US 20190274552A1

(19) **United States**

(12) **Patent Application Publication**

(10) **Pub. No.: US 2019/0274552 A1**

(43) **Pub. Date: Sep. 12, 2019**

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(54) **APPARATUS AND METHOD FOR MEASURING BLOOD PRESSURE**

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(21) Appl. No.: **16/298,527**

(22) Filed: **Mar. 11, 2019**

(30) **Foreign Application Priority Data**

Mar. 12, 2018 (KR) 10-2018-0028683

Publication Classification

(51) **Int. Cl.**

A61B 5/021 (2006.01)
A61B 5/11 (2006.01)
A61B 5/00 (2006.01)

(52) **U.S. Cl.**

CPC ***A61B 5/021*** (2013.01); ***A61B 5/1102*** (2013.01); ***A61B 5/7278*** (2013.01); *A61B 2562/0252* (2013.01); ***A61B 5/721*** (2013.01); ***A61B 5/681*** (2013.01); *A61B 2562/0219* (2013.01); ***A61B 5/7253*** (2013.01)

(57) **ABSTRACT**

An apparatus for measuring blood pressure according to one aspect may include a limb ballistocardiogram (BCG) sensor configured to attach to a limb of a user and measure a limb BCG signal of the user, and a processor configured to extract blood pressure-related features from the measured limb BCG signal and estimate blood pressure of the user based on at least part of the extracted blood pressure-related features.

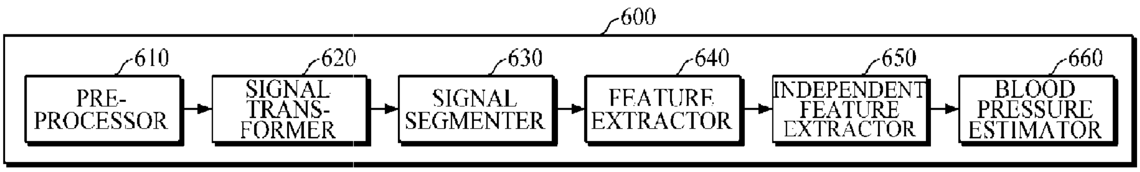


FIG. 1

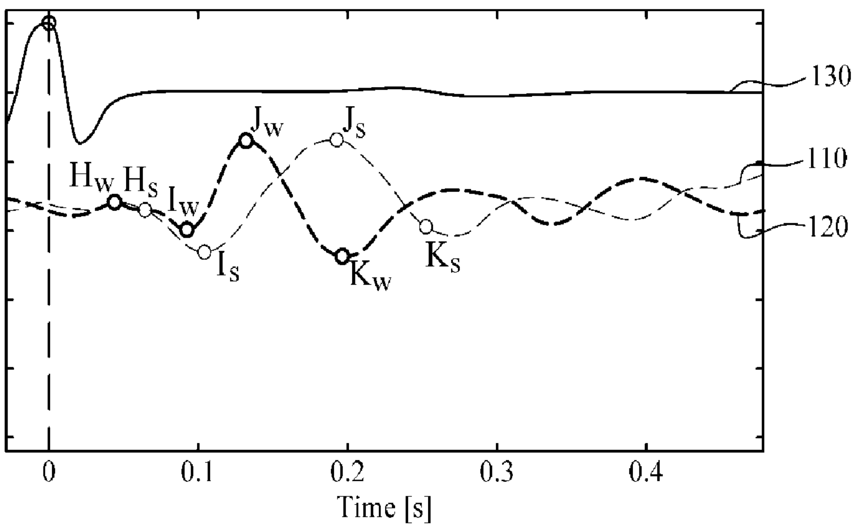


FIG. 2

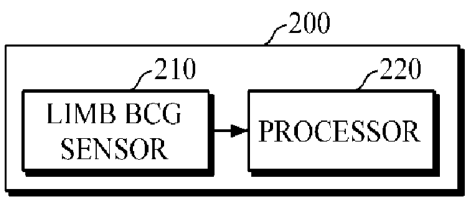


FIG. 3

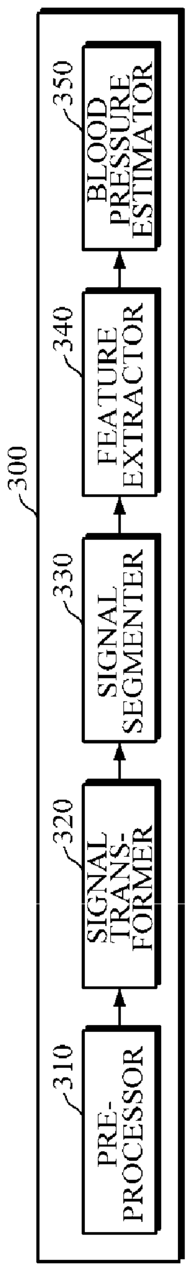

300
310
PRE-PROCESSOR
320
SIGNAL TRANS-FORMER
330
SIGNAL SEGMENTER
340
FEATURE EXTRACTOR
350
BLOOD PRESSURE ESTIMATOR

FIG. 4

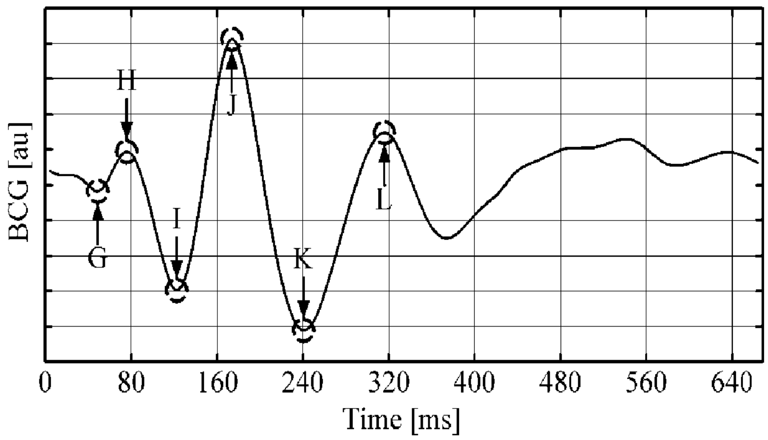


FIG. 5

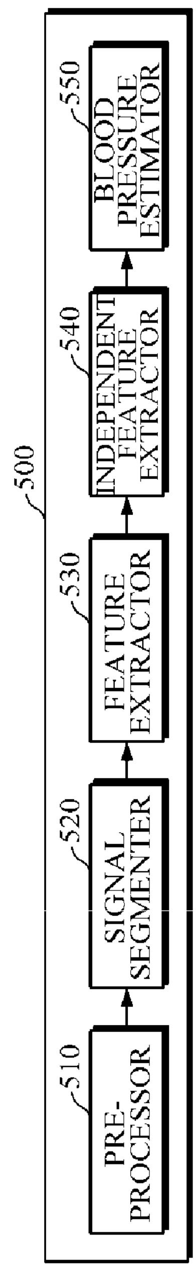

500
510
PRE-PROCESSOR
520
SIGNAL SEGMENTER
530
FEATURE EXTRACTOR
540
INDEPENDENT FEATURE EXTRACTOR
550
BLOOD PRESSURE ESTIMATOR

