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(19) **United States**(12) **Patent Application Publication**
SHIMUTA(10) **Pub. No.: US 2018/0263518 A1**(43) **Pub. Date: Sep. 20, 2018**(54) **PULSE WAVE TRANSIT TIME
MEASUREMENT DEVICE AND LIVING
BODY STATE ESTIMATION DEVICE***A61B 5/00* (2006.01)*A61B 5/021* (2006.01)(52) **U.S. CL.**CPC *A61B 5/02255* (2013.01); *A61B 5/0408*
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5/6822 (2013.01); *A61B 5/4806* (2013.01)(71) Applicant: **Murata Manufacturing Co., Ltd.**,
Nagaokakyo-shi (JP)(72) Inventor: **Toru SHIMUTA**, Nagaokakyo-shi (JP)(21) Appl. No.: **15/979,578**(22) Filed: **May 15, 2018****Related U.S. Application Data**(63) Continuation of application No. PCT/JP2016/
080796, filed on Oct. 18, 2016.(30) **Foreign Application Priority Data**

Nov. 17, 2015 (JP) 2015-225209

Publication Classification(51) **Int. Cl.***A61B 5/0225* (2006.01)*A61B 5/0408* (2006.01)(57) **ABSTRACT**

A pulse wave transit time measurement device includes a pulse wave transit time calculator that calculates a pulse wave transit time based on a peak time difference between an electrocardiographic signal and a pulse wave signal, a posture classifier that classifies time serial data of the pulse wave transit time based on a posture detected by an acceleration sensor, and a fluctuation identifier that sets a reference posture from among classified postures, corrects, in conformity with the reference posture, the time serial data of the pulse wave transit time classified into the posture different from the reference posture, and determines fluctuations in the pulse wave transit time based on the time serial data of the pulse wave transit time in the reference posture and the time serial data of the pulse wave transit time having been corrected.

