the time delay from the R wave peak of ECG signal to a peak point of finger photoplethysmogram in the same cardiac cycle as shown in the waveform of Fig. 2. It indicates that given a cardiac cycle the difference between the peak of PPG and R peak of ECG is used to calculate PTT.

[0016] According to an embodiment of the disclosure, the processor 108 also comprises the feature extraction module 114. The feature extraction module 114 extracts a plurality of features of the PPG signal. The plurality of features may include time domain features, frequency domain features and HRV features. The example of time domain features include systolic and diastolic time durations, systolic and diastolic areas, cycle duration, systolic and diastolic time and area ratios, ratio of pulse widths at different pulse heights etc. Once the features are extracted, then a feature matrix can be created containing PTT and the plurality of PPG features.

[0017] Generally, the extracted plurality of features are large in quantity therefore only a set of features are selected out of the plurality of features using the feature selection module 118. The PTT and the plurality of features of the PPG signal are provided to the feature selection module 118 using the input module 116. The feature selection module 118 applies a feature selection algorithm for selecting the set of features. The set of features are selected in such a way that to maximize the accuracy in classifying a low / normal BP class from a high BP class. It should be appreciated that the present disclosure is measuring the systolic BP of the person. It should also be appreciated that, the systolic BP value of more than 150 mm Hg is considered as high BP, while anything below this value will be considered as the low / normal BP.

[0018] According to an embodiment of the disclosure, different feature selection algorithms may be used for selecting the set of features. In an example, these algorithms may be minimum redundancy maximum relevance (mRMR) algorithm, maximum relevance maximum significance (mRMS) algorithm and μ HeM algorithm. The mRMR algorithm is a mutual information based method that selects a set of features by minimizing redundancy and maximizing relevance. While calculating redundancy between two features it does not consider class label information. On the other hand mRMS algorithm is a rough set based feature selection algorithm that selects a set of features by maximizing both relevance as well as significance and it incorporates class label information while calculating significance of a feature with respect to other features. For selecting features using the mRMR and mRMS algorithms the data set has to be in discretized form. In the process of discretization information loss is inevitable. However, the μ HEM algorithm can handle real valued data. It is a rough hypercuboid based method that selects a set of features by maximizing both relevance and significance. The relevance and significance are calculated based on rough hypercuboid concept. It should be appreciated that the use of any other algorithm is well within the scope of this disclosure.

[0019] According to an embodiment of the disclosure, the processor 108 also includes the classification module 120. The classification module 120 classifies the low / normal BP class from the high BP class using a support vector machine (SVM) based method. It should be appreciated that the use of any other classification technique is well within the scope of this disclosure.

[0020] According to an embodiment of the disclosure, the data corresponding to ECG signal, PPG signal and PTT classified as low / normal BP are then provided to the regression analysis module 122. The regression analysis module 122 performs the regression analysis to estimate the blood pressure of the person. This way it improved the overall accuracy of the system 100. It is assumed that the regression analysis module 122 will provide a better accuracy when the high BP data are classified out previously.

[0021] In operation, a flowchart 200 for estimating a blood pressure (BP) of a person is shown in Fig. 3A-3B according to an embodiment of the disclosure. Initially at step 202, an electrocardiogram (ECG) signal of the person is captured using the ECG sensor 102. The use of any kind of ECG sensor 102 is well within the scope of this disclosure. At step 204, a photoplethysmogram (PPG) signal of the person is captured using the PPG sensor 104. It should be appreciated the capturing should be done in such a way that the PPG signal is synchronized with the ECG signal. At step 206, the ECG signal and PPG signal are preprocessed to remove a plurality of noises.

[0022] At step 208, the pulse transit time (PTT) is estimated using the ECG signal and PPG signal of the person. PTT is defined as the time duration from a reference point of time, for the pulse pressure wave to travel to any specified point on the periphery. In the next step 210, a plurality of features are extracted from the PPG signal. The plurality of features include time domain features, frequency domain features and the Heart Rate Variability (HRV) features. At step 212, the PTT and the plurality of features are provided to the feature selection module. In the next step 214, the feature selection algorithm is applied for selecting a set of features. The set of features are selected in such a way to maximize the accuracy in classifying a low/normal BP class from a high BP class. In the next step 216, the ECG signal, PPG signal and PTT are classified in to the high BP class and the low / normal BP class based on the selected set of features using a classification module. And finally, at step 218 the regression analysis is performed on the ECG signal, the PPG signal and the PTT corresponding to the low / normal BP class to estimate the blood pressure of the person.

[0023] In another embodiment, the accuracy of the estimated blood pressure value can be evaluated the using Bland Altman plot.

[0024] According to an embodiment of the disclosure, an experiment was also conducted to determine the relation between the blood pressure and the PTT. It has been found that the BP is inversely proportional to the PTT. The correlation between BP and PTT can be calculated using pearson correlation coefficient. It is the ratio between the covariance of two vectors (x_i, x_j) of feature values of two subjects and product of their standard deviations and is given by following equation:

$$\rho(x_i, x_j) = \frac{Cov(x_i, x_j)}{\sigma_{x_i} \sigma_{x_j}};$$

that is,

$$\rho(x_i, x_j) = \frac{\sum_{k=1}^m (x_{ik} - \bar{x}_i)(x_{jk} - \bar{x}_j)}{\sqrt{\sum_{k=1}^m (x_{ik} - \bar{x}_i)^2} \sqrt{\sum_{k=1}^m (x_{jk} - \bar{x}_j)^2}},$$

where $\bar{x}_i$ and $\bar{x}_j$ are the means of x_{ik} and x_{jk} , respectively. It considers each feature as a random variable with m observations and measures the similarity between the two features by calculating the linear relationship between the distributions of the two corresponding random variables. The correlation between BP and PTT is calculated for multiple sessions of all the records using (2).