FIG. 6

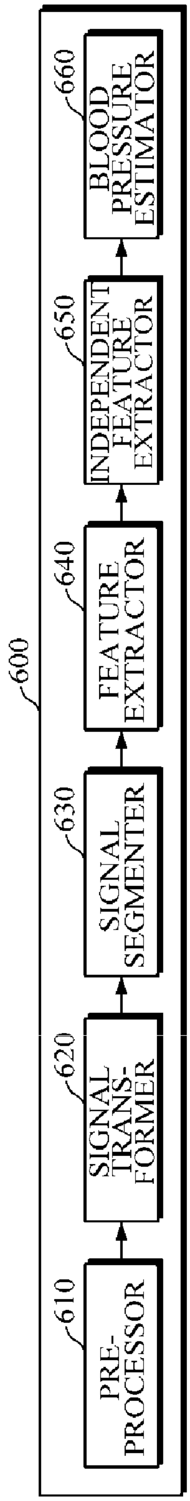

600
610
PRE-PROCESSOR
620
SIGNAL TRANS-FORMER
630
SIGNAL SEGMENTER
640
FEATURE EXTRACTOR
650
INDEPENDENT FEATURE EXTRACTOR
660
BLOOD PRESSURE ESTIMATOR

FIG. 7

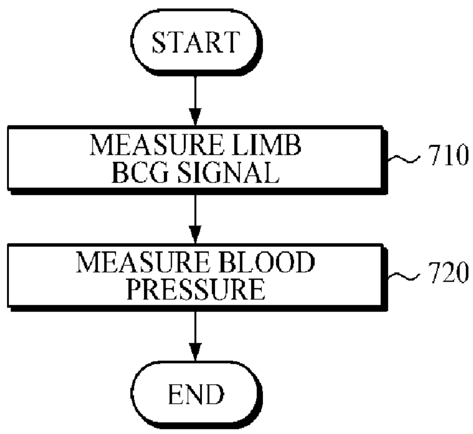

START
MEASURE LIMB BCG SIGNAL
710
MEASURE BLOOD PRESSURE
720
END

FIG. 8

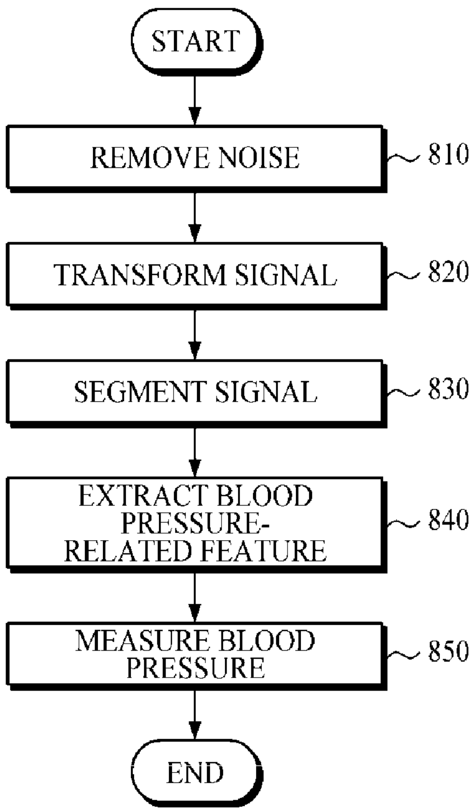

START
REMOVE NOISE
810
TRANSFORM SIGNAL
820
SEGMENT SIGNAL
830
EXTRACT BLOOD PRESSURE-RELATED FEATURE
840
MEASURE BLOOD PRESSURE
850
END

FIG. 9

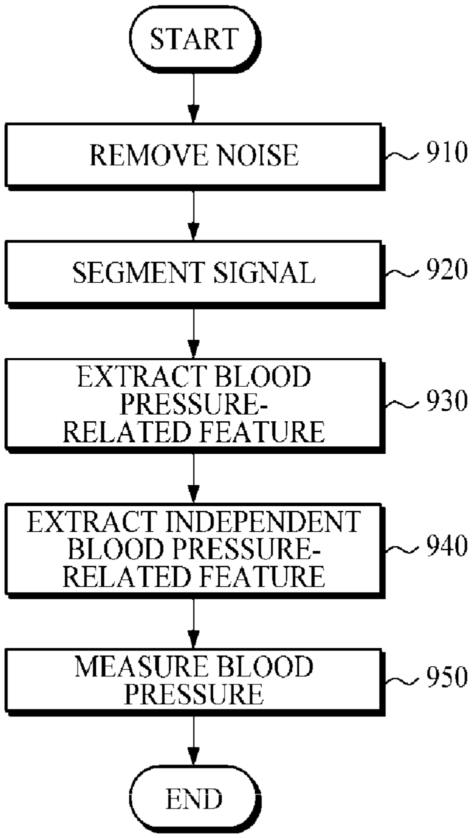

START
REMOVE NOISE
910
SEGMENT SIGNAL
920
EXTRACT BLOOD PRESSURE-RELATED FEATURE
930
EXTRACT INDEPENDENT BLOOD PRESSURE-RELATED FEATURE
940
MEASURE BLOOD PRESSURE
950
END

FIG. 10

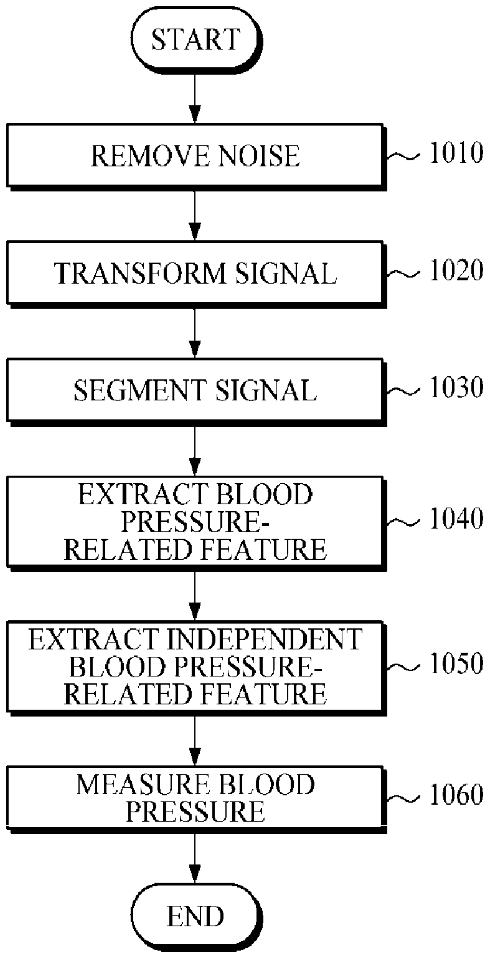

START
REMOVE NOISE
1010
TRANSFORM SIGNAL
1020
SEGMENT SIGNAL
1030
EXTRACT BLOOD PRESSURE-RELATED FEATURE
1040
EXTRACT INDEPENDENT BLOOD PRESSURE-RELATED FEATURE
1050
MEASURE BLOOD PRESSURE
1060
END