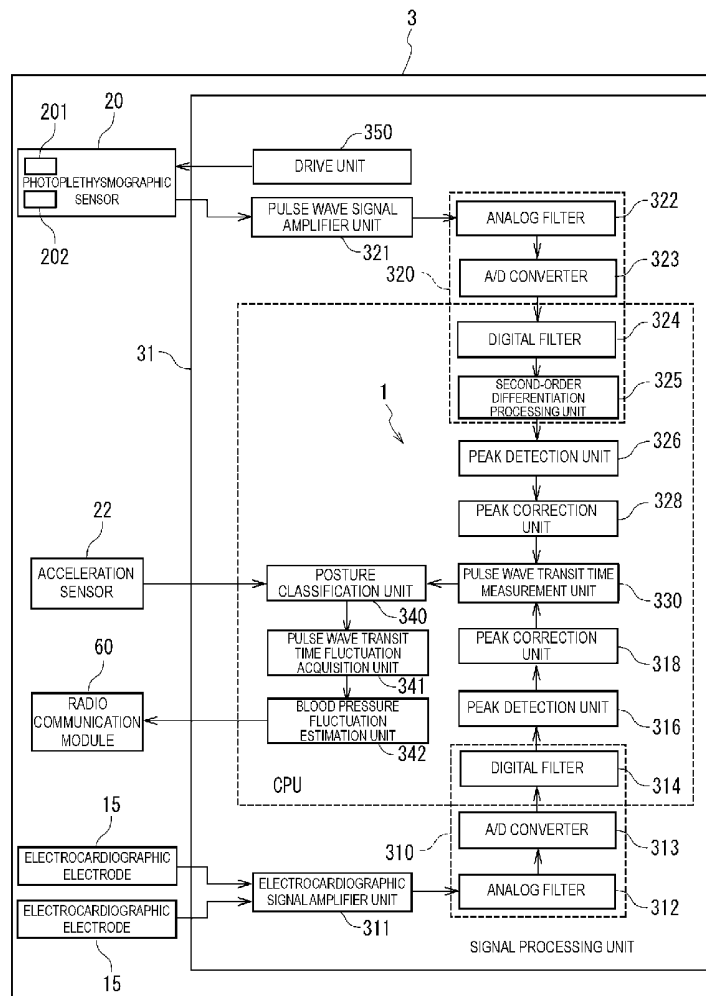


FIG. 1

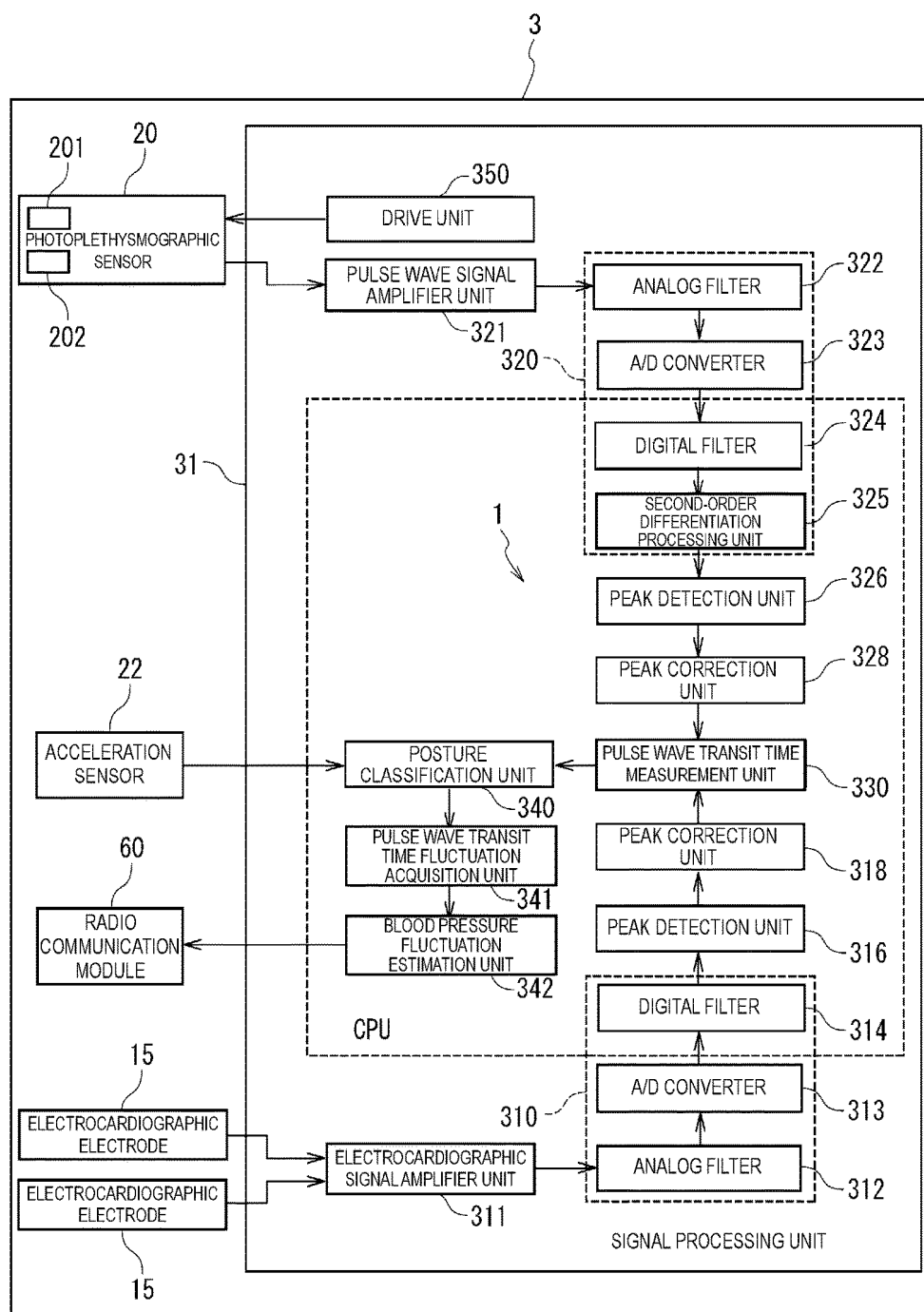


FIG. 2

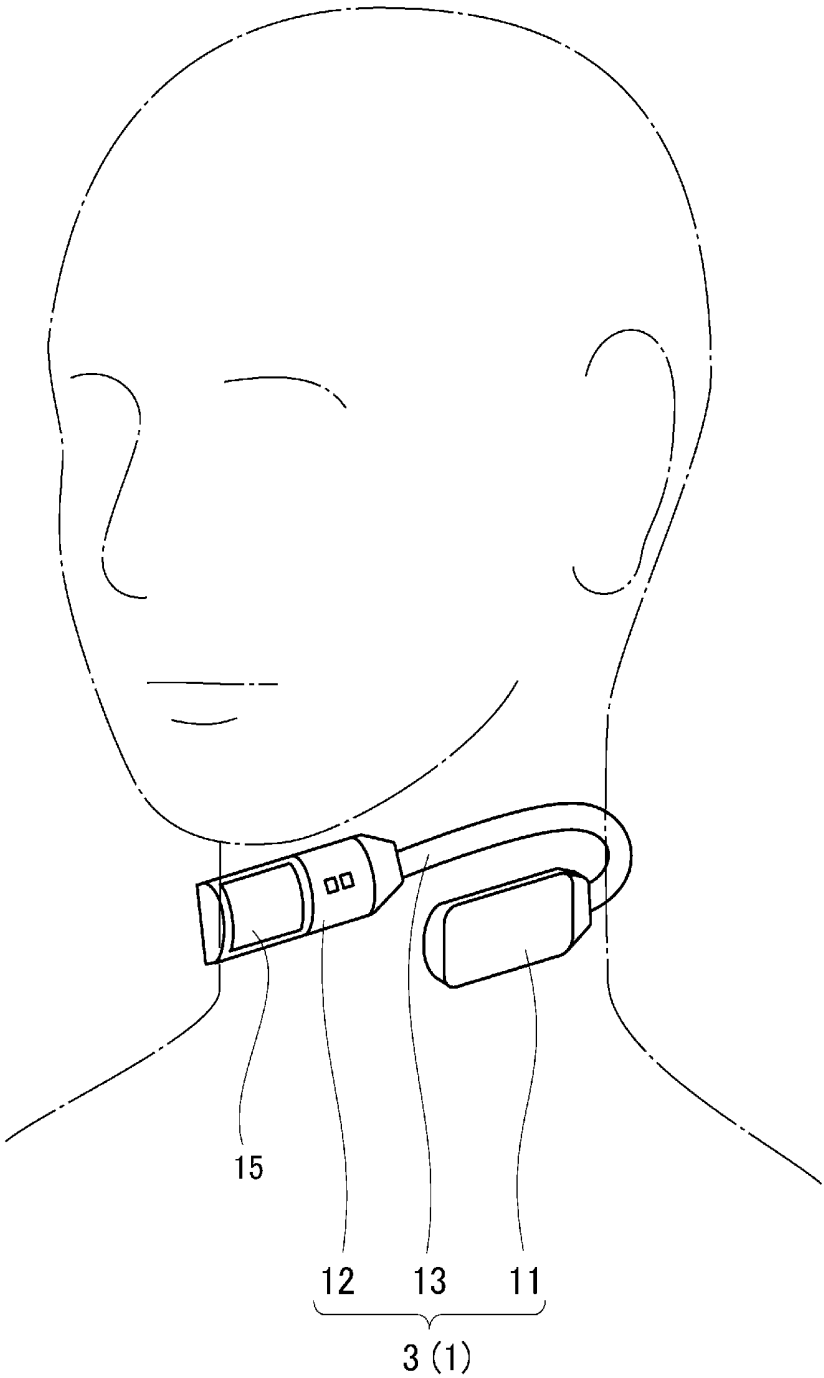


FIG. 3

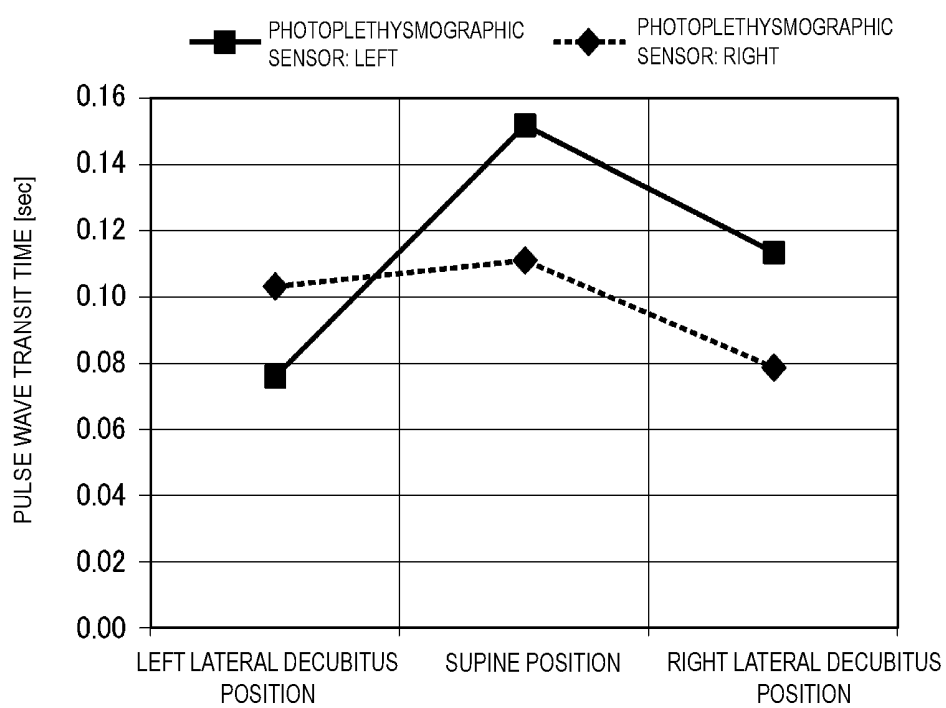


FIG. 4

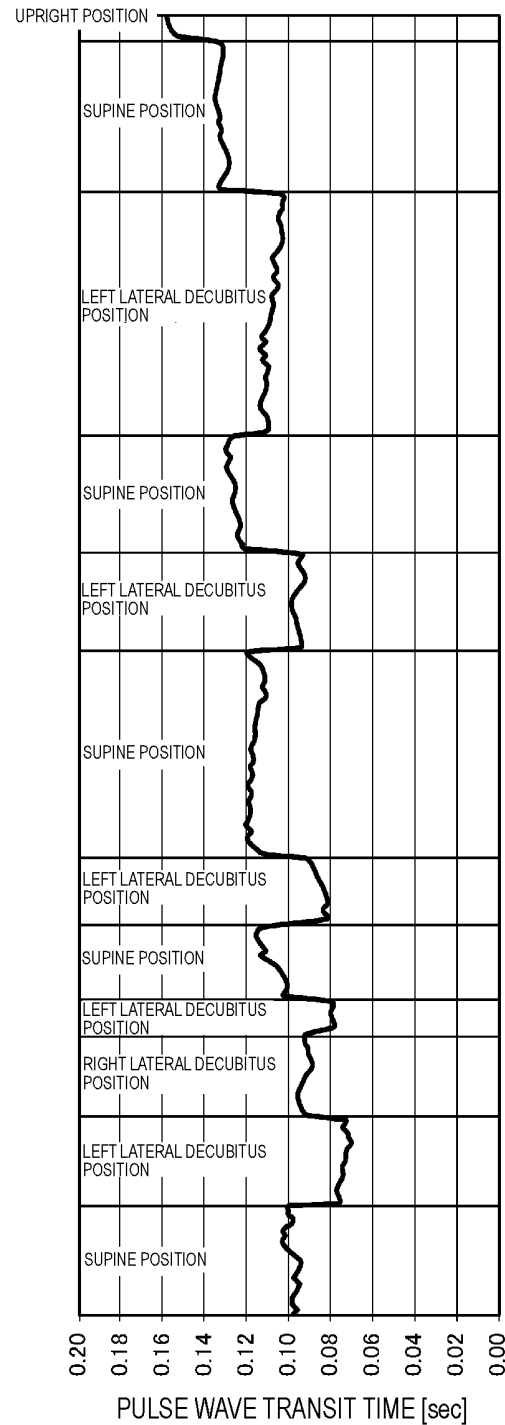


FIG. 5

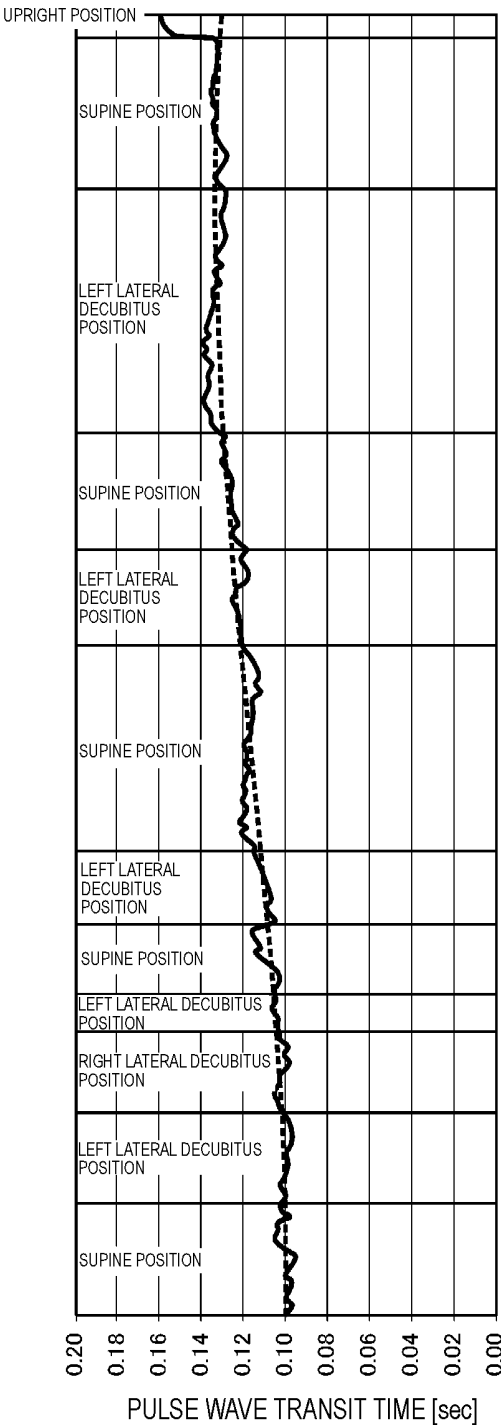
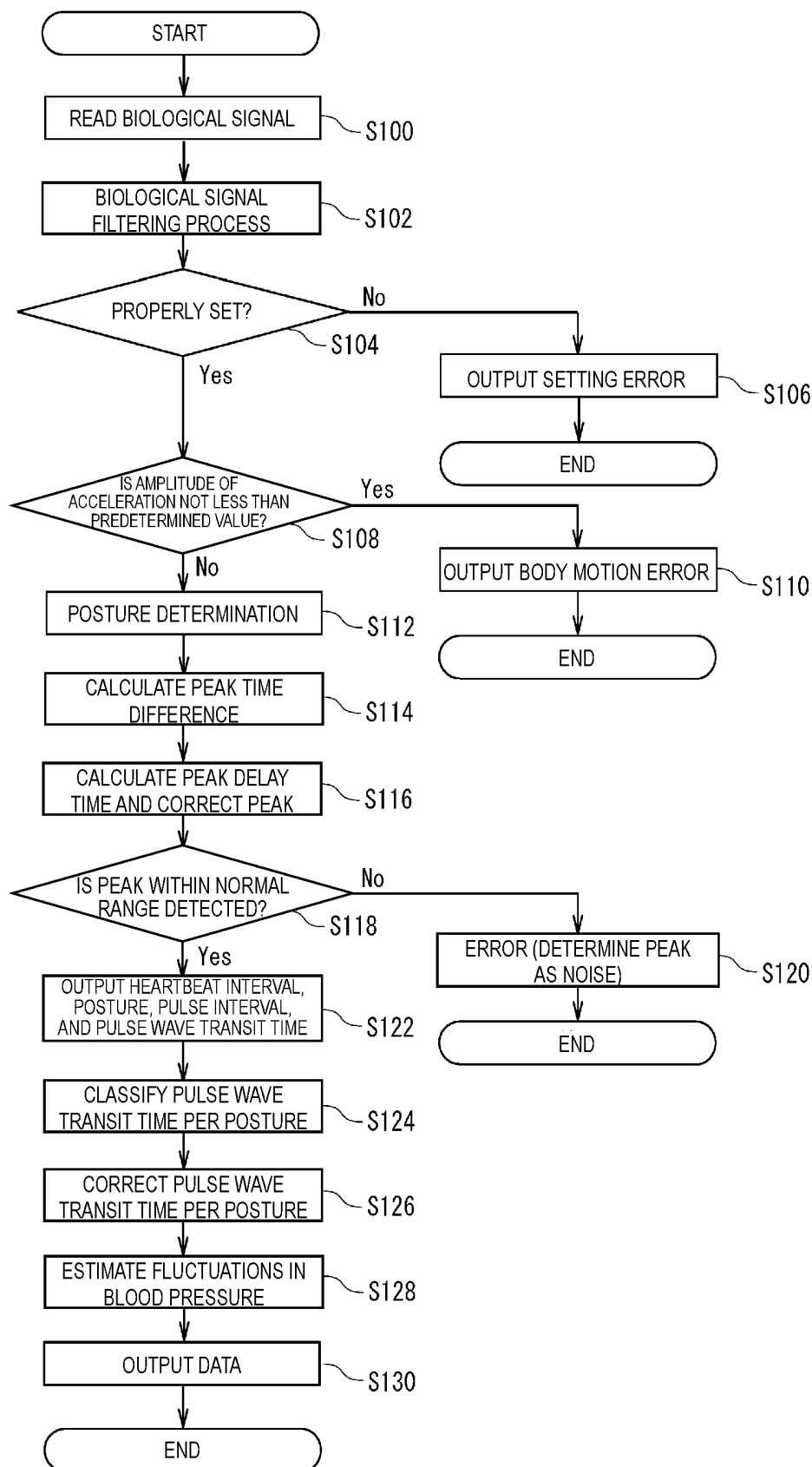