[0025] According to another embodiment of the disclosure, the performance of different feature selection algorithms is also analyzed in terms of classification accuracy, sensitivity, and specificity of SVM classifier. The records are grouped into the low / normal BP class and high BP class. From the Table 1 below it is seen that the mRMR algorithm obtains highest LOOCV accuracy of 87.90% with 4 features. On the other hand rough set based maximum relevance maximum-significance (mRMS) algorithm attains 87.90% accuracy with 5 features. The rough hypercuboid based μ HEM algorithm achieved highest accuracy of 88.71% with 18 features. Irrespective of any feature selection algorithm, the PTT feature is selected as the most potential feature. Results indicate that rough set based feature selection approaches can handle uncertainty, ambiguity, and incompleteness in class definition. The results indicate that in spite of domain knowledge of physiological sensing data the proposed approach can select relevant set of features that can generate better result in terms of accuracy, sensitivity, and specificity.

TABLE 1. PERFORMANCE OF DIFFERENT FEATURE SELECTION ALGORITHMS

Index	mRMR	RSMRMS	μ HEM
Accuracy (%)	87.90	87.90	88.71
Sensitivity	0.871	0.871	0.887
Specificity	0.887	0.887	0.887

(continued)

Index	mRMR	RSMRMS	μ HEM
No. of Features	4	5	18

[0026] Further, all the feature selection algorithms select PTT as the most potential feature. Importance of PTT feature is shown in Table 2 below. In order to study the importance of PTT feature next a study is conducted, classification accuracy is calculated with PTT feature as well as other features that are selected by feature selection algorithms and without PTT feature. The classification accuracy of the SVM classifier is shown with PTT feature and without PTT feature. From the table it is seen that the with PTT feature the classification accuracy improves. Hence, it signifies that the PTT is very important physiological parameter for estimation of BP.

TABLE 2. IMPORTANCE OF PTT

Algorithms		With PTT	Without PTT
mRMR	Accuracy (%)	87.90	86.29
	No. of Features	4	3
RSMRMS	Accuracy (%)	87.90	87.90
	No. of Features	5	7
μ HEM	Accuracy (%)	88.71	87.90
	No. of Features	18	11

[0027] It is, however to be understood that the scope of the protection includes a program and in addition to a computer-readable means having a message therein; such computer-readable storage means contain program-code means for implementation of one or more steps of the method, when the program runs on a server or mobile device or any suitable programmable device. The hardware device can be any kind of device which can be programmed including e.g. any kind of computer like a server or a personal computer, or the like, or any combination thereof. The device may also include means which could be e.g. hardware means like e.g. an application-specific integrated circuit (ASIC), a field-programmable gate array (FPGA), or a combination of hardware and software means, e.g. an ASIC and an FPGA, or at least one microprocessor and at least one memory with software modules located therein. Thus, the means can include both hardware means and software means. The method embodiments described herein could be implemented in hardware and software. The device may also include software means. Alternatively, the embodiments may be implemented on different hardware devices, e.g. using a plurality of CPUs.

[0028] The embodiments herein can comprise hardware and software elements. The embodiments that are implemented in software include but are not limited to, firmware, resident software, microcode, etc. The functions performed by various modules described herein may be implemented in other modules or combinations of other modules. For the purposes of this description, a computer-usable or computer readable medium can be any apparatus that can comprise, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

[0029] The medium can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system (or apparatus or device) or a propagation medium. Examples of a computer-readable medium include a semiconductor or solid state memory, magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk and an optical disk. Current examples of optical disks include compact disk-read only memory (CD-ROM), compact disk-read/write (CD-R/W) and DVD.

[0030] A data processing system suitable for storing and/or executing program code will include at least one processor coupled directly or indirectly to memory elements through a system bus. The memory elements can include local memory employed during actual execution of the program code, bulk storage, and cache memories which provide temporary storage of at least some program code in order to reduce the number of times code must be retrieved from bulk storage during execution.

[0031] Input/output (I/O) devices (including but not limited to keyboards, displays, pointing devices, etc.) can be coupled to the system either directly or through intervening I/O controllers. Network adapters may also be coupled to the system to enable the data processing system to become coupled to other data processing systems or remote printers or storage devices through intervening private or public networks. Modems, cable modem and Ethernet cards are just a few of the currently available types of network adapters.

[0032] A representative hardware environment for practicing the embodiments may include a hardware configuration of an information handling/computer system in accordance with the embodiments herein. The system herein comprises at least one processor or central processing unit (CPU). The CPUs are interconnected via system bus to various devices such as a random access memory (RAM), read-only memory (ROM), and an input/output (I/O) adapter. The I/O adapter can connect to peripheral devices, such as disk units and tape drives, or other program storage devices that are readable by the system. The system can read the inventive instructions on the program storage devices and follow these instructions to execute the methodology of the embodiments herein.

[0033] The system further includes a user interface adapter that connects a keyboard, mouse, speaker, microphone, and/or other user interface devices such as a touch screen device (not shown) to the bus to gather user input. Additionally, a communication adapter connects the bus to a data processing network, and a display adapter connects the bus to a display device which may be embodied as an output device such as a monitor, printer, or transmitter, for example.