FIG. 11

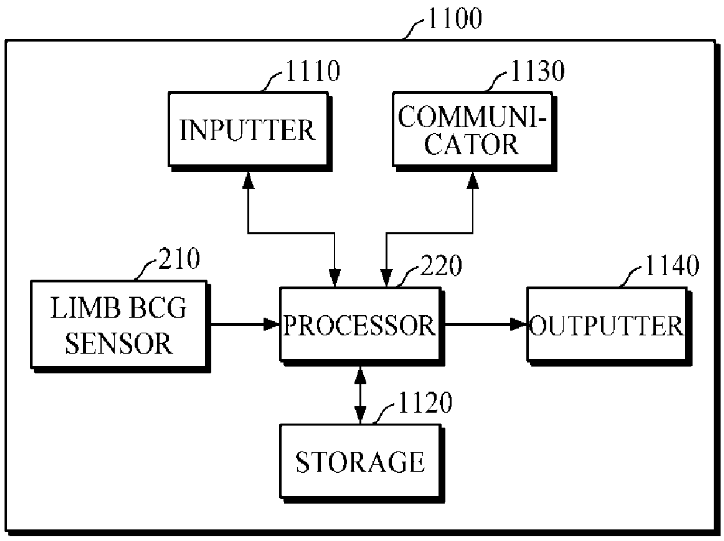
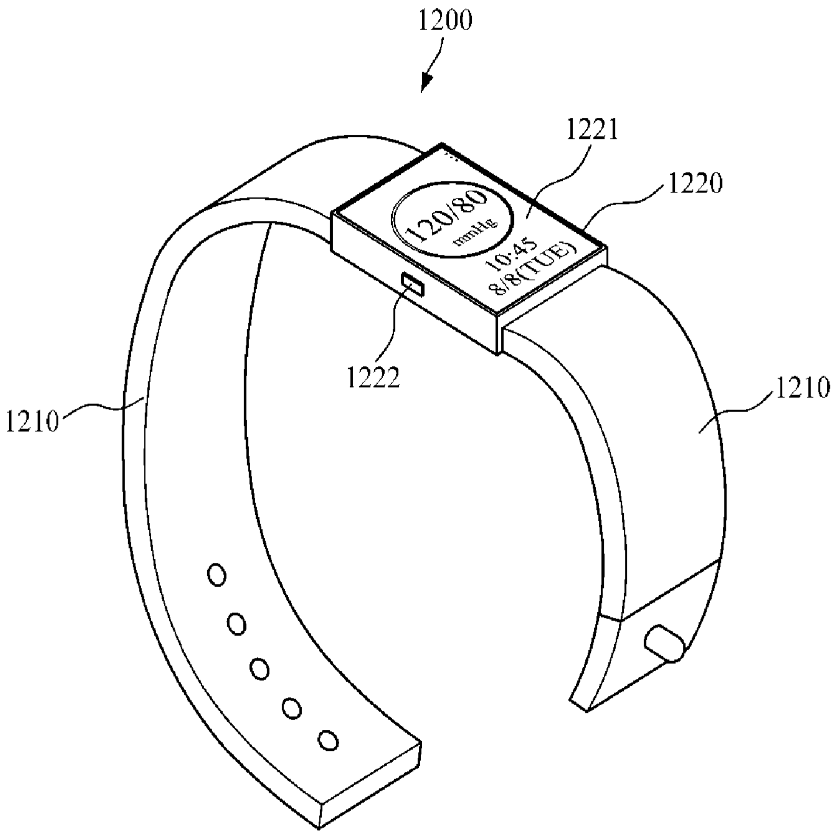

1100
1110
INPUTTER
1130
COMMUNI-
CATOR
210
LIMB BCG
SENSOR
220
PROCESSOR
1140
OUTPUTTER
1120
STORAGE

FIG. 12



APPARATUS AND METHOD FOR MEASURING BLOOD PRESSURE

CROSS-REFERENCE TO RELATED APPLICATION(S)

[0001] This application claims priority from Korean Patent Application No. 10-2018-0028683, filed on Mar. 12, 2018, in the Korean Intellectual Property Office, the entire disclosure of which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field

[0002] Apparatuses and methods consistent with exemplary embodiments relate to a cuffless blood pressure measurement technology.

2. Description of Related Art

[0003] Healthcare technology has attracted much attention due to the society's increasingly aging population and relevant social problems that accompany such societal changes, such as increase in medical expenses. Accordingly, medical devices that can be utilized by hospitals and inspection agencies as well as small-sized medical devices that can be carried by individuals such as wearable devices have been developed. In addition, a small-sized medical device may be worn by a user in the form of a wearable device capable of directly measuring cardiovascular health indicators such as a blood pressure or the like, so that the user can measure and manage her cardiovascular health status.

[0004] Therefore, recently, studies have been actively conducted on methods of estimating blood pressure by analyzing a bio-signal for the purpose of miniaturizing the size of a device and improving the accuracy of blood pressure estimation.

SUMMARY

[0005] One or more exemplary embodiments provide an apparatus and method for measuring blood pressure.

[0006] According to an aspect of an exemplary embodiment, there is provided an apparatus for measuring blood pressure, including: a limb ballistocardiogram (BCG) sensor configured to attach to a limb of a user and measure a limb BCG signal of the user; and a processor configured to extract blood pressure-related features from the measured limb BCG signal and estimate blood pressure of the user based on at least part of the extracted blood pressure-related features.

[0007] The limb BCG sensor may include at least one of an acceleration sensor, a load cell sensor, a polyvinylidene fluoride (PVDF) film sensor, and an electro mechanical film (EMFi) sensor.

[0008] The processor may include: a signal transformer configured to transform the measured limb BCG signal into a form of a whole-body BCG signal; a signal segmenter configured to segment the transformed limb BCG signal by each period to create a limb BCG signal segment; a feature extractor configured to extract at least one of the blood pressure-related features from the limb BCG signal segment; and a blood pressure estimator configured to estimate the blood pressure of the user based on the extracted at least one of the blood pressure-related features.

[0009] The signal transformer may be further configured to transform the measured limb BCG signal into the form of the whole-body BCG signal using at least one of an integrator and a personalized model that defines a relationship between the limb BCG signal and the whole-body BCG signal.

[0010] The feature extractor may be configured to extract characteristic points from the limb BCG signal segment and extract the at least one of the blood pressure-related features based on at least one of time intervals between the extracted characteristic points and amplitudes of the extracted characteristic points.

[0011] The feature extractor may be further configured to extract a maximum point and a minimum point of the limb BCG signal segment as the characteristic points.

[0012] The feature extractor may be further configured to determine a representative signal that represents the transformed limb BCG signal using the limb BCG signal segment and extract the at least one of the blood pressure-related features from the determined representative signal.

[0013] The processor may further include a preprocessor configured to remove noise from the measured limb BCG signal.

[0014] The processor may include: a signal segmenter configured to segment the measured limb BCG signal by each period to create a limb BCG signal segment; a feature extractor configured to extract at least one of the blood pressure-related features from the limb BCG signal segment; an independent feature extractor configured to extract at least one independent blood pressure-related feature from the extracted at least one of the blood pressure-related features; and a blood pressure estimator configured to estimate blood pressure of the user based on the extracted at least one independent blood pressure-related feature.