FIG. 6



**PULSE WAVE TRANSIT TIME
MEASUREMENT DEVICE AND LIVING
BODY STATE ESTIMATION DEVICE**

**CROSS REFERENCE TO RELATED
APPLICATIONS**

[0001] This application claims the benefit of priority to Japanese Patent Application No. 2015-225209 filed on Nov. 17, 2015 and is a Continuation Application of PCT Application No. PCT/JP2016/080796 filed on Oct. 18, 2016. The entire contents of each application are hereby incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates to a pulse wave transit time measurement device that measures a pulse wave transit time, and to a living body state estimation device including the pulse wave transit time measurement device.

2. Description of the Related Art

[0003] Recently, a pulse wave transit time representing a time taken for a pulse wave to transit in arteries inside a living body (e.g., a time from an R wave to the appearance of a pulse wave in an electrocardiogram) and reflecting change of blood pressure has been used as an index in, for example, evaluation of arterial stiffness and estimation of a vascular lifetime.

[0004] Japanese Unexamined Patent Application Publication No. 2014-105 discloses a technique of calculating a systolic blood pressure from a pulse wave transit time (i.e., a noninvasive continuous blood-pressure monitoring device). According to the disclosed technique, the pulse wave transit time is determined from biological signals obtained by a living body detection sensor (i.e., a pulse wave detection unit (PPG detection unit)) and an electrocardiographic detection unit (i.e., an ECG detection unit) both set on a subject, and the systolic blood pressure is calculated using the determined pulse wave transit time and a blood pressure calculation formula. In addition, according to the disclosed technique, not only fluctuations in blood pressure, but also a posture and a motion of the subject is able to be monitored at the same time by setting a 3-axis acceleration detection sensor on the subject, detecting the posture and the motion of the subject from detected data, and by simultaneously obtaining blood pressure data and motion data of the subject in the time series.

[0005] According to the technique (noninvasive continuous blood-pressure monitoring device) disclosed in Japanese Unexamined Patent Application Publication No. 2014-105, as described above, not only the fluctuations in the blood pressure (fluctuations in the pulse wave transit time), but also the posture and the motion of the subject are able to be monitored at the same time by calculating the blood pressure from the calculated pulse wave transit time while concurrently detecting the posture and the motion of the subject.

[0006] A value of the pulse wave transit time fluctuates based on the posture of the subject (user) and the measurement location. However, this factor is not taken into consideration in the technique (noninvasive continuous blood-pressure monitoring device) disclosed in Japanese Unexamined Patent Application Publication No. 2014-105.

Accordingly, when the posture of the user is changed during the measurement of the pulse wave transit time (e.g., during sleep) as represented, for example, in the case of continuously measuring the pulse wave transit time for a comparatively long time (e.g., for several hours) and checking a trend of the fluctuations in the pulse wave transit time, the measured pulse wave transit time is changed before and after the change of the posture (for instance, if the user rolls over in sleep, the measured pulse wave transit time is changed between before and after the rolling-over in sleep). Thus, the fluctuations in the pulse wave transit time (fluctuations in the blood pressure in Japanese Unexamined Patent Application Publication No. 2014-105) cannot be measured accurately.

SUMMARY OF THE INVENTION

[0007] Preferred embodiments of the present invention provide pulse wave transit time measurement devices each capable of continuously measuring fluctuations in pulse wave transit time with higher accuracy even when a posture of a user is changed during measurement of the pulse wave transit time, and living body state estimation devices each including the pulse wave transit time measurement device.

[0008] A pulse wave transit time measurement device according to a preferred embodiment of the present invention includes a pulse wave transit time calculator that calculates a pulse wave transit time based on a peak time difference between an electrocardiographic signal and a pulse wave signal, a posture detector that detects a posture of a user when the pulse wave transit time is calculated by the pulse wave transit time calculator, a classifier that classifies time serial data of the calculated pulse wave transit time for each posture based on the posture detected by the posture detector, and a fluctuation identifier that determines fluctuations in the pulse wave transit time based on the time serial data of the pulse wave transit time having been classified for each posture by the classifier.

[0009] With a pulse wave transit time measurement device according to a preferred embodiment of the present invention, the time serial data of the calculated pulse wave transit time is classified for each posture, and the fluctuations in the pulse wave transit time are determined based on the time serial data of the pulse wave transit time having been classified for each posture. Therefore, it is possible to determine, for each posture, whether obtained data, i.e., the time serial data of the pulse wave transit time, is to be used or not, and to correct the obtained data. As a result, even when the posture of the user is changed during the measurement of the pulse wave transit time, the fluctuations in the pulse wave transit time are able to be continuously calculated with higher accuracy.

[0010] In a pulse wave transit time measurement device according to a preferred embodiment of the present invention, preferably, the fluctuation identifier sets a reference posture from among the classified postures, corrects, in conformity with the reference posture, the time serial data of the pulse wave transit time having been classified into the posture different from the reference posture, and determines the fluctuations in the pulse wave transit time based on both the time serial data of the pulse wave transit time in the reference posture and the time serial data of the pulse wave transit time having been corrected.

[0011] In the above case, the reference posture is set from among the classified postures, and the time serial data of the pulse wave transit time having been classified into the

posture different from the reference posture is corrected in conformity with the reference posture. The fluctuations in the pulse wave transit time are then determined based on both of the time serial data of the pulse wave transit time in the reference posture and the time serial data of the pulse wave transit time having been corrected (after the correction). In other words, when the posture of the user is changed during the measurement of the pulse wave transit time, the time serial data of the pulse wave transit time having been classified into the posture different from the reference posture is corrected in conformity with the reference posture, that is, in such a manner as to provide the time serial data on the assumption that the relevant time serial data is obtained in the reference posture. As a result, even when the posture of the user is changed during the measurement of the pulse wave transit time, the fluctuations in the pulse wave transit time are able to be continuously determined with higher accuracy.

[0012] In a pulse wave transit time measurement device according to a preferred embodiment of the present invention, preferably, the fluctuation identifier sets, as the reference posture, the posture in which a time of the time serial data of the calculated pulse wave transit time is longest.

[0013] In the above case, the posture in which the time span of the time serial data of the calculated pulse wave transit time is longest is set as the reference posture. Therefore, a ratio of the time serial data requiring the correction to all of the time serial data of the calculated pulse wave transit time is able to be reduced. As a result, the fluctuations in the pulse wave transit time are able to be determined with higher accuracy, and a processing load required for the correction is reduced.

[0014] In a pulse wave transit time measurement device according to a preferred embodiment of the present invention, preferably, the fluctuation identifier corrects the time serial data of the pulse wave transit time for each posture such that a correlation coefficient of an approximation curve resulting from approximating the time serial data of the pulse wave transit time for each posture with a curve is increased, and determines the fluctuations in the pulse wave transit time from the time serial data after the correction.

[0015] In this case, the time serial data of the pulse wave transit time for each posture is corrected such that the correlation coefficient of the approximation curve is increased. The fluctuations in the pulse wave transit time are then determined from the time serial data after the correction. Therefore, the time serial data of the pulse wave transit time having been classified into the posture different from the reference posture is able to be appropriately corrected in conformity with the reference posture, that is, to provide the time serial data on the assumption that the relevant time serial data is obtained in the reference posture.

[0016] In a pulse wave transit time measurement device according to a preferred embodiment of the present invention, preferably, the fluctuation identifier determines the fluctuations in the pulse wave transit time based on, among all of the classified time serial data of the pulse wave transit time, only the time serial data of the pulse wave transit time corresponding to a predetermined posture.