Claims

1. A method for estimating a blood pressure (BP) of a person, the method comprising a processor implemented steps of:

capturing an electrocardiogram (ECG) signal of the person using an ECG sensor (102);
 capturing a photoplethysmogram (PPG) signal of the person using a PPG sensor (104), wherein the PPG signal is synchronized with the ECG signal;
 preprocessing the ECG signal and PPG signal to remove a plurality of noises;
 estimating a pulse transit time (PTT) using the ECG signal and PPG signal;
 extracting a plurality of features of the PPG signal;
 providing the PTT and the plurality of features to a feature selection module (118);
 applying a feature selection algorithm for selecting a set of features, wherein the set of features are selected to maximize the accuracy in classifying a low/normal BP class from a high BP class;
 classifying the data corresponding to ECG signal, PPG signal and PTT in to the high BP class and the low/normal BP class based on the selected set of features using a classification module (120); and
 performing a regression analysis on the ECG signal, the PPG signal and the PTT corresponding to the low/normal BP class to estimate the blood pressure of the person.

2. The method according to claim 1 further includes the step of creating a feature matrix containing PTT and the plurality of PPG features.

3. The method according to claim 1, wherein the feature selection algorithm is at least one of a maximum relevance minimum redundancy (mRMR) algorithm, a maximum relevance maximum significance (mRMS) algorithm or a μ HEM algorithm.

4. The method according to claim 1 wherein the classification module is a support vector machine (SVM) classifier designed using the selected set of features.

5. The method according to claim 1, wherein the high BP class is with systolic BP more than or equal to 150 mmHg and normal/low BP class is with systolic BP less than 150 mmHg.

6. The method according to claim 1, wherein the plurality of features include time domain, frequency domain and heart rate variability (HRV) domain features.

7. The method according to claim 1 further include the step of evaluating the accuracy of the estimated BP using Bland Altman plot.

8. A system for estimating a blood pressure (BP) of a person, the system comprising:

an ECG sensor (102) for capturing an electrocardiogram (ECG) signal of the person;
 a PPG sensor (104) for capturing a photoplethysmogram (PPG) signal of the person, wherein the PPG signal is synchronized with the ECG signal;
 a memory (106); and
 a processor (108) in communication with the memory, wherein the processor further comprises:

a preprocessor (110) for preprocessing the ECG signal and PPG signal to remove a plurality of noises,
 a pulse transit time estimation module (112) for estimating a pulse transit time (PTT) using the ECG signal and PPG signal,
 a feature extraction module (114) for extracting a plurality of features of the PPG signal,
 an input module (116) for providing the PTT and the plurality of features to a feature selection module,
 a feature selection module (118) for applying a feature selection algorithm for selecting a set of features,
 wherein the set of features are selected to maximize the accuracy in classifying a low/normal BP class from a high BP class,
 a classification module (120) for classifying the ECG signal, PPG signal and PTT in to the high BP class and the low/normal BP class based on the selected set of features, and
 a regression analysis module (122) for performing a regression analysis on the ECG signal, the PPG signal and the PTT corresponding to the low/normal BP class to estimate the blood pressure of the person.

9. A non-transitory computer-readable medium having embodied thereon a computer program for estimating a blood pressure (BP) of a person, the method comprising a processor implemented steps of:

capturing an electrocardiogram (ECG) signal of the person using an ECG sensor (102);
 capturing a photoplethysmogram (PPG) signal of the person using a PPG sensor (104), wherein the PPG signal is synchronized with the ECG signal;
 preprocessing the ECG signal and PPG signal to remove a plurality of noises;
 estimating a pulse transit time (PTT) using the ECG signal and PPG signal;
 extracting a plurality of features of the PPG signal;
 providing the PTT and the plurality of features to a feature selection module (118);
 applying a feature selection algorithm for selecting a set of features, wherein the set of features are selected to maximize the accuracy in classifying a low/normal BP class from a high BP class;
 classifying the data corresponding to ECG signal, PPG signal and PTT in to the high BP class and the low/normal BP class based on the selected set of features using a classification module (120); and
 performing a regression analysis on the ECG signal, the PPG signal and the PTT corresponding to the low/normal BP class to estimate the blood pressure of the person.

Patentansprüche

1. Verfahren zum Schätzen eines Blutdrucks (BP) einer Person, wobei das Verfahren die folgenden von einem Prozessor implementierten Schritte umfasst:

Erfassen eines Elektrokardiogramm (EKG)-Signals der Person unter Verwendung eines EKG-Sensors (102);
 Erfassen eines Photoplethysmogramm (PPG)-Signals der Person unter Verwendung eines PPG-Sensors (104), wobei das PPG-Signal mit dem EKG-Signal synchronisiert ist;
 Vorverarbeitung des EKG-Signals und des PPG-Signals, um eine Mehrzahl von Geräuschen zu entfernen;
 Schätzen einer Pulswellenlaufzeit (PTT) unter Verwendung des EKG-Signals und des PPG-Signals;
 Extrahieren mehrerer Merkmale des PPG-Signals;
 Liefern der PTT und der Merkmale an ein Merkmalsauswahlmodul (118);
 Anwenden eines Merkmalsauswahlalgorithmus zum Auswählen eines Satzes von Merkmalen, wobei der Satz von Merkmalen so ausgewählt wird, dass die Genauigkeit bei der Klassifizierung einer niedrigen/normalen Blutdruckklasse gegenüber einer hohen Blutdruckklasse maximiert wird;
 Klassifizieren der dem EKG-Signal, PPG-Signal und PTT entsprechenden Daten in die hohe Blutdruckklasse und die niedrige/normale Blutdruckklasse basierend auf dem ausgewählten Merkmalsatz unter Verwendung eines Klassifizierungsmoduls (120); und
 Durchführen einer Regressionsanalyse des EKG-Signals, des PPG-Signals und der PTT, die der niedrigen/normalen Blutdruckklasse entsprechen, um den Blutdruck der Person zu schätzen.