[0015] The independent feature extractor may be further configured to extract the at least one independent blood pressure-related feature from the extracted at least one of the blood pressure-related features using a dimensionality reduction method.

[0016] The processor may include: a signal transformer configured to transform the measured limb BCG signal into a form of a whole-body BCG signal; a signal segmenter configured to segment the transformed limb BCG signal by each period to create a limb BCG signal segment; a feature extractor configured to extract at least one of the blood pressure-related features from the limb BCG signal segment; an independent feature extractor configured to extract at least one independent blood pressure-related feature from the extracted at least one of the blood pressure-related features; and a blood pressure estimator configured to estimate blood pressure of the user based on the extracted at least one independent blood pressure-related feature.

[0017] According to an aspect of an exemplary embodiment, there is provided a method of measuring blood pressure, including: measuring a limb BCG signal of a user; extracting blood pressure-related features from the measured limb BCG signal; and estimating blood pressure of the user based on at least part of the extracted blood pressure-related features.

[0018] The extracting the blood pressure-related features may include: transforming the measured limb BCG signal into a form of a whole-body BCG signal; segmenting the transformed limb BCG signal by each period to create a limb BCG signal segment; extracting at least one of the blood pressure-related features from the limb BCG signal segment; and estimating blood pressure of the user based on the extracted at least one of the blood pressure-related features.

[0019] The transforming the measured limb BCG signal may include transforming the measured limb BCG signal into the form of the whole-body BCG signal using at least one of an integrator and a personalized model that defines a relationship between the limb BCG signal and the whole-body BCG signal.

[0020] The extracting the at least one of the blood pressure-related features may include extracting characteristic points from the limb BCG signal segment and extracting the at least one blood pressure-related features based on at least one of time intervals between the extracted characteristic points and amplitudes of the extracted characteristic points.

[0021] The extracting the characteristic points may include extracting a maximum point and a minimum point of the limb BCG signal segment as the characteristic points.

[0022] The extracting the at least one of the blood pressure-related features may include determining a representative signal that represents the transformed limb BCG signal using the limb BCG signal segment and extracting the at least one of the blood pressure-related features from the determined representative signal.

[0023] The extracting the blood pressure-related features may include segmenting the measured limb BCG signal by each period to generate a limb BCG signal segment; extracting at least one of the blood pressure-related features from the limb BCG signal segment; and extracting at least one independent blood pressure-related feature from the extracted at least one of the blood pressure-related features; and estimating blood pressure of the user based on the extracted at least one independent blood pressure-related feature.

[0024] The at least one independent blood pressure-related feature may be extracted using a dimensionality reduction method.

[0025] The extracting the blood pressure-related features may include: transforming the measured limb BCG signal into a form of a whole-body BCG signal; segmenting the transformed limb BCG signal by each period to create a limb BCG signal segment; extracting at least one of the blood pressure-related features from the limb BCG signal segment; and extracting at least one independent blood pressure-related feature from the extracted at least one of the blood pressure-related features.

[0026] Other features and aspects will be apparent from the following detailed description, the drawings, and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The above and/or other aspects will be more apparent by describing certain exemplary embodiments, with reference to the accompanying drawings, in which:

[0028] FIG. **1** is a graph showing examples of a whole-body ballistocardiogram (BCG) signal and a limb BCG signal;

[0029] FIG. **2** is a block diagram illustrating an apparatus for measuring blood pressure according to an exemplary embodiment;

[0030] FIG. **3** is a block diagram illustrating a processor according to an exemplary embodiment;

[0031] FIG. **4** is a graph for describing characteristic points;

[0032] FIG. **5** is a block diagram illustrating a processor according to another exemplary embodiment;

[0033] FIG. **6** is a block diagram illustrating a processor according to still another exemplary embodiment;

[0034] FIG. **7** is a flowchart illustrating a method of measuring blood pressure according to an exemplary embodiment;

[0035] FIG. **8** is a flowchart illustrating a process of estimating blood pressure according to an exemplary embodiment;

[0036] FIG. **9** is a flowchart illustrating a process of estimating blood pressure according to another exemplary embodiment;

[0037] FIG. **10** is a flowchart illustrating a process of estimating blood pressure according to still another exemplary embodiment;

[0038] FIG. **11** is a block diagram illustrating an apparatus for measuring blood pressure according to another exemplary embodiment; and

[0039] FIG. **12** is a diagram illustrating a wrist-wearable device.

DETAILED DESCRIPTION

[0040] Exemplary embodiments are described in greater detail below with reference to the accompanying drawings.

[0041] In the following description, like drawing reference numerals are used for like elements, even in different drawings. The matters defined in the description, such as detailed construction and elements, are provided to assist in a comprehensive understanding of the exemplary embodiments. However, it is apparent that the exemplary embodiments can be practiced without those specifically defined matters. Also, well-known functions or constructions are not described in detail since they might obscure the description with unnecessary detail.

[0042] It should be noted that in some alternative implementations, the functions, steps, actions noted in the blocks may occur out of the order noted in the flowcharts. For example, two blocks shown in succession may in fact be executed substantially concurrently or the blocks may sometimes be executed in the reverse order, depending upon the functionality or actions involved.

[0043] Terms described in below are selected by considering functions in the embodiment and meanings may vary depending on, for example, a user or operator's intentions or customs. Therefore, in the following embodiments, when terms are specifically defined, the meanings of terms should be interpreted based on definitions, and otherwise, should be interpreted based on general meanings recognized by those skilled in the art.

[0044] As used herein, the singular forms are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," or "includes" and/or "including" when used in this description, specify the presence of stated features, numbers, steps, operations, elements, components or combinations thereof, but do not preclude the presence or addition of one or more other features, numbers, steps, operations, elements, components or combinations thereof.

[0045] Expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list. For example, the expression, "at least one of a, b, and c," should be understood as including only a, only b, only c, both a and b, both a and c, both b and c, or all of a, b, and c.

[0046] It will also be understood that the elements or components in the following description are discriminated in accordance with their respective main functions. In other words, two or more elements may be made into one element or one element may be divided into two or more elements in accordance with a subdivided function. Additionally, each of the elements in the following description may perform a part or whole of the function of another element as well as its main function, and some of the main functions of each of the elements may be performed exclusively by other elements. Each element may be realized in the form of a hardware component (e.g., circuits, microchips, processors, etc.), a software component (e.g., instructions, programs, applications, firmware, etc.), and/or a combination thereof.

[0047] Throughout the drawings and the detailed description, unless otherwise described, the same drawing reference numerals will be understood to refer to the same elements, features, and structures. The relative size and depiction of these elements may be exaggerated for clarity, illustration, and convenience.

[0048] The word "exemplary" is used herein to mean "serving as an example or illustration." Any aspect or design described herein as "exemplary" is not to be construed as preferred or advantageous over other aspects or designs.

[0049] A whole-body ballistocardiogram (BCG) signal described in the present description refers to a vibration signal of the body which is caused by the heart rate, and a limb BCG signal may represent a skin vibration signal of the limbs or other body parts (e.g., wrists, ankles, a neck, forearms, etc.).