[0017] In this case, the fluctuations in the pulse wave transit time are determined based on, among all of the classified time serial data of the pulse wave transit time, only the time serial data of the pulse wave transit time corresponding to the predetermined posture. Thus, when the

posture of the user is changed during the measurement of the pulse wave transit time, the fluctuations in the pulse wave transit time are determined after excluding, from the obtained data, the time serial data of the pulse wave transit time having been classified into the posture different from the predetermined posture. As a result, the fluctuations in the pulse wave transit time are able to be accurately determined even when the posture of the user is changed during the measurement of the pulse wave transit time.

[0018] In a pulse wave transit time measurement device according to a preferred embodiment of the present invention, preferably, the classifier classifies the time serial data of the pulse wave transit time for each of the postures including at least an upright position, an inverted position, a supine position, a left lateral decubitus position, a right lateral decubitus position, and a prone position.

[0019] In this case, the time serial data of the pulse wave transit time is classified for each of the postures including at least the upright position, the inverted position, the supine position, the left lateral decubitus position, the right lateral decubitus position, and the prone position. Therefore, the posture during the measurement of the pulse wave transit time is able to be classified more precisely. In checking, for example, a trend of the fluctuations in the pulse wave transit time during sleep of the user, the time serial data of the pulse wave transit time is able to be more appropriately corrected even when the posture of the user is changed (for example, even when the user rolls over in sleep), and the fluctuations in the pulse wave transit time are able to be continuously determined with higher accuracy.

[0020] In a pulse wave transit time measurement device according to a preferred embodiment of the present invention, preferably, the pulse wave transit time calculator includes an electrocardiographic electrode detecting an electrocardiographic signal, and a pulse wave sensor detecting a pulse wave signal, the posture detector includes an acceleration sensor detecting a direction in which a gravitational acceleration is applied, and the pulse wave sensor and the acceleration sensor are disposed adjacent to or in a vicinity of each other and are set on a trunk or a neck of the user when used.

[0021] In this case, the pulse wave sensor and the acceleration sensor are positioned on the trunk or the neck of the user close to each other. Therefore, the posture of a body part at which the pulse wave transit time is measured is able to be accurately determined, and the correlation between the determination of the posture and the pulse wave transit time is able to be increased.

[0022] A living body state estimation device according to a preferred embodiment of the present invention includes any of the pulse wave transit time measurement devices described above, and a blood pressure fluctuation estimator that estimates fluctuations in blood pressure based on both of data of the fluctuations in the calculated pulse wave transit time and a predetermined relationship between the pulse wave transit time and a blood pressure.

[0023] With a living body state estimation device according to a preferred embodiment of the present invention, by including any of the pulse wave transit time measurement devices described above, the fluctuations in the pulse wave transit time are able to be continuously determined with higher accuracy even when the posture of the user is changed during the measurement of the pulse wave transit time. Thus, the fluctuations in the blood pressure are able to

be continuously estimated with higher accuracy even when the posture of the user is changed during the measurement of the pulse wave transit time.

[0024] In a living body state estimation device according to a preferred embodiment of the present invention, preferably, the blood pressure fluctuation estimator previously performs calibration of a relationship between an output signal of the posture detector and the posture of the user, determines a relational expression between a deviation in angle from a reference posture and a distance from a heart to a pulse-wave measurement location, and stores the relational expression; when measuring the pulse wave transit time, the blood pressure fluctuation estimator calculates, based on a result of the calibration, a deviation in angle between the posture of the user and the reference posture; and when calculating a value of blood pressure from the pulse wave transit time, the blood pressure fluctuation estimator determines the distance from the heart to the pulse-wave measurement location based on both of the calculated deviation in angle and the relational expression stored in advance, and corrects the value of the blood pressure based on the determined distance.

[0025] The pulse wave transit time greatly fluctuates based on the distance of the pulse-wave measurement location from the heart, and it fluctuates even with slight change of the posture. In the above-described case, however, when measuring the pulse wave transit time, the deviation in angle between the posture of the user and the reference posture is calculated based on the result of the calibration performed in advance. When calculating the value of the blood pressure from the pulse wave transit time, the distance from the heart to the pulse-wave measurement location is determined based on both of the calculated deviation in angle and the relational expression stored in advance, and the value of the blood pressure is corrected based on the determined distance. Thus, the value of the blood pressure is able to be more accurately estimated by finely calculating the deviation angle from the reference posture in addition to a major change of the posture.

[0026] According to preferred embodiments of the present invention, the pulse wave transit time is able to be continuously calculated with higher accuracy even when the posture of the user is changed during the measurement of the pulse wave transit time.

[0027] The above and other elements, features, steps, characteristics and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments with reference to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] FIG. 1 is a block diagram illustrating a configuration of a blood pressure fluctuation estimation device including a pulse wave transit time measurement device according to a preferred embodiment of the present invention.

[0029] FIG. 2 is a perspective view illustrating an external appearance of the blood pressure fluctuation estimation device of neck band type including a pulse wave transit time measurement device according to a preferred embodiment of the present invention.

[0030] FIG. 3 is a graph depicting relationships between postures (supine position, left lateral decubitus position, and right lateral decubitus position) and a pulse wave transit time.

[0031] FIG. 4 is a graph representing a measurement example of fluctuations in pulse wave transit time during sleep before correction, the pulse wave transit time being classified for each posture.

[0032] FIG. 5 is a graph representing a measurement example of fluctuations in pulse wave transit time during sleep after correction, the pulse wave transit time being classified for each posture.

[0033] FIG. 6 is a flowchart illustrating processing procedures of a blood pressure fluctuation estimation process executed by a blood pressure fluctuation estimation device according to a preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0034] Preferred embodiments of the present invention will be described in detail below with reference to the drawings. In the drawings, the same or equivalent components are denoted by the same reference signs. Furthermore, the same elements are denoted by the same reference signs in the drawings, and duplicate explanation of the same elements is omitted. The following description is provided in connection with a case in which a pulse wave transit time measurement device included in a blood pressure fluctuation estimation device, which corresponds to “a living body state estimation device”.

[0035] First, a configuration of a blood pressure fluctuation estimation device 3 including a pulse wave transit time measurement device 1 according to a preferred embodiment of the present invention is described with reference to FIGS. 1 and 2. FIG. 1 is a block diagram illustrating the configuration of the blood pressure fluctuation estimation device 3 including the pulse wave transit time measurement device 1. FIG. 2 is a perspective view illustrating an external appearance of the blood pressure fluctuation estimation device 3 of neck band type using the pulse wave transit time measurement device 1.

[0036] The blood pressure fluctuation estimation device 3 detects an electrocardiographic signal and a photoplethysmographic signal, measures a pulse wave transit time from a time difference between an R-wave peak of the detected electrocardiographic signal (electrocardiographic wave) and a peak (rising point) of the detected photoplethysmographic signal (pulse wave), and estimates fluctuations in blood pressure of a user based on time serial data of the measured pulse wave transit time. In particular, the blood pressure fluctuation estimation device 3 detects and classifies postures of the user, corrects the pulse wave transit time in accordance with a classifier, and estimates the fluctuations in the blood pressure based on the time serial data of the pulse wave transit time after the correction.

[0037] The blood pressure fluctuation estimation device 3 includes a pair of electrocardiographic electrodes 15 and 15 that detect the electrocardiographic signal, a photoplethysmographic sensor 20 that detects the photoplethysmographic signal, an acceleration sensor 22 that detects the posture of the user, and a signal processor 31 configured or programmed to measure and correct the pulse wave transit time from both of the detected electrocardiographic signal and photoplethysmographic signal, and further estimate the fluctuations in the blood pressure.

[0038] In the present preferred embodiment, as illustrated in FIG. 2, the blood pressure fluctuation estimation device 3

is neck band type device. The blood pressure fluctuation estimation device 3 is worn on the neck as illustrated in FIG. 2, by way of example, to calculate the time serial data of the pulse wave transit time and to estimate the fluctuations in the blood pressure. The blood pressure fluctuation estimation device 3 includes a neck band 13 preferably having a U-shape, a substantial U-shape, a C-shape, or a substantially C-shape, for example, and is worn around the neck of the user from the backside in a state of grasping the neck with the aid of elastic force, and a pair of sensors 11 and 12 disposed at both ends of the neck band 13 to be in contact with both lateral sides of the user's neck.

[0039] The neck band 13 is wearable around the neck of the user in a circumferential direction of the neck. In other words, as illustrated in FIG. 2, the neck band 13 is worn along the back of the user's neck from one lateral side to the other lateral side of the neck. More specifically, the neck band 13 preferably includes, for example, a band-shaped leaf spring, and a rubber coating coated around the leaf spring. Thus, the neck band 13 is biased inward in opposing directions such that, when the user wears the neck band 13, the neck band 13, and specifically, the sensors 11 and 12, are in a state in contact with the user's neck.

[0040] The rubber coating used in the neck band preferably has biocompatibility. A coating made of plastic, for example, may also be used instead of the rubber coating. Cables electrically connecting the sensors 11 and 12 are provided in the rubber coating. The cables are preferably coaxial cables, for example, in order to reduce noise.

[0041] The sensors 11 and 12 include a pair of electrocardiographic electrodes 15 and 15. The electrocardiographic electrode 15 may preferably be made of, for example, silver-silver chloride, conductive gel, conductive rubber, conductive plastic, a metal preferably being highly resistant to corrosion and less metal-allergic, such as stainless steel or Au, a conductive cloth, or a capacitive coupling electrode defined by a metal surface coated with an insulating layer. The conductive cloth may preferably be, for example, a woven fabric, a knit fabric, or an unwoven fabric made by using conductive fibers with electrical conductivity. The conductive fibers may preferably be, for example, resin fibers plated with a metal such as Ag, coated with carbon nanotubes, or coated with a conductive polymer such as PEDOT. Alternatively, a conductive polymer fiber with electrical conductivity may also be used. In the present preferred embodiment, a conductive cloth 15 preferably having a rectangular or substantially rectangular planar shape is preferably used as the electrocardiographic electrode 15. The pair of electrocardiographic electrodes 15 and 15 is connected to the signal processor 31 and outputs the electrocardiographic signal to the signal processor 31.