2. Das Verfahren nach Anspruch 1, welches ferner den Schritt des Erstellens einer Merkmalsmatrix beinhaltet, die PTT und die PPG-Merkmale enthält.
3. Das Verfahren nach Anspruch 1, worin der Merkmalsauswahlalgorithmus von einem Maximalrelevanz-Minimalredundanz (mRMR)-Algorithmus, einem Maximalrelevanz-Maximalsignifikanz (mRMS)-Algorithmus oder einem μ HEM-Algorithmus mindestens einer ist.

4. Das Verfahren nach Anspruch 1, worin das Klassifizierungsmodul ein Support-Vector-Machine (SVM)-Klassifikator ist, der unter Verwendung des ausgewählten Satzes von Merkmalen entwickelt wurde.
5. Das Verfahren nach Anspruch 1, worin die hohe Blutdruckklasse mit systolischem Blutdruck größer oder gleich 150 mmHg und die normale/niedrige Blutdruckklasse mit systolischem Blutdruck kleiner als 150 mmHg ist.
6. Das Verfahren nach Anspruch 1, worin die Merkmale Merkmale im Zeitbereich, im Frequenzbereich und im Herzfrequenzvariabilitäts (HRV)-Bereich beinhalten.
7. Das Verfahren nach Anspruch 1, welches ferner den Schritt des Evaluierens der Genauigkeit des geschätzten Blutdrucks unter Verwendung eines Bland Altman-Diagramms beinhaltet.

8. System zum Schätzen eines Blutdrucks (BP) einer Person, wobei das System umfasst:

einen EKG-Sensor (102) zum Erfassen eines Elektrokardiogramm (EKG)-Signals der Person;
einen PPG-Sensor (104) zum Erfassen eines Photoplethysmogramm (PPG)-Signals der Person, wobei das PPG-Signal mit dem EKG-Signal synchronisiert ist;
einen Speicher (106); und
einen Prozessor (108) in Verbindung mit dem Speicher, wobei der Prozessor ferner umfasst:

einen Präprozessor (110) zum Vorverarbeiten des EKG-Signals und des PPG-Signals zum Entfernen einer Mehrzahl von Geräuschen,
ein Pulswellenlaufzeit-Schätzmodul (112) zum Schätzen einer Pulswellenlaufzeit (PTT) unter Verwendung des EKG-Signals und des PPG-Signals,
ein Merkmalsextraktionsmodul (114) zum Extrahieren mehrerer Merkmale des PPG-Signals,
ein Eingangsmodul (116) zum Liefern der PTT und der Merkmale an ein Merkmalsauswahlmodul,
ein Merkmalsauswahlmodul (118) zum Anwenden eines Merkmalsauswahlalgorithmus zum Auswählen eines Satzes von Merkmalen, wobei der Satz von Merkmalen ausgewählt wird, um die Genauigkeit bei der Klassifizierung einer niedrigen/normalen Blutdruckklasse gegenüber einer hohen Blutdruckklasse zu maximieren,
ein Klassifizierungsmodul (120) zum Klassifizieren des EKG-Signals, des PPG-Signals und der PTT in die hohe Blutdruckklasse und die niedrige/normale Blutdruckklasse basierend auf dem ausgewählten Satz von Merkmalen, und
ein Regressionsanalysemodul (122) zum Durchführen einer Regressionsanalyse des EKG-Signals, des PPG-Signals und der PTT, die der niedrigen/normalen Blutdruckklasse entsprechen, um den Blutdruck der Person zu schätzen.

9. Nichtflüchtiges, computerlesbares Medium, auf dem ein Computerprogramm zum Schätzen eines Blutdrucks (BP) einer Person verkörpert ist, wobei das Verfahren die folgenden prozessorimplementierten Schritte umfasst:

Erfassen eines Elektrokardiogramm (EKG)-Signals der Person unter Verwendung eines EKG-Sensors (102);
Erfassen eines Photoplethysmogramm (PPG)-Signals der Person unter Verwendung eines PPG-Sensors (104),
wobei das PPG-Signal mit dem EKG-Signal synchronisiert ist;
Vorverarbeitung des EKG-Signals und des PPG-Signals, um eine Mehrzahl von Geräuschen zu entfernen;
Schätzen einer Pulswellenlaufzeit (PTT) unter Verwendung des EKG-Signals und des PPG-Signals;
Extrahieren mehrerer Merkmale des PPG-Signals;
Liefern der PTT und der Merkmale an ein Merkmalsauswahlmodul (118);
Anwenden eines Merkmalsauswahlalgorithmus zum Auswählen eines Satzes von Merkmalen, wobei der Satz von Merkmalen ausgewählt wird, um die Genauigkeit bei der Klassifizierung einer niedrigen/normalen Blutdruckklasse gegenüber einer hohen Blutdruckklasse zu maximieren;
Klassifizieren der dem EKG-Signal, PPG-Signal und PTT entsprechenden Daten in die hohe Blutdruckklasse und die niedrige/normale Blutdruckklasse basierend auf dem ausgewählten Merkmalsatz unter Verwendung eines Klassifizierungsmoduls (120); und
Durchführen einer Regressionsanalyse des EKG-Signals, des PPG-Signals und der PTT, die der niedrigen/normalen Blutdruckklasse entsprechen, um den Blutdruck der Person zu schätzen.