[0050] FIG. **1** is a graph showing examples of a whole-body BCG signal and a limb BCG signal. In FIG. **1**, the limb BCG signal **120** may be a wrist skin vibration signal measured at a wrist.

[0051] Referring to FIG. **1**, it can be seen that the whole-body BCG signal **110** and the limb BCG signal **120** have similar characteristic points (e.g., H, I, J, K, and the like), but exhibit different characteristics due to channel characteristics (e.g., compliant human body and the like). For example, as shown in FIG. **1**, it can be seen that, when the whole-body BCG signal **110** and the limb BCG signal **120** are beat-gated by an R-wave of an electrocardiogram (ECG) signal, characteristic points of the limb BCG signal **120** appear to be trailed by the whole-body BCG signal **110** and the time difference in which mutually corresponding characteristic points appear increases as the time elapses.

[0052] FIG. **2** is a block diagram illustrating an apparatus for measuring blood pressure according to an exemplary embodiment.

[0053] The apparatus **200** of FIG. **2** for measuring blood pressure may be implemented by a software module or manufactured in the form of a hardware chip and may be mounted in an electronic device. The electronic device may be a mobile phone, a smartphone, a tablet computer, a notebook computer, a personal digital assistant (PDA), a portable multimedia player (PMP), a navigation system, an MP3 player, a digital camera, a wearable device, and the like. The wearable device may be of a wristwatch type, a wrist band type, a belt type, a necklace type, an ankle band type, a thigh band type, a forearm band type, and the like. However, the electronic device and the wearable device are not limited to the above examples.

[0054] Referring to FIG. **2**, the apparatus **200** may include a limb BCG sensor **210** and a processor **220**.

[0055] The limb BCG sensor **210** may be attached to a limb or other body part of a user and may measure a limb BCG signal of the user. To this end, the limb BCG sensor **210** may include various types of sensors, such as an acceleration sensor, a load cell sensor, a polyvinylidene fluoride (PVDF) film sensor, and an electro mechanical film (EMFi) sensor, and the like. The limb or other body parts may include a wrist, an ankle, a neck, a forearm, and the like.

[0056] The processor **220** may control an overall operation of the apparatus **200**.

[0057] The processor **220** may periodically, or when a specific event such as a user command occurs, measure a limb BCG signal of the user by driving the limb BCG sensor **210**.

[0058] The processor **220** may extract features related to blood pressure by analyzing the limb BCG signal measured by the limb BCG sensor **210**, and estimate the user's blood pressure based on all or part of the extracted blood pressure-related features.

[0059] Hereinafter, the processor **220** of the present disclosure will be described in detail with reference to FIGS. **3** to **6**.

[0060] FIG. **3** is a block diagram illustrating a processor according to an exemplary embodiment, and FIG. **4** is a graph for describing characteristic points. The processor **300** of FIG. **3** may be an exemplary embodiment of the processor **220** of FIG. **2**.

[0061] Referring to FIG. **3**, the processor **300** may include a preprocessor **310**, a signal transformer **320**, a signal segmenter **330**, a feature extractor **340**, and a blood pressure estimator **350**. The various components and elements shown in FIG. **3** and other figures may be implemented with hardware, software, or a combination of both.

[0062] The preprocessor **310** may remove noise from a limb BCG signal. In this case, the preprocessor **310** may remove noise from the limb BCG signal using various noise removal techniques, such as filtering, smoothing, and the like.

[0063] The signal transformer **320** may transform the limb BCG signal into the form of a whole-body BCG signal.

[0064] According to an exemplary embodiment, the signal transformer **320** may transform the limb BCG signal into the form of whole-body BCG signal using a transfer function, such as an integrator or a differentiator. In this case, the type of transfer function may be determined according to the type of a sensor that measures the limb BCG signal (or a form (e.g., displacement, velocity, or acceleration) of the limb BCG signal. For example, when the limb BCG signal is measured by an acceleration sensor, the limb BCG signal may be transformed into the form of a whole-body BCG signal by integrating the limb BCG signal twice using an integrator.

[0065] According to another exemplary embodiment, the signal transformer **320** may transform the limb BCG signal into the form of a whole-body BCG signal using a personalized transfer function. In this case, the personalized transfer function, which is a personalized model that defines a relationship between limb BCG signals and whole-body BCG signals, may be constructed in advance through various model construction schemes (e.g., machine learning, regression analysis, and the like) based on a user's limb

BCG signal and whole-body BCG signal that are measured simultaneously and be stored in an internal or external database.

[0066] The signal segmenter **330** may generate a plurality of single-period signals by segmenting the transformed limb BCG signal by each period. In this case, the signal segmenter **330** may segment the transformed limb BCG signal by each period by analyzing a signal form of the transformed limb BCG signal itself, or segment the transformed limb BCG signal by each period based on a result of beat-gating of the limb BCG signal on the basis of another signal (e.g., ECG signal, photoplethysmogram (PPG) signal, and the like) measured simultaneously with the limb BCG signal.

[0067] The feature extractor **340** may extract characteristic points from the limb BCG signal segments. According to an exemplary embodiment, the feature extractor **340** may extract a maximum point and/or a minimum point of the limb BCG signal segment. For example, as shown in FIG. **4**, the feature extractor **340** may extract G, H, I, J, K, and L as characteristic points from the limb BCG signal segment. The characteristic points may be inflection points in the graph of FIG. **4**.

[0068] According to an exemplary embodiment, the feature extractor **340** may extract a characteristic point from each of the single-period signals, or determine a representative signal that represents limb BCG signals transformed based on a mutual similarity of a plurality of single-period signals and extract a characteristic point from the representative signal. For example, among the plurality of single-period signals, the feature extractor **340** may determine a single-period signal having the highest average similarity with other single-period signals as a representative signal, or determine an ensemble average of a predetermined number of single-period signals having a higher average similarity with other single-period signals as a representative signal. Alternatively, the feature extractor **340** may determine an ensemble average of two or more single-period signals having average similarities with other single-period signals greater than or equal to a predetermined threshold as a representative signal and then extract a maximum point and/or a minimum point of the determined representative signal as characteristic points. In this case, the feature extractor **340** may use various similarity calculation algorithms, such as Euclidean distance, Manhattan distance, cosine distance, Mahalanobis distance, Jaccard coefficient, extended Jaccard coefficient, Pearson's correlation coefficient, Spearman's correlation coefficient, and the like.

[0069] The feature extractor **340** may extract a blood pressure-related feature by combining time and/or amplitude of the extracted characteristic points. For example, referring to FIG. **4**, the feature extractor **340** may extract time interval between points G and H, time interval between points G and I, time interval between points G and J, time interval between points G and K, time interval between points G and L, time interval between points H and I, time interval between points H and J, time interval between points H and K, time interval between points H and L, time interval between points I and J, time interval between points I and K, time interval between points I and L, time interval between points J and K, time interval between points J and L, time interval between points K and L, a proportion of these time intervals, an amplitude of point G, an amplitude of point H, an amplitude of point I, an amplitude of point J, an amplitude of point K, an amplitude of point L, and a proportion of these amplitudes as the blood pressure-related features.