[0042] The acceleration sensor 22 that detects a posture of the user (neck) during the measurement of the pulse wave transit time is attached to the sensor 12. Thus, the acceleration sensor 22 defines and functions as a "posture detector". The acceleration sensor 22 is a 3-axis acceleration sensor that detects a direction in which a gravitational acceleration G is applied (i.e., a vertical direction). For example, whether the user is standing or lying is able to be determined from a detected signal of the acceleration sensor 22.

[0043] More specifically, the posture of the user is able to be determined by previously performing calibration with respect to a positional relationship between a body of the user and the acceleration sensor 22, and by performing

coordinate transformation of an output of the acceleration sensor 22 on the assumption that the direction in which the gravitational acceleration is applied represents a downward direction (vertical direction), for example. The acceleration sensor 22 is also connected to the signal processor 31 and outputs a detected signal (3-axis acceleration data) to the signal processor 31. A gyroscope sensor, for example, may also be used, instead of the acceleration sensor 22.

[0044] The photoplethysmographic sensor 20 including a light emitting element 201 and a light receiving element 202 and detecting the photoplethysmographic signal is disposed at an inner surface, i.e., a surface in contact with the neck, of the sensor 12 near the electrocardiographic electrode 15 and the acceleration sensor 22. The photoplethysmographic sensor 20 is a sensor that optically detects the photoplethysmographic signal by utilizing light absorption characteristics of blood hemoglobin.

[0045] The photoplethysmographic sensor 20 and the acceleration sensor 22 are disposed close to each other and are disposed on the neck of the user when used, i.e., during the measurement. Since the photoplethysmographic sensor 20 and the acceleration sensor 22 that determines the posture are disposed at the same or substantially the same location as described above, correlation between the determination of the posture and the pulse wave transit time is increased. Furthermore, since the sensors are disposed on the neck (or a trunk) instead of a hand or a leg, for example, a blood pressure within blood vessels in the neck (or the trunk), which is thought as having relatively high correlation to the risk of cerebral stroke, cardiac infarction, and other medical problems, is able to be estimated, instead of a blood pressure within blood vessels in the hand or the leg. In addition, since the plurality of sensors are collectively disposed on the neck (or the trunk) without being set at separate locations, the complexity during setting of the plurality of sensors is reduced, and restrictions on daily activity of the user are also reduced.

[0046] The light emitting element 201 emits light in response to a pulse-shaped drive signal output from a driver 350 in the signal processor 31 described later. The light emitting element 201 may preferably be, for example, an LED, a VCSEL (Vertical Cavity Surface Emitting LASER), or a resonator type LED. The driver 350 produces and outputs the pulse-shaped drive signal to drive the light emitting element 201.

[0047] The light receiving element 202 outputs a detected signal based on the intensity of the light emitted from the light emitting element 201 and coming into the light receiving element 202 after passing through the neck or being reflected by the neck. The light receiving element 202 is preferably a photodiode or a phototransistor, for example. In the present preferred embodiment, a photodiode is used as the light receiving element 202.

[0048] The light receiving element 202 is connected to the signal processor 31, and the detected signal (photoplethysmographic signal) from the light receiving element 202 is output to the signal processor 31.

[0049] A battery (not illustrated) supplying electric power to the photoplethysmographic sensor 20, the signal processor 31, a radio communication module 60, and other components is included inside one sensor 11. The signal processor 31 and the radio communication module 60 configured or programmed to transmit biological information, such as the fluctuations in the blood pressure, the

measured pulse wave transit time, the electrocardiographic signal, and the photoplethysmographic signal, to an external device are included inside the other sensor 12.

[0050] As described above, the pair of electrocardiographic electrodes 15 and 15 and the photoplethysmographic sensor 20 are connected to the signal processor 31 such that the detected electrocardiographic signal and the detected photoplethysmographic signal are input to the signal processor 31. The acceleration sensor 22 is also connected to the signal processor 31 such that the detected 3-axis acceleration signal is input to the signal processor 31.

[0051] The signal processor 31 is configured or programmed to process the input electrocardiographic signal and measure a heart rate, a heartbeat interval, and other parameters. The signal processor 31 further processes the input photoplethysmographic signal and measures a pulse rate, a pulse interval, and other parameters. In addition, the signal processor 31 measures the pulse wave transit time from a time difference between an R-wave peak of the detected electrocardiographic signal (electrocardiographic wave) and a peak (rising point) of the detected photoplethysmographic signal (acceleration pulse wave signal). Thereafter, the signal processor 31 estimates the fluctuations in the blood pressure of the user from the time serial data (fluctuations) of the measured pulse wave transit time.

[0052] To this end, the signal processor 31 includes an electrocardiographic signal amplifier 311, a pulse wave signal amplifier 321, a first signal processor 310, a second signal processor 320, peak detectors 316 and 326, peak correctors 318 and 328, a pulse wave transit time measurement calculator 330, a posture classifier 340, a pulse wave transit time fluctuation identifier 341, and a blood pressure fluctuation estimator 342. The first signal processor 310 includes an analog filter 312, an A/D converter 313, and a digital filter 314. The second signal processor 320 includes an analog filter 322, an A/D converter 323, a digital filter 324, and a second-order differentiation processor 325.

[0053] Among the above-described components and elements, the digital filters 314 and 324, the second-order differentiation processor 325, the peak detectors 316 and 326, the peak corrector 318 and 328, the pulse wave transit time measurement calculator 330, the posture classifier 340, the pulse wave transit time fluctuation identifier 341, and the blood pressure fluctuation estimator 342 are preferably defined by a CPU, or a plurality of CPUs, executing arithmetic processing, a ROM storing programs and data necessary to operate the CPU to execute various types of processing, and a RAM temporarily storing various data, such as calculation results. In other words, the functions of the above-described components and elements are provided by the CPU or CPUs executing the programs stored in the ROM.

[0054] The electrocardiographic signal amplifier 311 is preferably defined by an amplifier including an operational amplifier, for example, and it amplifies the electrocardiographic signal detected by the pair of electrocardiographic electrodes (conductive clothes) 15 and 15. The electrocardiographic signal amplified by the electrocardiographic signal amplifier 311 is output to the first signal processor 310. Similarly, the pulse wave signal amplifier 321 is preferably defined by an amplifier using an operational amplifier, for example, and it amplifies the photoplethysmographic signal detected by the photoplethysmographic sensor 20. The pho-

toplethysmographic signal amplified by the pulse wave signal amplifier 321 is output to the second signal processor 320.

[0055] The first signal processor 310 includes the analog filter 312, the A/D converter 313, and the digital filter 314, and extracts a pulsatile component by executing a filtering process on the electrocardiographic signal amplified by the electrocardiographic signal amplifier 311.

[0056] The second signal processor 320 includes the analog filter 322, the A/D converter 323, the digital filter 324, and the second-order differentiation processor 325, and extracts a pulsatile component by executing a filtering process and a second-order differentiation process on the photoplethysmographic signal amplified by the pulse wave signal amplifier 321.

[0057] The analog filters 312 and 322 and the digital filters 314 and 324 perform filtering to remove components (noise) at frequencies other than the frequencies of the electrocardiographic signal and the photoplethysmographic signal, and to increase the S/N ratio. More specifically, because frequency components from about 0.1 Hz to about 200 Hz are typically dominant in the electrocardiographic signal and frequency components from about 0.1 Hz to about several tens Hz are typically dominant in the photoplethysmographic signal, the S/N ratio is increased by using the analog filters 312 and 322 and the digital filters 314 and 324, which are preferably, for example, low pass filters or band pass filters, to perform the filtering process such that only signals in the above-described frequency ranges selectively pass through the filters.

[0058] In the case of extracting only the pulsatile component, components other than the pulsatile component may be cut by more restrictively narrowing a frequency pass band with the intent to improve noise immunity. Both types of the analog filters 312 and 322 and the digital filters 314 and 324 are not always required to be disposed, and the configuration may be modified to include only one type of the analog filters 312 and 322 and the digital filters 314 and 324. The electrocardiographic signal having been subjected to the filtering process through the analog filter 312 and the digital filter 314 is output to the peak detector 316. Similarly, the photoplethysmographic signal having been subjected to the filtering process through the analog filter 322 and the digital filter 324 is output to the second-order differentiation processor 325.

[0059] The second-order differentiation processor 325 obtains a second-order differentiation pulse wave (acceleration pulse wave) signal through second-order differentiation of the photoplethysmographic signal. The obtained acceleration pulse wave signal is output to the peak detector 326. Because change of a peak (rising point) of a photoplethysmographic pulse wave is not definite and is difficult to detect in some cases, the peak is preferably detected after converting the photoplethysmographic pulse wave to an acceleration pulse wave. However, the second-order differentiation processor 325 is not always required to be provided, and it may be omitted in another configuration.

[0060] The peak detector 316 detects the peak (R-wave) of the electrocardiographic signal on which the signal processing has been executed in the first signal processor 310, that is, from which the pulsatile component has been extracted. On the other hand, the peak detector 326 detects the peak of the photoplethysmographic signal (acceleration pulse wave) on which the filtering process has been executed in the

second signal processor 320. The peak detector 316 and the peak detector 326 perform the peak detection within normal ranges of the heartbeat interval and the pulse interval, and store information, such as peak time and peak amplitude, for all of the detected peaks in the RAM, for example.

[0061] The peak corrector 318 determines a delay time of the electrocardiographic signal caused in the first signal processor 310 (i.e., the analog filter 312, the A/D converter 313, and the digital filter 314). Based on the determined delay time of the electrocardiographic signal, the peak corrector 318 corrects the peak of the electrocardiographic signal, which has been detected by the peak detector 316. Similarly, the peak corrector 328 determines a delay time of the photoplethysmographic signal caused in the second signal processor 320, i.e., the analog filter 322, the A/D converter 323, the digital filter 324, and the second-order differentiation processor 325. Based on the determined delay time of the photoplethysmographic signal, the peak corrector 328 corrects the peak of the photoplethysmographic signal, which has been detected by the peak detector 326. The peak of the electrocardiographic signal after the correction and the peak of the photoplethysmographic signal (acceleration pulse wave) after the correction are output to the pulse wave transit time measurement calculator 330. The peak corrector 318 is not always required to be provided, and it may be omitted in another configuration.