Revendications

1. Procédé d'estimation de la pression artérielle (BP) d'une personne, le procédé comprenant les étapes, mises en oeuvre par un processeur, ci-dessous consistant à :

capturer un signal d'électrocardiogramme (ECG) de la personne en faisant appel à un capteur ECG (102) ;
 capturer un signal de photopléthysmogramme (PPG) de la personne, en faisant appel à un capteur PPG (104),
 dans lequel le signal PPG est synchronisé avec le signal ECG ;
 prétraiter le signal ECG et le signal PPG en vue d'éliminer une pluralité de bruits ; estimer un temps de transit
 du pouls (PTT) en utilisant le signal ECG et le signal PPG ;
 extraire une pluralité de caractéristiques du signal PPG ;
 fournir le temps PTT et la pluralité de caractéristiques à un module de sélection de caractéristiques (118) ;
 appliquer un algorithme de sélection de caractéristiques en vue de sélectionner un ensemble de caractéristiques,
 dans lequel l'ensemble de caractéristiques est sélectionné de manière à maximiser la précision dans le cadre
 de la classification d'une classe de pression BP faible/normale par rapport à une classe de pression BP élevée ;
 classer les données correspondant au signal ECG, au signal PPG et au temps PTT dans la classe de pression
 BP élevée et dans la classe de pression BP faible/normale, sur la base de l'ensemble de caractéristiques
 sélectionné, en utilisant un module de classification (120) ; et
 mettre en oeuvre une analyse de régression sur le signal ECG, le signal PPG et le temps PTT, correspondant
 à la classe de pression BP faible/normale, en vue d'estimer la pression artérielle de la personne.

2. Procédé selon la revendication 1, incluant en outre l'étape consistant à créer une matrice de caractéristiques contenant le temps PTT et la pluralité de caractéristiques PPG.

3. Procédé selon la revendication 1, dans lequel l'algorithme de sélection de caractéristiques correspond à au moins un algorithme parmi un algorithme de redondance minimale et pertinence maximale (mRMR), un algorithme d'importance maximale et pertinence maximale (mRMS) ou un algorithme μ HEM.

4. Procédé selon la revendication 1, dans lequel le module de classification est un classificateur de machine à vecteurs de support (SVM) conçu en utilisant l'ensemble de caractéristiques sélectionné.

5. Procédé selon la revendication 1, dans lequel la classe de pression BP élevée présente une pression BP systolique supérieure ou égale à 150 mmHg, et la classe de pression BP faible/normale présente une pression BP systolique inférieure à 150 mmHg.

6. Procédé selon la revendication 1, dans lequel la pluralité de caractéristiques inclut des caractéristiques du domaine temporel, des caractéristiques du domaine fréquentiel et des caractéristiques du domaine de variabilité de fréquence cardiaque (HRV).

7. Procédé selon la revendication 1, incluant en outre l'étape consistant à évaluer la précision de la pression BP estimée, au moyen du graphique de Bland Altman.

8. Système destiné à estimer une pression artérielle (BP) d'une personne, le système comprenant :

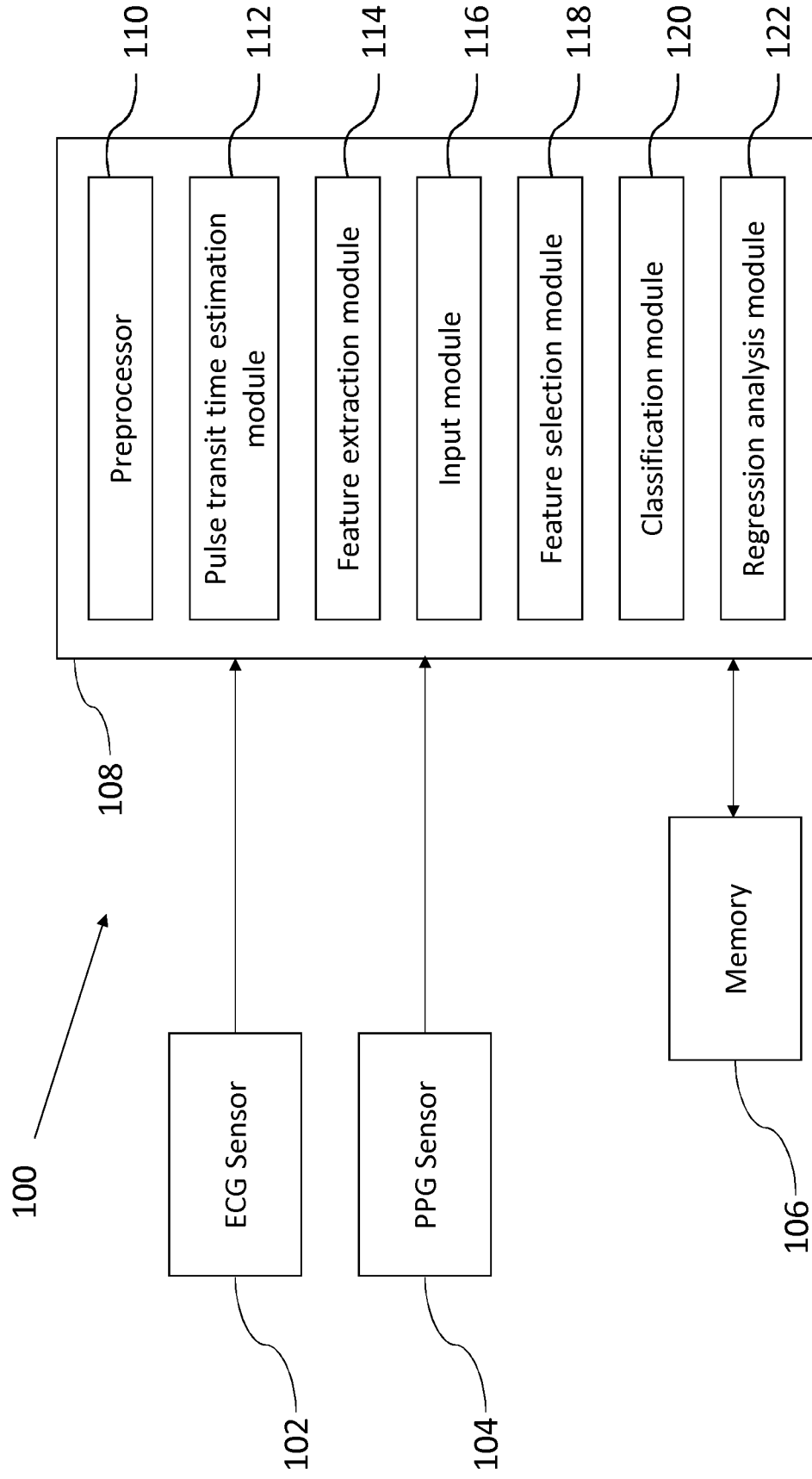
un capteur ECG (102) destiné à capturer un signal d'électrocardiogramme (ECG) de la personne ;
 un capteur PPG (104) destiné à capturer un signal de photopléthysmogramme (PPG) de la personne, dans
 lequel le signal PPG est synchronisé avec le signal ECG ;
 une mémoire (106) ; et
 un processeur (108) en communication avec la mémoire, dans lequel le processeur comprend en outre :