[0070] The blood pressure estimator **350** may estimate a user's blood pressure on the basis of the extracted blood pressure-related features. In this case, the blood pressure estimator **350** may use a feature-blood pressure model that defines a relationship between the blood pressure-related feature and blood pressure. The feature-blood pressure model may be constructed in advance using various model construction schemes (e.g., machine learning, regression analysis, and the like) and be stored in an internal or external database.

[0071] FIG. **5** is a block diagram illustrating a processor according to another exemplary embodiment. The processor **500** of FIG. **5** may be one exemplary embodiment of the processor **220** of FIG. **2**.

[0072] Referring to FIG. **5**, the processor **500** includes a preprocessor **510**, a signal segmenter **520**, a feature extractor **530**, an independent feature extractor **540**, and a blood pressure estimator **550**.

[0073] The preprocessor **510** may remove noise from a limb BCG signal. In this case, the preprocessor **510** may remove noise from a limb BCG signal using various noise removal techniques, such as filtering, smoothing, and the like.

[0074] The signal segmenter **520** may generate a plurality of single-period signals by segmenting the limb BCG signal by each period. In this case, the signal segmenter **520** may segment the limb BCG signal by each period by analyzing a signal form of the limb BCG signal itself, or transform a limb BCG signal by each period based on a result of beat-gating of the limb BCG signal with respect to another signal (e.g., ECG signal, PPG signal, and the like) measured simultaneously with the limb BCG signal.

[0075] The feature extractor **530** may detect a maximum point (e.g., a local maximum amplitude) and/or a minimum point (e.g., a local minimum amplitude) from the limb BCG signal segment and extract the detected maximum point and/or minimum point as characteristic points. In addition, the feature extractor **530** may extract a blood pressure-related features based on time intervals between the extracted characteristic and/or amplitudes of the extracted characteristic points (e.g., by combining the times and/or amplitudes of the extracted characteristic points).

[0076] The independent feature extractor **540** may extract a feature independently associated with blood pressure (hereinafter, referred to as an "independent blood pressure-related feature"). In this case, the independent feature extractor **540** may extract the independent blood pressure-related feature using a dimensionality reduction method. The dimensionality reduction method may include, but not limited to, principal component analysis (PCA), independent component analysis (ICA), linear discriminant analysis (LDA), canonical correlation analysis (CCA), singular value decomposition (SVD), non-negative matrix factorization (NMF), locality preserving projection (LPP), margin preserving projection (MPP), Fisher linear discriminant (FLD), and the like.

[0077] The blood pressure estimator **550** may estimate a blood pressure of the user on the basis of the extracted independent blood pressure-related feature. In this case, the blood pressure estimator **550** may use an independent feature-blood pressure model that defines a relationship between the independent blood pressure-related feature and blood pressure. The independent feature-blood pressure model may be constructed in advance using various model construction schemes (e.g., machine learning, regression analysis, and the like) and be stored in an internal or external database.

[0078] FIG. **6** is a block diagram illustrating a processor according to still another exemplary embodiment. The processor **600** of FIG. **6** may be one exemplary embodiment of the processor **220** of FIG. **2**.

[0079] Referring to FIG. **6**, the processor **600** includes a preprocessor **610**, a signal transformer **620**, a signal segmenter **630**, a feature extractor **640**, a feature extractor **640**, an independent feature extractor **650**, and a blood pressure estimator **660**.

[0080] The preprocessor **610** may remove noise from a limb BCG signal. In this case, the preprocessor **610** may remove noise from the limb BCG signal using various noise removal techniques, such as filtering, smoothing, and the like.

[0081] The signal transformer **620** may transform the limb BCG signal into the form of a whole-body BCG signal. For example, the signal transformer **620** may transform the limb BCG signal into the form of whole-body BCG signal using a transfer function, such as an integrator or a differentiator, or a personalized transfer function.

[0082] The signal segmenter **630** may generate a plurality of single-period signals by segmenting the transformed limb BCG signal by each period.

[0083] The feature extractor **640** may extract a maximum point (e.g., a local maximum amplitude) and/or a minimum point (e.g., a local minimum amplitude) from the limb BCG signal segment as characteristic points. In addition, the feature extractor **640** may extract a blood pressure-related features based on time intervals between the extracted characteristic and/or amplitudes of the extracted characteristic points (e.g., by combining the times and/or amplitudes of the extracted characteristic points).

[0084] The independent feature extractor **650** may extract an independent blood pressure-related feature among the extracted blood pressure-related features. In this case, the independent feature extractor **650** may extract the blood pressure-related feature using a dimensionality reduction method.

[0085] The blood pressure estimator **660** may estimate user's blood pressure on the basis of the extracted independent blood pressure-related feature. In this case, the blood pressure estimator **660** may use an independent feature-blood pressure model that defines a relationship between the independent blood pressure-related feature and blood pressure.

[0086] FIG. **7** is a flowchart illustrating a method of measuring blood pressure according to one exemplary embodiment. The method of measuring blood pressure of FIG. **7** may be performed by the apparatus **200** for measuring blood pressure of FIG. **2**.

[0087] Referring to FIGS. **2** and **7**, the apparatus **200** for measuring blood pressure may measure a limb BCG signal of a user in **710**. To this end, the apparatus **200** may include various types of sensors, such as an acceleration sensor, a load cell sensor, a PVDF film sensor, and an EMFi sensor, and the like.

[0088] The apparatus **200** may extract a blood pressure-related feature by analyzing the measured limb BCG signal and estimate the user's blood pressure on the basis of all or part of the extracted blood pressure-related feature in **720**.

[0089] FIG. **8** is a flowchart illustrating a process **720** of estimating blood pressure according to one exemplary embodiment.

[0090] Referring to FIGS. **2** and **8**, the apparatus **200** for measuring blood pressure may remove noise from a limb BCG signal in **810**. In this case, the apparatus **200** may use various noise removal techniques, such as filtering, smoothing, and the like.

[0091] The apparatus **200** may transform the limb BCG signal into the form of a whole-body BCG signal in **820**. For example, the apparatus **200** may transform the limb BCG signal into the form of whole-body BCG signal using a transfer function, such as an integrator or a differentiator, or a personalized transfer function.

[0092] The apparatus **200** may generate a plurality of single-period signal by segmenting the transformed limb BCG signal by each period in **830**.

[0093] The apparatus **200** may extract characteristic points from the limb BCG signal segment and extract blood pressure-related features based on time intervals between the extracted characteristic and/or amplitudes of the extracted characteristic points (e.g., by combining times and/or amplitudes of the extracted characteristic points). According to one exemplary embodiment, the apparatus **200** may extract characteristic points from each of the single-period signals, or determine a representative signal that represents limb BCG signals transformed based on a mutual similarity of a plurality of single-period signals and extract characteristic points from the representative signal.

[0094] The apparatus **200** may estimate the user's blood pressure on the basis of the extracted blood pressure-related feature in **850**. In this case, the apparatus **200** may use a feature-blood pressure model that defines a relationship between the blood pressure-related feature and blood pressure.

[0095] FIG. **9** is a flowchart illustrating a process **720** of estimating blood pressure according to another exemplary embodiment.