[0062] The pulse wave transit time measurement calculator 330 time-serially calculates a pulse wave transit time from an interval (time difference) between the R-wave peak of the electrocardiographic signal having been corrected by the peak corrector 318 and the peak of the photoplethysmographic signal (acceleration pulse wave) having been corrected by the peak corrector 328. Thus, the pulse wave transit time measurement calculator 330 defines and functions as a “pulse wave transit time calculator”.

[0063] The pulse wave transit time measurement calculator 330 calculates, in addition to the pulse wave transit time, the heart rate, the heartbeat interval, a change rate of the heartbeat interval, and other parameters from the electrocardiographic signal. Similarly, the pulse wave transit time measurement calculator 330 further calculates the pulse rate, the pulse interval, a change rate of the pulse interval, and other parameters from the photoplethysmographic signal (acceleration pulse wave). The time serial data of the pulse wave transit time is output to the posture classifier 340.

[0064] The posture classifier 340 determines (estimates) the posture of the user based on the detected signal from the acceleration sensor 22 (i.e., the 3-axis acceleration data), and classifies the time serial data of the pulse wave transit time for each posture based on the determined posture. More specifically, the posture classifier 340 classifies the time serial data of the pulse wave transit time for each of postures including at least an upright position, an inverted position, a supine position, a left lateral decubitus position, a right lateral decubitus position, and a prone position. Thus, the posture classifier 340 defines and functions as a “classifier”.

[0065] FIG. 3 depicts relationships between the postures (supine position, left lateral decubitus position, and right lateral decubitus position) and the pulse wave transit time. When the photoplethysmographic sensor 20 is provided on the left side of the neck (see a solid line), the pulse wave transit time is shortened in the left lateral decubitus position. On the other hand, when the photoplethysmographic sensor 20 is provided on the right side of the neck (see a dotted

line), the pulse wave transit time is shortened in the right lateral decubitus position. Those results are attributable to the fact that the blood pressure is increased and the pulse wave transit time is shortened in the position in which the measurement location is on the lower side. Thus, when the blood pressure fluctuation estimator 3 is worn around the neck as illustrated in FIG. 2, for example, the pulse wave transit time is greatly different between the lateral decubitus position and the supine position.

[0066] FIG. 4 represents a measurement example of the pulse wave transit time during sleep before the correction, the pulse wave transit time being classified for each posture. In FIG. 4, the horizontal axis indicates time, and the vertical axis indicates the pulse wave transit time (sec). In attempting to calculate the pulse wave transit time (fluctuations in the blood pressure) during sleep, for example, it often happens that the posture is changed from one to another among the left lateral decubitus position, the right lateral decubitus position, and the supine position, and that the pulse wave transit time fluctuates based on the change of the posture. Therefore, the postures are preferably classified into at least the above-described six postures. A classification result of the pulse wave transit time obtained by the posture classifier 340, i.e., the classified time serial data of the pulse wave transit time, is output to the pulse wave transit time fluctuation identifier 341.

[0067] The pulse wave transit time fluctuation identifier 341 determines fluctuations in the pulse wave transit time based on the time serial data of the pulse wave transit time having been classified for each posture by the posture classifier 340. Thus, the pulse wave transit time fluctuation identifier 341 defines and functions as a “fluctuation identifier”.

[0068] In more detail, the pulse wave transit time fluctuation identifier 341 first sets one posture, e.g., the supine position) as a reference from among the classified postures, and corrects, in conformity with the reference posture, the time serial data of the pulse wave transit time having been classified into the postures, e.g., the upright position, the inverted position, the left lateral decubitus position, the right lateral decubitus position, and the prone position, different from the reference posture. Then, the pulse wave transit time fluctuation identifier 341 determines the fluctuations in the pulse wave transit time based on both of the time serial data of the pulse wave transit time in the reference posture and the time serial data of the pulse wave transit time having been corrected (after the correction).

[0069] At this time, the pulse wave transit time fluctuation identifier 341 sets, as the reference posture, the posture, e.g., the supine position, in which a time span of the time serial data of the calculated pulse wave transit time is longest. Then, the pulse wave transit time fluctuation identifier 341 corrects the time serial data of the pulse wave transit time for each posture such that a correlation coefficient of an approximation curve resulting from approximating the time serial data of the pulse wave transit time for each posture with a curve is increased, and preferably, maximized. Furthermore, the pulse wave transit time fluctuation identifier 341 determines the fluctuations in the pulse wave transit time from the time serial data after the correction. Thus, by correcting the pulse wave transit time for each posture by increasing the correlation coefficient of the approximation curve and estimating a trend of the fluctuations in the pulse wave transit time from the time serial data after the correction, the trend

of the fluctuations in the pulse wave transit time (trend of the fluctuations in the blood pressure) for a long time is able to be estimated without requiring complex calibration even when the posture is changed. For example, the least square method may preferably be used as a method of determining the above-described approximation curve.

[0070] FIG. 5 represents a measurement example of the pulse wave transit time during sleep after the correction, the pulse wave transit time being classified for each posture. In FIG. 5, the horizontal axis indicates time, and the vertical axis indicates the pulse wave transit time (sec). Furthermore, in FIG. 5, a solid line represents the pulse wave transit time during sleep after the correction, and a dotted line represents an approximation curve. In the example illustrated in FIG. 5, a range of the time serial data of the pulse wave transit time illustrated in FIG. 4, the range corresponding to a period during sleep, is extracted, and the pulse wave transit time is corrected for each posture such that a correlation coefficient of the approximation curve in the above range is maximized. At that time, the supine position is set as the reference position, and the pulse wave transit time in the posture other than the supine position is corrected in conformity with the reference posture. As a result of the correction, the following trend is determined, namely, the pulse wave transit time gradually increases with the lapse of sleeping time, as illustrated in FIG. 5.

[0071] Instead of the above-described manner, the pulse wave transit time for each posture may be arrayed in the time series, and an approximation curve may be determined for each of the postures. In this case, although a plurality of approximation curves are determined, one of those approximation curves, the one having a greater correlation coefficient is selected from among the approximation curves corresponding to the postures in which the measurement has been performed for a time at a predetermined rate or more. The data obtained by the pulse wave transit time fluctuation identifier 341 and representing the fluctuations in the pulse wave transit time is output to the blood pressure fluctuation estimator 342.

[0072] The blood pressure fluctuation estimator 342 estimates the fluctuations in the blood pressure based on both of the data of the fluctuations in the pulse wave transit time after the correction and a predetermined relationship (correlation formula) between the pulse wave transit time and the blood pressure. Thus, the blood pressure fluctuation estimator 342 functions as a “blood pressure fluctuation estimator”. The blood pressure fluctuation estimator 342 is able to estimate the fluctuations in the blood pressure from the fluctuations in the pulse wave transit time after the correction by estimating the fluctuations in the blood pressure with the aid of, for example, a predetermined correlation formula between the pulse wave transit time and the blood pressure in the reference posture, e.g., the supine position. In the above-described example illustrated in FIG. 5, there is a trend that the pulse wave transit time gradually increases, that is, the blood pressure gradually decreases. Such a trend is converted to a blood pressure fluctuation value with the predetermined correlation formula. The correlation formula between the pulse wave transit time and the blood pressure may be determined in the posture other than the supine position, or for each of the plurality of postures.

[0073] Furthermore, the blood pressure fluctuation estimator 342 performs, based on the estimated fluctuations in the blood pressure, classification into the dipper type, the

non-dipper type, the riser type, and the extreme-dipper type. In the normal case, the fluctuations in the blood pressure exhibit the dipper type in which the blood pressure decreases during sleep. On the other hand, in the case of hypertensive patients, the blood pressure at night is relatively high or is not decreased, i.e., the riser type or the non-dipper type), and the risk of cerebral stroke, cardiac infarction, and other medical problems increases. In the case of patients taking antihypertensive drugs, the blood pressure may decrease excessively during sleep (i.e., the extreme-dipper type), and the risk of cerebral stroke, cardiac infarction, and other medical problems may increase occasionally. Thus, the determination regarding the riser type, the non-dipper type, and the extreme-dipper type is able to be made by obtaining the fluctuations in the blood pressure during sleep.

[0074] The blood pressure fluctuation estimator 342 may previously perform, in a state of the user wearing the device, calibration for the determination of the posture, i.e., calibration of a relationship between the output signal, in the vertical direction, of the acceleration sensor 22 and the posture of the user, e.g., the upright position or the supine position, may determine a relational expression between a deviation in angle from the reference posture, i.e., a deviation angle, and a distance from the heart to a pulse-wave measurement location, i.e., a setting location of the photoplethysmographic sensor 20 (neck in the present preferred embodiment), and may store the relational expression in a memory, such as a RAM. When measuring the pulse wave transit time, i.e., in use, the blood pressure fluctuation estimator 342 may calculate, based on a result of the calibration performed in advance, a deviation in angle (deviation angle) between the posture of the user detected by the acceleration sensor 22 and the reference posture. When calculating a value of blood pressure from the pulse wave transit time, the blood pressure fluctuation estimator 342 may determine the distance from the heart to the pulse-wave measurement location, i.e., the setting location, (neck) of the photoplethysmographic sensor 20, based on both of the calculated deviation in angle (deviation angle) and the relational expression stored in advance, and may correct the value of the blood pressure based on the determined distance. The value of the blood pressure is not always required to be determined.

[0075] Measurement data including not only the estimated fluctuations in the blood pressure and the value of the blood pressure, but also the calculated pulse wave transit time, the heart rate, the heartbeat interval, the pulse rate, the pulse interval, the photoplethysmographic pulse wave, the acceleration pulse wave, and the 3-axis accelerations is output to, for example, the memory such as the RAM, or to the radio communication module 60. The measurement data may be stored in the memory to be readable together with the daily fluctuation history, or may be wirelessly transmitted in real time to an external device, such as a personal computer (PC) or a smartphone, for example. Alternatively, the measurement data may be stored in the memory inside the device during the measurement, and may be transmitted to an external device by automatically connecting the relevant device to the external device after the end of the measurement.