un préprocesseur (110) destiné à prétraiter le signal ECG et le signal PPG en vue d'éliminer une pluralité
 de bruits ;
 un module d'estimation de temps de transit du pouls (112) destiné à estimer un temps de transit du pouls
 (PTT) en utilisant le signal ECG et le signal PPG ;
 un module d'extraction de caractéristiques (114) destiné à extraire une pluralité de caractéristiques du
 signal PPG ;
 un module d'entrée (116) destiné à fournir le temps PTT et la pluralité de caractéristiques à un module de
 sélection de caractéristiques ;

un module de sélection de caractéristiques (118) destiné à appliquer un algorithme de sélection de caractéristiques en vue de sélectionner un ensemble de caractéristiques, dans lequel l'ensemble de caractéristiques est sélectionné de manière à maximiser la précision dans le cadre de la classification d'une classe de pression BP faible/normale par rapport à une classe de pression BP élevée ;
 un module de classification (120) destiné à classer le signal ECG, le signal PPG et le temps PTT dans la classe de pression BP élevée et la classe de pression BP faible/normale sur la base de l'ensemble de caractéristiques sélectionné ; et
 un module d'analyse de régression (122) destiné à mettre en oeuvre une analyse de régression sur le signal ECG, le signal PPG et le temps PTT correspondant à la classe de pression BP faible/normale en vue d'estimer la pression artérielle de la personne.

9. Support non transitoire lisible par ordinateur sur lequel est incorporé un programme informatique pour estimer une pression artérielle (BP) d'une personne, le procédé comprenant les étapes ci-dessous, mises en oeuvre par un processeur, consistant à :

capturer un signal d'électrocardiogramme (ECG) de la personne en faisant appel à un capteur ECG (102) ;
 capturer un signal de photopléthysmogramme (PPG) de la personne, en faisant appel à un capteur PPG (104), dans lequel le signal PPG est synchronisé avec le signal ECG ;
 prétraiter le signal ECG et le signal PPG en vue d'éliminer une pluralité de bruits ;
 estimer un temps de transit du pouls (PTT) en utilisant le signal ECG et le signal PPG ;
 extraire une pluralité de caractéristiques du signal PPG ;
 fournir le temps PTT et la pluralité de caractéristiques à un module de sélection de caractéristiques (118) ;
 appliquer un algorithme de sélection de caractéristiques en vue de sélectionner un ensemble de caractéristiques, dans lequel l'ensemble de caractéristiques est sélectionné de manière à maximiser la précision dans le cadre de la classification d'une classe de pression BP faible/normale par rapport à une classe de pression BP élevée ;
 classer les données correspondant au signal ECG, au signal PPG et au temps PTT dans la classe de pression BP élevée et dans la classe de pression BP faible/normale, sur la base de l'ensemble de caractéristiques sélectionné, en utilisant un module de classification (120) ; et
 mettre en oeuvre une analyse de régression sur le signal ECG, le signal PPG et le temps PTT, correspondant à la classe de pression BP faible/normale, en vue d'estimer la pression artérielle de la personne.