[0096] Referring to FIGS. **2** and **9**, the apparatus **200** may remove noise from a limb BCG signal in **910**. In this case, the apparatus **200** may use various noise removal techniques, such as filtering, smoothing, and the like.

[0097] The apparatus **200** may generate a plurality of single-period signals by segmenting the limb BCG signal by each period in **920**.

[0098] The apparatus **200** may extract characteristic points from the limb BCG signal segment and extract blood pressure-related features by combining times and/or amplitudes of the extracted characteristic points in **930**.

[0099] The apparatus **200** may extract an independent blood pressure-related feature among the extracted blood pressure-related features in **940**. In this case, the apparatus **200** may use a dimensionality reduction method.

[0100] The apparatus **200** may estimate the user's blood pressure on the basis of the extracted independent blood pressure-related feature in **950**. At this time, the apparatus **200** may use an independent feature-blood pressure model.

[0101] FIG. **10** is a flowchart illustrating a process **720** of estimating blood pressure according to still another exemplary embodiment.

[0102] Referring to FIGS. **2** and **10**, the apparatus **200** may remove noise from a limb BCG signal in **1010**. In this case, the apparatus **200** may use various noise removal techniques, such as filtering, smoothing, and the like.

[0103] The apparatus **200** may transform the limb BCG signal into the form of a whole-body BCG signal in **1020**. For example, the apparatus **200** may transform the limb BCG signal into the form of whole-body BCG signal using a transfer function, such as an integrator or a differentiator, or a personalized transfer function.

[0104] The apparatus **200** may generate a plurality of single-period signals by segmenting the limb BCG signal by each period in **1030**.

[0105] The apparatus **200** may extract characteristic points from the limb BCG signal segment and extract blood pressure-related features by combining times and/or amplitudes of the extracted characteristic points in **1040**.

[0106] The apparatus **200** may extract an independent blood pressure-related feature among the extracted blood pressure-related features in **1050**. In this case, the apparatus **200** may use a dimensionality reduction method.

[0107] The apparatus **200** may estimate the user's blood pressure on the basis of the extracted independent blood pressure-related feature in **1060**. At this time, the apparatus **200** may use an independent feature-blood pressure model.

[0108] FIG. **11** is a block diagram illustrating an apparatus for measuring blood pressure according to another exemplary embodiment.

[0109] Referring to FIG. **11**, an apparatus **1100** for measuring blood pressure includes a limb BCG sensor **210**, a processor **220**, an inputter **1110**, a storage **1120**, a communicator **1130**, and an outputter **1140**.

[0110] Here, the limb BCG sensor **210** and the processor **220** are the same as those described with reference to FIGS. **2** to **6**, and hence detailed descriptions thereof will be omitted.

[0111] The inputter **1110** may receive various operation signals from a user. According to one exemplary embodiment, the inputter **1110** may include a keypad, a dome switch, a resistive or capacitive touch pad, a jog wheel, a jog switch, a hardware button, and the like. In particular, when a touch pad has a layered structure with a display, this structure may be referred to as a touch screen.

[0112] Programs or instructions for operations of the apparatus **1110** may be stored in the storage **1120** and data input to and output from the apparatus **1110** may also be stored in the storage **1120**. In addition, data processed by the apparatus **1100** and data required by the apparatus **1100** to process data may be stored in the storage **1120**.

[0113] The storage **1120** may include at least one type of storage media, such as a flash memory, a hard disk type memory, a multimedia card micro type memory, a card-type memory (e.g., Secure Digital (SD) or xD-Picture Card memory), random access memory (RAM), static random access memory (SRAM), read-only memory (ROM), electrically erasable programmable read-only memory (EEPROM), programmable read-only memory (PROM), magnetic memory, and optical disk. In addition, the apparatus **1100** may operate an external storage medium, such as web storage providing a storage function of the storage **1120**.

[0114] The communicator **1130** may communicate with an external device. For example, the communicator **1130** may transmit data handled by the apparatus **1100** or processing result data of the apparatus **1100** to the external device or receive various pieces of data necessary or helpful for blood pressure estimation from the external device.

[0115] In this case, the external device may be medical equipment that uses the data handled by the apparatus **1100** or the processing result data of the apparatus **1100** or a printer or a display device to output a result. In addition, the external device may be a digital TV, a desktop computer, a mobile phone, a smartphone, a tablet computer, a notebook computer, a PDA, a PMP, a navigation system, an MP3 player, a digital camera, a wearable device, or the like, but is not limited thereto.

[0116] The communicator **1130** may communicate with the external device through various communication schemes, such as Bluetooth communication, Bluetooth low energy communication, near-field communication (NFC), wireless local area network (WLAN) communication, ZigBee communication, infrared data association (IrDA) communication, radio frequency identification communication, third generation (3G) communication, fourth generation (4G) communication, fifth generation (5G) communication, and the like. However, these are merely examples, and the communication scheme is not limited thereto.

[0117] The outputter **1140** may output the data handled by the apparatus **1100** or the processing result data of the apparatus **1100**. According to one exemplary embodiment, the outputter **1140** may output the data handled by the apparatus **1100** or the processing result data of the apparatus **1100** in at least one of visual, audible, and tactile manners. To this end, the outputter **1140** may include a display, a speaker, a vibrator, and the like.

[0118] FIG. **12** is a diagram illustrating a wrist-wearable device.

[0119] Referring to FIG. **12**, the wrist-wearable device **1200** includes a strap **1210** and a main body **1220**.

[0120] The strap **1210** may be composed of separate strap members that are connected to each side of the main body **1220** and capable of being coupled to each other, or may be integrally formed in the form of a smart band. The strap **1210** may be formed of a flexible member to wrap around the user's wrist such that the main body **1220** can be worn on the user's wrist.

[0121] The above-described apparatus **200** or **1100** for measuring blood pressure may be equipped inside the main body **1220**. In addition, a battery may be embedded in the main body **1220** to supply power to the wrist-wearable device **1200** and the apparatus **200** or **1100** for measuring blood pressure.

[0122] The wrist-wearable device **1200** may further include a display **1221** and an inputter **1222** which are mounted on the main body **1220**. The display **1221** may display data processed by the wrist-wearable device **1200** and the apparatus **200** or **1100** for measuring blood pressure and processing result data. The inputter **1222** may receive various operating signals from the user.

[0123] The embodiments may be implemented as computer-readable code in a computer-readable record medium. Code and code segments constituting the computer program may be implemented by a skilled computer programmer in the art. The computer-readable record medium includes all types of record media in which computer-readable data are stored. Examples of the computer readable record medium include a ROM, a RAM, a compact disc ROM (CD-ROM), a magnetic tape, a floppy disk, and an optical data storage. Further, the record medium may be implemented in the form of a carrier wave such as Internet transmission. In addition, the computer-readable record medium may be distributed to computer systems over a network, in which computer-readable code may be stored and executed in a distributed manner.

[0124] A number of examples have been described above. Nevertheless, it will be understood that various modifications may be made. For example, suitable results may be achieved if the described techniques are performed in a different order and/or if components in a described system, architecture, device, or circuit are combined in a different manner and/or replaced or supplemented by other components or their equivalents. Accordingly, other implementations are within the scope of the following claims.