[0076] The operation of the blood pressure fluctuation estimator 3 will be described below with reference to FIG. 6. FIG. 6 is a flowchart illustrating processing procedures of a blood pressure fluctuation estimation process executed by

the blood pressure fluctuation estimator 3. The processing procedures illustrated in FIG. 6 are repeatedly executed at predetermined timing primarily by the signal processor 31.

[0077] When the blood pressure fluctuation estimator 3 is worn around the neck, such that the sensors 11 and 12 (specifically, the electrocardiographic electrodes 15 and 15 and the photoplethysmographic sensor 20) are in contact with the neck, the electrocardiographic signal detected by the pair of electrocardiographic electrodes 15 and 15 and the photoplethysmographic signal detected by the photoplethysmographic sensor 20 are read in step S100. In step S102, the filtering process is performed on the electrocardiographic signal and the photoplethysmographic signal both having been read in step S100. Furthermore, an acceleration pulse wave is obtained through the second differentiation of the photoplethysmographic signal.

[0078] Then, in step S104, a setting state of the pulse wave transit time measurement device 1 is determined, for example, based on the intensity of light received by the photoplethysmographic sensor 20. More specifically, in the photoplethysmographic sensor 20, light emitted from the limit emitting element 201 and returned after passing through or being reflected by a living body is received by the light receiving element 202, and fluctuations in the intensity of the received light are detected as the photoplethysmographic signal. Therefore, the intensity of the received signal light is reduced in the state in which the device is not properly set. Taking the above point into account, in step S104, it is determined whether the intensity of the received light is not less than a predetermined value. If the intensity of the received light is not less than the predetermined value, the processing shifts to step S108. On the other hand, if the intensity of the received light is less than the predetermined value, this is determined to be a setting error, and setting error information (warning information) is output in step S106. Thereafter, the processing is brought to an end. Instead of the above-described method of utilizing the intensity of the light received by the photoplethysmographic sensor 20, the setting state may be determined by another method of utilizing, for example, the magnitude of the photoplethysmographic signal, stability of the baseline of an electrocardiographic waveform, or a rate of a noise frequency component.

[0079] In step S108, it is determined whether an acceleration of the neck detected by the acceleration sensor 22 is not less than a predetermined threshold, i.e., whether the neck is moved and body motion noise is increased. If the acceleration of the neck is less than the predetermined threshold, the processing shifts to step S112. On the other hand, if the acceleration of the neck is not less than the predetermined threshold, body motion error information is output in step S110, and the processing is then brought to an end.

[0080] In step S112, the posture of the user (measurement location) is determined based on the 3-axis acceleration data. In next step S114, peaks of the electrocardiographic signal and the photoplethysmographic signal (acceleration pulse wave signal) are detected. Then, a time difference (peak time difference) between the detected R-wave peak of the electrocardiographic signal and the detected peak of the photoplethysmographic signal (acceleration pulse wave) is calculated.

[0081] In step S116, respective delay times (deviations) of the R-wave peak of the electrocardiographic signal and the peak of the photoplethysmographic signal (acceleration

pulse wave) are determined, and the time difference (peak time difference) between the R-wave peak of the electrocardiographic signal and the peak of the photoplethysmographic signal (acceleration pulse wave) is corrected based on the determined delay times.

[0082] Then, in step S118, it is determined whether the peak time difference corrected in step S116 is not less than a predetermined time, e.g., about 0.01 sec. If the peak time difference is not less than the predetermined time, the processing shifts to step S122. On the other hand, if the peak time difference is less than the predetermined time, error information (indicating the peak being determined as noise) is output in step S120. Thereafter, the processing is brought to an end.

[0083] In step S122, the peak time difference calculated in step S114 is definitively determined to be the pulse wave transit time, and the pulse wave interval is obtained.

[0084] Then, in step S124, the pulse wave transit time is classified for each posture of the user. Because a method for use in classifying the pulse wave transit time is described above, detailed description of the method is omitted here.

[0085] In next step S126, the pulse wave transit time is corrected such that the correlation coefficient of the approximation curve is maximized. Because a method for use in correcting the pulse wave transit time is described above, detailed description of the method is omitted here.

[0086] Then, in step S128, the fluctuations in the blood pressure are estimated from the fluctuations in the pulse wave transit time after the correction. Because a method for use in estimating the fluctuations in the blood pressure is described above, detailed description of the method is omitted here. In step S130, the obtained data of the fluctuations in the blood pressure are output to the memory or the external device, such as the smartphone, for example. Thereafter, the processing is brought to an end.

[0087] According to the present preferred embodiment, as described in detail above, the time serial data of the calculated pulse wave transit time is classified for each posture, and the fluctuations in the pulse wave transit time are determined based on the time serial data of the pulse wave transit time having been classified for each posture. Therefore, the time serial data of the pulse wave transit time is able to be corrected for each posture, for example. As a result, even when the posture of the user is changed during the measurement of the pulse wave transit time, the fluctuations in the pulse wave transit time are able to be continuously calculated with higher accuracy. In particular, an absolute value of the pulse wave transit time greatly fluctuates based on individual differences (in blood vessel length, arterial stiffness, level of hypertension, and other factors), the posture, the distance of the pulse wave measurement location from the heart, and other factors. For that reason, intricate calibration is essential to determine the absolute value of blood pressure. According to the present preferred embodiment, however, since the pulse wave transit time is classified for each posture and a trend of the time-dependent fluctuations in the pulse wave transit time is determined, useful information is able to be obtained without performing the intricate calibration.

[0088] In particular, according to the present preferred embodiment, the reference posture is set from among the classified postures, and the time serial data of the pulse wave transit time having been classified into the posture different from the reference posture is corrected in conformity with

the reference posture. The fluctuations in the pulse wave transit time are then determined based on both of the time serial data of the pulse wave transit time in the reference posture and the time serial data of the pulse wave transit time having been corrected (after the correction). In other words, when the posture of the user is changed during the measurement of the pulse wave transit time, the time serial data of the pulse wave transit time having been classified into the posture different from the reference posture is corrected in conformity with the reference posture, that is, in such a manner as to provide the time serial data on the assumption that the relevant time serial data is obtained in the reference posture). As a result, even when the posture of the user is changed during the measurement of the pulse wave transit time, the fluctuations in the pulse wave transit time are able to be continuously determined with higher accuracy.

[0089] In the above-described process, according to the present preferred embodiment, the posture in which the time span of the time serial data of the calculated pulse wave transit time is longest is set as the reference posture. Therefore, a ratio of the time serial data requiring the correction to all of the time serial data of the calculated pulse wave transit time is able to be reduced. As a result, the fluctuations in the pulse wave transit time are able to be determined with higher accuracy, and a processing load required for the correction is reduced.

[0090] According to the present preferred embodiment, the time serial data of the pulse wave transit time for each posture is corrected such that the correlation coefficient of the approximation curve is increased, and preferably maximized. The fluctuations in the pulse wave transit time are then determined from the time serial data after the correction. Therefore, the time serial data of the pulse wave transit time having been classified into the posture different from the reference posture is able to be appropriately corrected in conformity with the reference posture, that is, in such a manner as to provide the time serial data on the assumption that the relevant time serial data is obtained in the reference posture.

[0091] According to the present preferred embodiment, the time serial data of the pulse wave transit time is classified for each of the postures including at least the upright position, the inverted position, the supine position, the left lateral decubitus position, the right lateral decubitus position, and the prone position. Therefore, the posture during the measurement of the pulse wave transit time is able to be classified more precisely. Thus, in checking, for example, a trend of the fluctuations in the pulse wave transit time during sleep of the user, the time serial data is able to be more appropriately corrected even when the posture of the user is changed, for example, even when the user rolls over in sleep, and the fluctuations in the pulse wave transit time are able to be continuously determined with higher accuracy.

[0092] According to the present preferred embodiment, in use of the device, the photoplethysmographic sensor **20** and the acceleration sensor **22** are positioned on the neck (or the trunk) of the user close to each other. Therefore, the posture of a body part, i.e., the neck or the trunk, at which the pulse wave transit time is measured is able to be accurately determined, and the correlation between the determination of the posture and the pulse wave transit time is increased. Moreover, since the sensors are disposed on the neck (or the trunk) instead of the hand or the leg, for example, a blood pressure within blood vessels in the neck (or the trunk),

which is thought as having relatively high correlation to the risk of cerebral stroke, cardiac infarction, and other medical problems, is able to be estimated. In addition, since the plurality of sensors are collectively disposed on the neck (or the trunk) without being disposed at separate locations, the complexity in setting the plurality of sensors is reduced, and restrictions on daily activity of the user is also reduced.

[0093] According to the present preferred embodiment, by including the pulse wave transit time measurement device **1**, even when the posture of the user is changed during the measurement of the pulse wave transit time, the fluctuations in the blood pressure are able to be continuously estimated with higher accuracy. As a result, according to the present preferred embodiment, the determination regarding the dipper type, the non-dipper type, the riser type, and the extreme-dipper type is able to be made, and the risk of cerebral stroke, cardiac infarction, and other medical problems is able to be estimated by measuring the fluctuations in the blood pressure during sleep, for example.

[0094] While preferred embodiments of the present invention have been described in detail above, the present invention may be variously modified without being limited to the above-described preferred embodiments. For instance, while the above-described preferred embodiments have been described, by way of example, in connection with the blood pressure fluctuation estimator **3**, i.e., the pulse wave transit time measurement device **1**, of the neck band type in which the neck band **13** is worn around the neck of the user, the blood pressure fluctuation estimator may be used in a state bonded to the neck of the user on the backside over a range spanning from one lateral side of the neck to the other lateral side. Furthermore, instead of wearing the device around the neck (nape) of the user, the device may be modified into a configuration in which the electrocardiographic electrodes, the pulse wave sensor, and the 3-axis acceleration sensor are bonded to a chest region (trunk) as with a Holter monitor, for example, or a configuration of a chest strap type measuring heartbeats during running.