**FIG. 1**

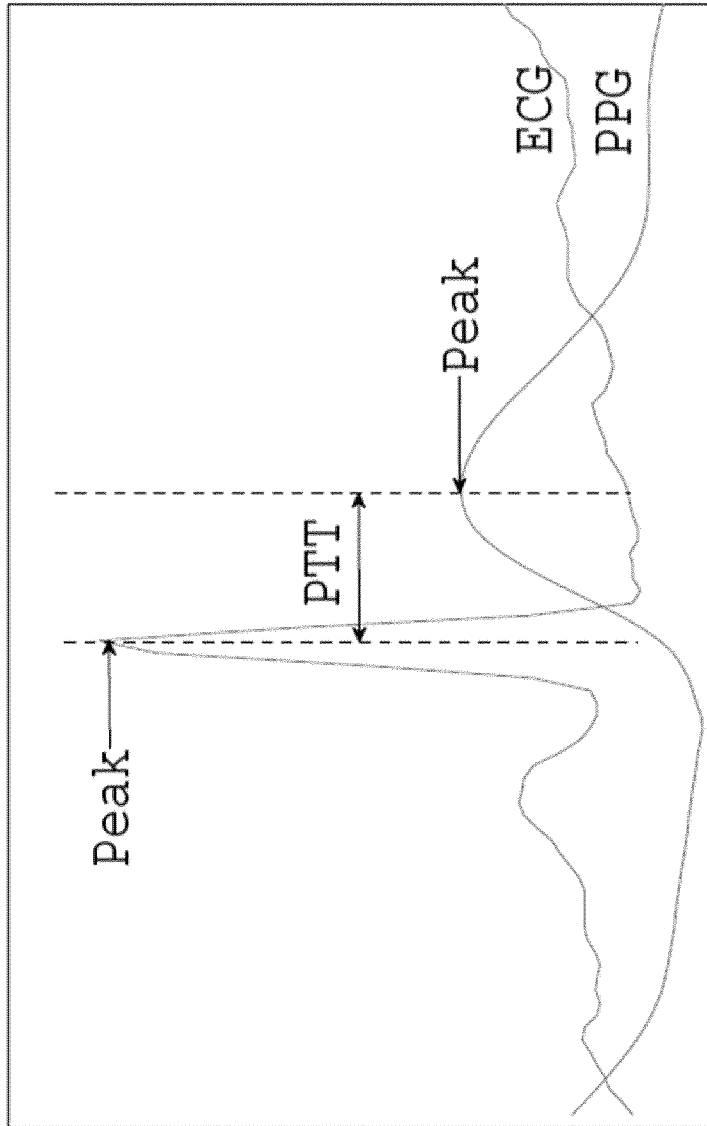
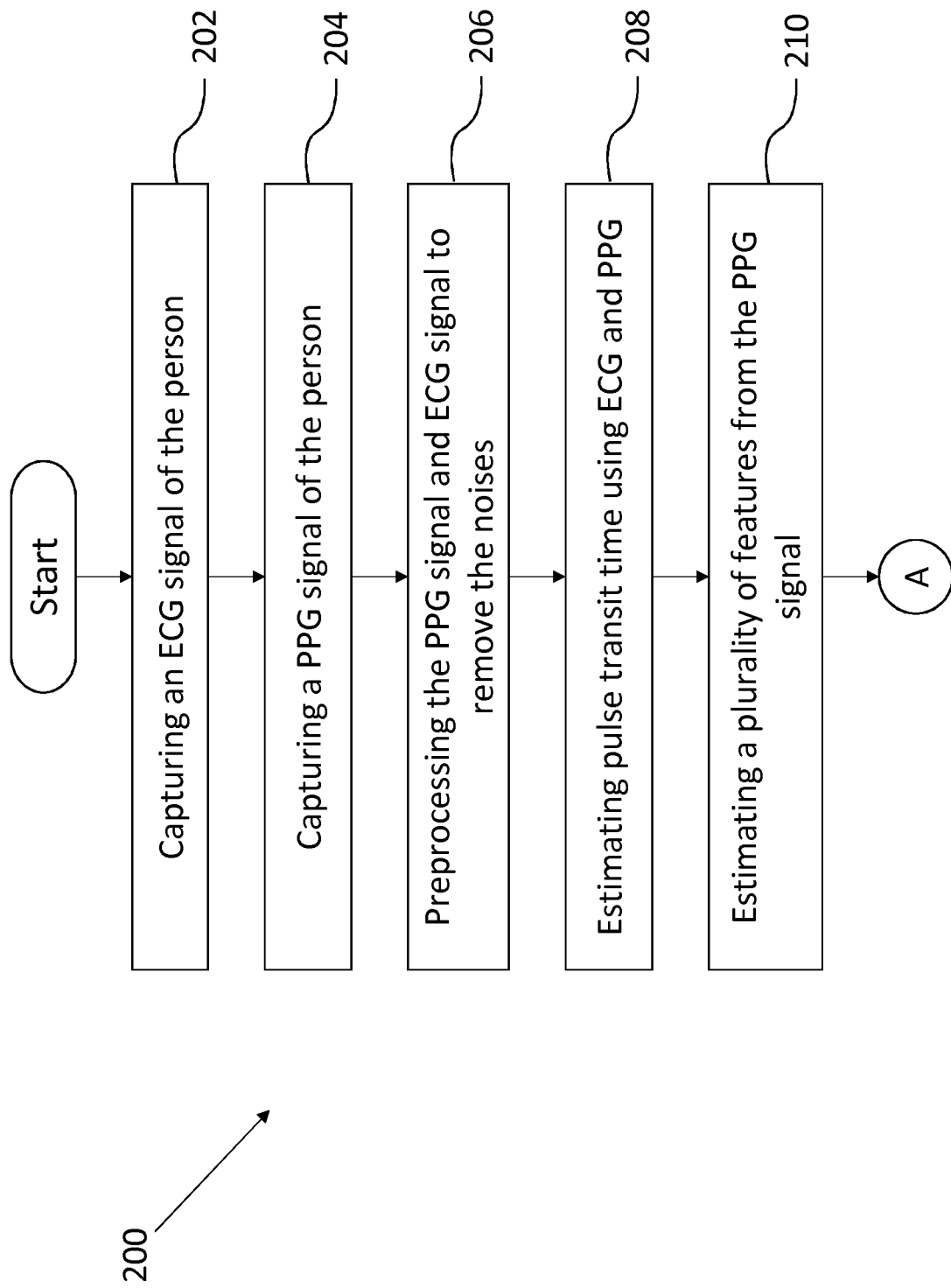