What is claimed is:

1. An apparatus for measuring blood pressure, the apparatus comprising:
- a limb ballistocardiogram (BCG) sensor configured to attach to a limb of a user and measure a limb BCG signal of the user; and
- a processor configured to extract blood pressure-related features from the measured limb BCG signal and estimate a blood pressure of the user based on at least part of the extracted blood pressure-related features.

2. The apparatus of claim **1**, wherein the limb BCG sensor comprises at least one of an acceleration sensor, a load cell sensor, a polyvinylidene fluoride (PVDF) film sensor, and an electro mechanical film (EMFi) sensor.

3. The apparatus of claim **1**, wherein the processor comprises:
- a signal transformer configured to transform the measured limb BCG signal into a form of a whole-body BCG signal;
- a signal segmenter configured to segment the transformed limb BCG signal by each period to create a limb BCG signal segment;
- a feature extractor configured to extract at least one of the blood pressure-related features from the limb BCG signal segment; and
- a blood pressure estimator configured to estimate the blood pressure of the user based on the extracted at least one of the blood pressure-related features.

4. The apparatus of claim **3**, wherein the signal transformer is further configured to transform the measured limb BCG signal into the form of the whole-body BCG signal using at least one of an integrator and a personalized model that defines a relationship between the limb BCG signal and the whole-body BCG signal.

5. The apparatus of claim **3**, wherein the feature extractor is further configured to extract characteristic points from the limb BCG signal segment and extract the at least one of the blood pressure-related features based on at least one of time intervals between the extracted characteristic points and amplitudes of the extracted characteristic points.

6. The apparatus of claim **5**, wherein the feature extractor is further configured to extract a maximum point and a minimum point of the limb BCG signal segment as the characteristic points.

7. The apparatus of claim **3**, wherein the feature extractor is further configured to determine a representative signal that represents the transformed limb BCG signal using the limb BCG signal segment and extract the at least one of the blood pressure-related features from the determined representative signal.

8. The apparatus of claim **3**, wherein the processor further comprises a preprocessor configured to remove noise from the measured limb BCG signal.

9. The apparatus of claim **1**, wherein the processor comprises:
- a signal segmenter configured to segment the measured limb BCG signal by each period to create a limb BCG signal segment;
- a feature extractor configured to extract at least one of the blood pressure-related features from the limb BCG signal segment;
- an independent feature extractor configured to extract at least one independent blood pressure-related feature from the extracted at least one of the blood pressure-related features; and
- a blood pressure estimator configured to estimate the blood pressure of the user based on the extracted at least one independent blood pressure-related feature.

10. The apparatus of claim **9**, wherein the independent feature extractor is further configured to extract the at least one independent blood pressure-related feature from the extracted at least one of the blood pressure-related features using a dimensionality reduction method.

11. The apparatus of claim **1**, wherein the processor comprises:
- a signal transformer configured to transform the measured limb BCG signal into a form of a whole-body BCG signal;
- a signal segmenter configured to segment the transformed limb BCG signal by each period to create a limb BCG signal segment;
- a feature extractor configured to extract at least one of the blood pressure-related features from the limb BCG signal segment;
- an independent feature extractor configured to extract at least one independent blood pressure-related feature from the extracted at least one of the blood pressure-related features; and
- a blood pressure estimator configured to estimate the blood pressure of the user based on the extracted at least one independent blood pressure-related feature.

12. A method of measuring blood pressure, the method comprising:
- measuring a limb ballistocardiogram (BCG) signal of a user;
- extracting blood pressure-related features from the measured limb BCG signal; and
- estimating a blood pressure of the user based on at least part of the extracted blood pressure-related features.

13. The method of claim **12**, wherein the extracting the blood pressure-related features comprises:
- transforming the measured limb BCG signal into a form of a whole-body BCG signal;
- segmenting the transformed limb BCG signal by each period to create a limb BCG signal segment;
- extracting at least one of the blood pressure-related features from the limb BCG signal segment; and
- estimating the blood pressure of the user based on the extracted at least one of the blood pressure-related features.

14. The method of claim **13**, wherein the transforming the measured limb BCG signal comprises transforming the measured limb BCG signal into the form of the whole-body BCG signal using at least one of an integrator and a personalized model that defines a relationship between the limb BCG signal and the whole-body BCG signal.

15. The method of claim **13**, wherein the extracting the at least one of the blood pressure-related features comprises extracting characteristic points from the limb BCG signal segment and extracting the at least one of the blood pressure-related features based on at least one of time intervals between the extracted characteristic points and amplitudes of the extracted characteristic points.

16. The method of claim **15**, wherein the extracting the characteristic points comprises extracting a maximum point and a minimum point of the limb BCG signal segment as the characteristic points.

17. The method of claim **13**, wherein the extracting the at least one of the blood pressure-related features comprises determining a representative signal that represents the transformed limb BCG signal using the limb BCG signal segment and extracting the at least one of the blood pressure-related features from the determined representative signal.

18. The method of claim **12**, wherein the extracting the blood pressure-related features comprises:

segmenting the measured limb BCG signal by each period to generate a limb BCG signal segment;

extracting at least one of the blood pressure-related features from the limb BCG signal segment; and

extracting at least one independent blood pressure-related feature from the extracted at least one of the blood pressure-related features; and

estimating the blood pressure of the user based on the extracted at least one independent blood pressure-related feature.

19. The method of claim **18**, wherein the at least one independent blood pressure-related feature is extracted using a dimensionality reduction method.

20. The method of claim **12**, wherein the extracting the blood pressure-related features comprises:

transforming the measured limb BCG signal into a form of a whole-body BCG signal;

segmenting the transformed limb BCG signal by each period to create a limb BCG signal segment;

extracting at least one of the blood pressure-related features from the limb BCG signal segment; and

extracting at least one independent blood pressure-related feature from the extracted at least one of the blood pressure-related features.

* * * * *

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专利名称(译)	用于测量血压的装置和方法		
公开(公告)号	US20190274552A1	公开(公告)日	2019-09-12
申请号	US16/298527	申请日	2019-03-11
[标]申请(专利权)人(译)	三星电子株式会社 马里兰大学		
申请(专利权)人(译)	SAMSUNG ELECTRONICS CO.，LTD. 马里兰大学帕克分校		
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发明人	JANG, DAE GEUN KIM, YOUN HO YOUSEFIAN, PEYMAN HANN, JIN-OH SHIN, SUNGTAE MOUSAVI, AZIN SADAT		
IPC分类号	A61B5/021 A61B5/11 A61B5/00		
CPC分类号	A61B5/681 A61B5/721 A61B2562/0219 A61B2562/0252 A61B5/7253 A61B5/1102 A61B5/7278 A61B5/021 A61B5/7264 G16H50/20		
优先权	1020180028683 2018-03-12 KR		
外部链接	Espacenet USPTO		

摘要(译)

根据一个方面的用于测量血压的装置可以包括肢体心冲击描记器（BCG）传感器，其被配置为附接到用户的肢体并且测量用户的肢体BCG信号，以及处理器，被配置为从中提取血压相关的特征。测量的肢体BCG信号和基于提取的血压相关特征的至少一部分估计用户的血压。