[0095] While, in the above-described preferred embodiments, the time serial data of the pulse wave transit time for each posture preferably is corrected such that the correlation coefficient of the approximation curve is increased, and preferably maximized, the time serial data of the pulse wave transit time for each posture may be corrected using a conversion table that specifies, for each posture, a relationship of change of the pulse wave transit time from that in the reference posture.

[0096] While, in the above-described preferred embodiments, the predetermined correlation formula between the pulse wave transit time and the blood pressure preferably is used to estimate the fluctuations in the blood pressure from the fluctuations in the pulse wave transit time, a conversion table specifying a relationship between the pulse wave transit time and the blood pressure for each posture may be used instead of the correlation formula.

[0097] While the photoplethysmographic sensor is preferably used as the pulse wave sensor in the above-described preferred embodiments, a piezoelectric pulse wave sensor may be used in another example. Other biological sensors, such as an oxygen saturation sensor, a sound sensor (microphone), a displacement sensor, a temperature sensor, and a humidity sensor, may also be used in addition to the above-described sensors.

[0098] While, in the above-described preferred embodiments, the time serial data of the pulse wave transit time is preferably classified per each of six postures, i.e., the upright position, the inverted position, the supine position, the left lateral decubitus position, the right lateral decubitus position, and the prone position, the posture may be more precisely classified into a larger number of positions including the above six positions.

[0099] While, in the above-described preferred embodiments, the reference posture, e.g., the supine position, preferably is set and the time serial data of the pulse wave transit time having been classified into the posture different from the reference posture is corrected in conformity with the reference posture, the fluctuations in the pulse wave transit time may be determined, instead of using such a method, based on only a portion of the classified time serial data of the pulse wave transit time, the portion corresponding to the predetermined posture, e.g., the supine position. In that case, when the posture of the user is changed during the measurement of the pulse wave transit time, the fluctuations in the pulse wave transit time are determined after excluding, from the obtained data, the time serial data of the pulse wave transit time having been classified into the other postures different from the predetermined posture. As a result, the fluctuations in the pulse wave transit time are able to be accurately determined even when the posture of the user is changed during the measurement of the pulse wave transit time.

[0100] While, in the above-described preferred embodiments, the signal processor 31 preferably executes various types of processing, such as the determination of the posture, the correction of the pulse wave transit time for each posture, and the estimation of the fluctuations in the blood pressure, the obtained data including the electrocardiographic signal, the photoplethysmographic signal, and the 3-axis accelerations may be wirelessly output to a personal computer (PC) or a smartphone, for example, and the PC or the smartphone may execute the various types of processing, such as the determination of the posture, the correction of the pulse wave transit time for each posture, and the estimation of the fluctuations in the blood pressure. In that case, the above-described data, such as the correlation formula, is stored in the PC or the smartphone.

[0101] While preferred embodiments of the present invention have been described above, it is to be understood that variations and modifications will be apparent to those skilled in the art without departing from the scope and spirit of the present invention. The scope of the present invention, therefore, is to be determined solely by the following claims.

What is claimed is:

1. A pulse wave transit time measurement device comprising:

- a pulse wave transit time calculator that calculates a pulse wave transit time based on a peak time difference between an electrocardiographic signal and a pulse wave signal;
- a posture detector that detects a posture of a user when the pulse wave transit time is calculated by the pulse wave transit time calculator;
- a classifier that classifies time serial data of the calculated pulse wave transit time for each posture based on the posture detected by the posture detector; and
- a fluctuation identifier that determines fluctuations in the pulse wave transit time based on the time serial data of

the pulse wave transit time having been classified for each posture by the classifier.

2. The pulse wave transit time measurement device according to claim 1, wherein the fluctuation identifier sets a reference posture from among the classified postures, corrects, in conformity with the reference posture, the time serial data of the pulse wave transit time having been classified into the posture different from the reference posture, and determines the fluctuations in the pulse wave transit time based on both the time serial data of the pulse wave transit time in the reference posture and the time serial data of the pulse wave transit time having been corrected.

3. The pulse wave transit time measurement device according to claim 2, wherein the fluctuation identifier sets, as the reference posture, the posture in which a time span of the time serial data of the calculated pulse wave transit time is longest.

4. The pulse wave transit time measurement device according to claim 2, wherein the fluctuation identifier corrects the time serial data of the pulse wave transit time for each posture such that a correlation coefficient of an approximation curve resulting from approximating the time serial data of the pulse wave transit time for each posture with a curve is increased, and determines the fluctuations in the pulse wave transit time from the time serial data after the correction.

5. The pulse wave transit time measurement device according to claim 1, wherein the fluctuation identifier determines the fluctuations in the pulse wave transit time based on, among all of the classified time serial data of the pulse wave transit time, only the time serial data of the pulse wave transit time corresponding to a predetermined posture.

6. The pulse wave transit time measurement device according to claim 1, wherein the classifier classifies the time serial data of the pulse wave transit time for each of the postures including at least an upright position, an inverted position, a supine position, a left lateral decubitus position, a right lateral decubitus position, and a prone position.

7. The pulse wave transit time measurement device according to claim 1, wherein

the pulse wave transit time calculator includes an electrocardiographic electrode that detects an electrocardiographic signal, and a pulse wave sensor that detects a pulse wave signal;

the posture detector is an acceleration sensor that detects a direction in which a gravitational acceleration is applied; and

the pulse wave sensor and the acceleration sensor are disposed adjacent to or in a vicinity of each other and are disposed on a trunk or a neck of the user when used.

8. The pulse wave transit time measurement device according to claim 7, wherein the electrocardiographic electrode is made of silver-silver chloride, conductive gel, conductive rubber, conductive plastic, stainless steel, or Au.

9. The pulse wave transit time measurement device according to claim 7, wherein the electrocardiographic electrode includes a conductive cloth having a rectangular or substantially rectangular planar shape.

10. A living body state estimation device comprising:

the pulse wave transit time measurement device according to claim 1; and

a blood pressure fluctuation estimator that estimates fluctuations in blood pressure based on both data of the fluctuations in the calculated pulse wave transit time

and a predetermined relationship between the pulse wave transit time and a blood pressure.

11. The living body state estimation device according to claim 10, wherein

the blood pressure fluctuation estimator previously performs calibration of a relationship between an output signal of the posture detector and the posture of the user, determines a relational expression between a deviation in angle from a reference posture and a distance from a heart to a pulse-wave measurement location, and stores the relational expression;

when measuring the pulse wave transit time, the blood pressure fluctuation estimator calculates, based on a result of the calibration, a deviation in angle between the posture of the user and the reference posture; and when calculating a value of blood pressure from the pulse wave transit time, the blood pressure fluctuation estimator determines the distance from the heart to the pulse-wave measurement location based on both of the calculated deviation in angle and the relational expression stored in advance, and corrects the value of the blood pressure based on the determined distance.

12. The living body state estimation device according to claim 10, wherein the fluctuation identifier, for each posture, sets a reference posture from among the classified postures, corrects, in conformity with the reference posture, the time serial data of the pulse wave transit time having been classified into the posture different from the reference posture, and determines the fluctuations in the pulse wave transit time based on both the time serial data of the pulse wave transit time in the reference posture and the time serial data of the pulse wave transit time having being corrected.

13. The living body state estimation device according to claim 12, wherein the fluctuation identifier sets, as the reference posture, the posture in which a time span of the time serial data of the calculated pulse wave transit time is longest.

14. The living body state estimation device according to claim 12, wherein the fluctuation identifier corrects the time

serial data of the pulse wave transit time for each posture such that a correlation coefficient of an approximation curve resulting from approximating the time serial data of the pulse wave transit time for each posture with a curve is increased, and determines the fluctuations in the pulse wave transit time from the time serial data after the correction.

15. The living body state estimation device according to claim 10, wherein the fluctuation identifier determines the fluctuations in the pulse wave transit time based on, among all of the classified time serial data of the pulse wave transit time, only the time serial data of the pulse wave transit time corresponding to a predetermined posture.

16. The living body state estimation device according to claim 10, wherein the classifier classifies the time serial data of the pulse wave transit time for each of the postures including at least an upright position, an inverted position, a supine position, a left lateral decubitus position, a right lateral decubitus position, and a prone position.

17. The living body state estimation device according to claim 10, wherein

the pulse wave transit time calculator includes an electrocardiographic electrode that detects an electrocardiographic signal, and a pulse wave sensor that detects a pulse wave signal;

the posture detector includes an acceleration sensor that detects a direction in which a gravitational acceleration is applied; and

the pulse wave sensor and the acceleration sensor are disposed adjacent to or in a vicinity of each other and are disposed on a trunk or a neck of the user when used.

18. The living body state estimation device according to claim 17, wherein the electrocardiographic electrode is made of silver-silver chloride, conductive gel, conductive rubber, conductive plastic, stainless steel, or Au.

19. The living body state estimation device according to claim 17, wherein the electrocardiographic electrode includes a conductive cloth having a rectangular or substantially rectangular planar shape.

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[标]申请(专利权)人(译)	有限公司村田生产厂		
申请(专利权)人(译)	株式会社村田制作所. , LTD.		
当前申请(专利权)人(译)	株式会社村田制作所. , LTD.		
[标]发明人	SHIMUTA TORU		
发明人	SHIMUTA, TORU		
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摘要(译)

脉搏波传播时间测量装置包括：脉搏波传播时间计算器，其基于心电图信号和脉搏波信号之间的峰值时间差来计算脉搏波传播时间；脉搏波传播时间计算器，其对脉搏波传输的时间序列数据进行分类的姿势分类器基于由加速度传感器检测到的姿势的时间，以及从分类姿势中设定基准姿势的波动标识符，根据基准姿势校正被分类为不同于的姿势的脉搏波传播时间的时间序列数据。参考姿势，并且基于参考姿势中的脉搏波传播时间的时间序列数据和已经校正的脉搏波传播时间的时间序列数据，确定脉搏波传播时间的波动。