FIG. 2

**FIG. 3A**

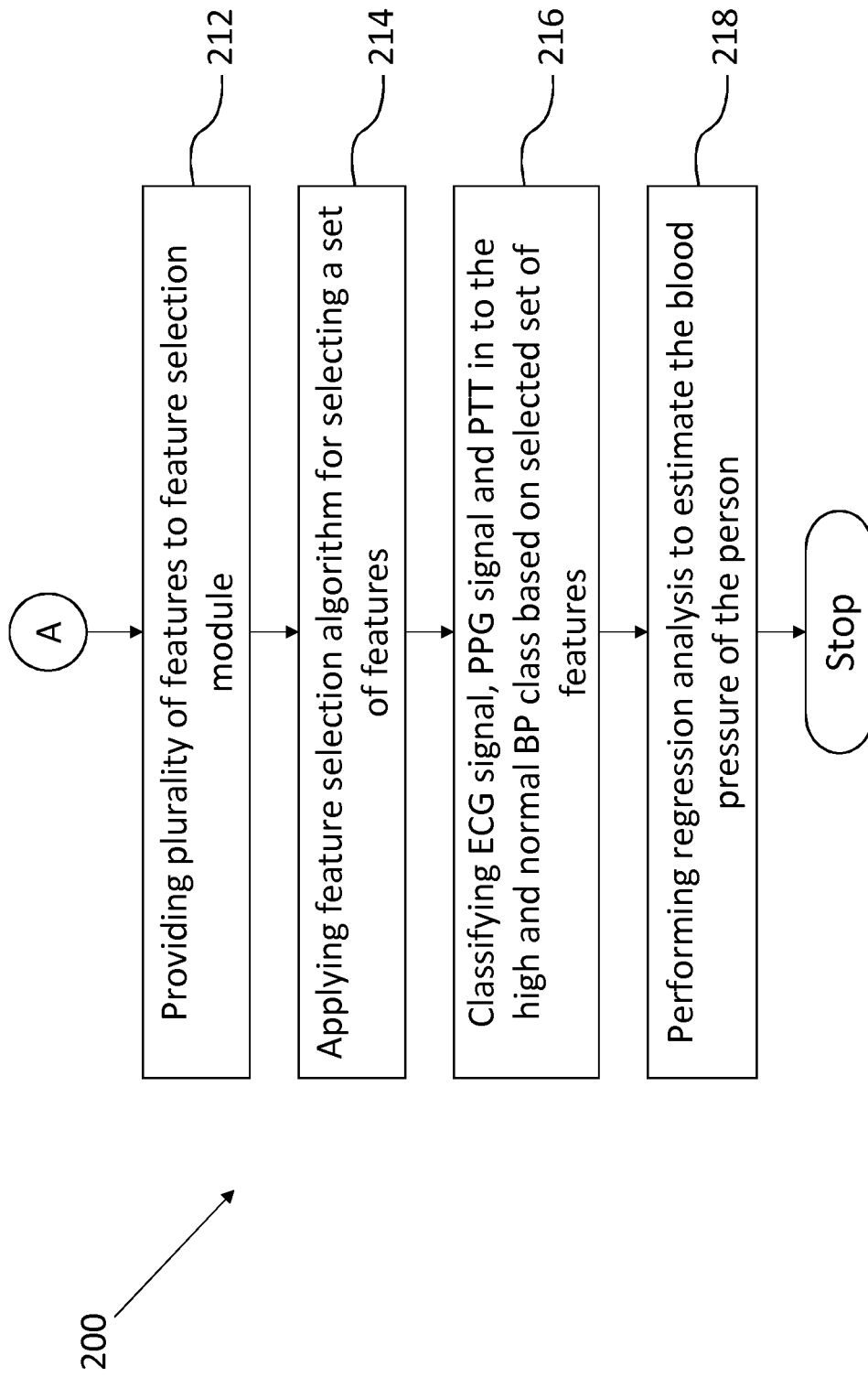


FIG. 3B

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- Improving the performance of continuous non-invasive estimation of blood pressure using ECG and PPG. **BOSE S SREE NIRANJANAA et al.** 2015 ANNUAL IEEE INDIA CONFERENCE (INDICON). IEEE, 17 December 2015 [0005]

专利名称(译)	光电容积特性和脉冲运行时间下的小球血液压力估计方法和系统		
公开(公告)号	EP3366203B1	公开(公告)日	2019-12-25
申请号	EP2018156830	申请日	2018-02-15
申请(专利权)人(译)	塔塔咨询服务有限公司		
当前申请(专利权)人(译)	塔塔咨询服务有限公司		
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IPC分类号	A61B5/021 A61B5/0456 A61B5/024 A61B5/00		
CPC分类号	A61B5/02125 A61B5/02416 A61B5/0456 A61B5/7264 G16H50/20 A61B5/0245 A61B5/7278 A61B5/7282		
其他公开文献	EP3366203A1		
外部链接	Espacenet		

摘要(译)

提供了一种用于人的血压 (BP) 估计的方法和系统。系统正在使用人的 ECG信号和PPG信号估计脉冲传播时间 (PTT)。从PPG中提取多个特征。提供多个PPG特征和PTT作为自动特征选择算法的输入。该算法选择适合于BP估计的一组特征。选定的要素将输入到分类器, 以将数据库分类为低/正常BP范围和高BP范围。然后使用正确分类的正常BP数据创建回归模型, 以根据所选特征预测BP。当前的方法使用自动特征选择机制, 并且还使用一个块来拒绝极端BP数据。因此, 预计预测BP的可用精度将比现有的BP估计方法更高。

$$\rho(x_i, x_j) = \frac{\text{Cov}(x_i, x_j)}{\sigma_{x_i} \sigma_{x_j}};$$