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DEVICE, SYSTEM, AND PROGRAM**(30) **Foreign Application Priority Data**

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ABSTRACT

A biological information analysis device includes: an indicator extraction unit configured to extract, from data regarding blood pressure waveforms consecutively measured by a sensor configured to be worn on a body part of a sleeping user and to be capable of non-invasively measuring a blood pressure waveform for each heartbeat, an indicator that is related to the functionality of respiratory organs of the user, based on characteristics of the blood pressure waveforms; and a processing unit configured to perform processing that is based on the indicator thus extracted.

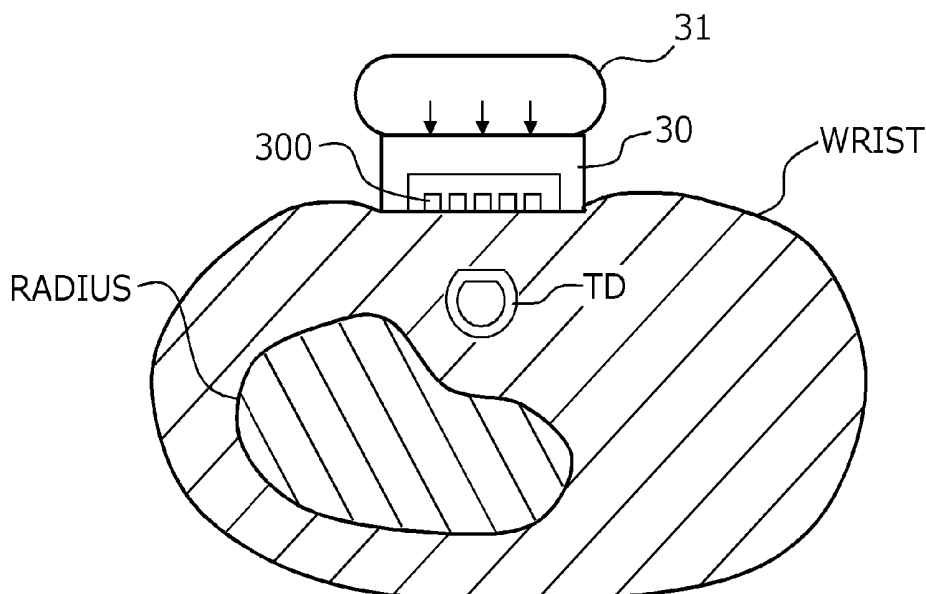


FIG. 1

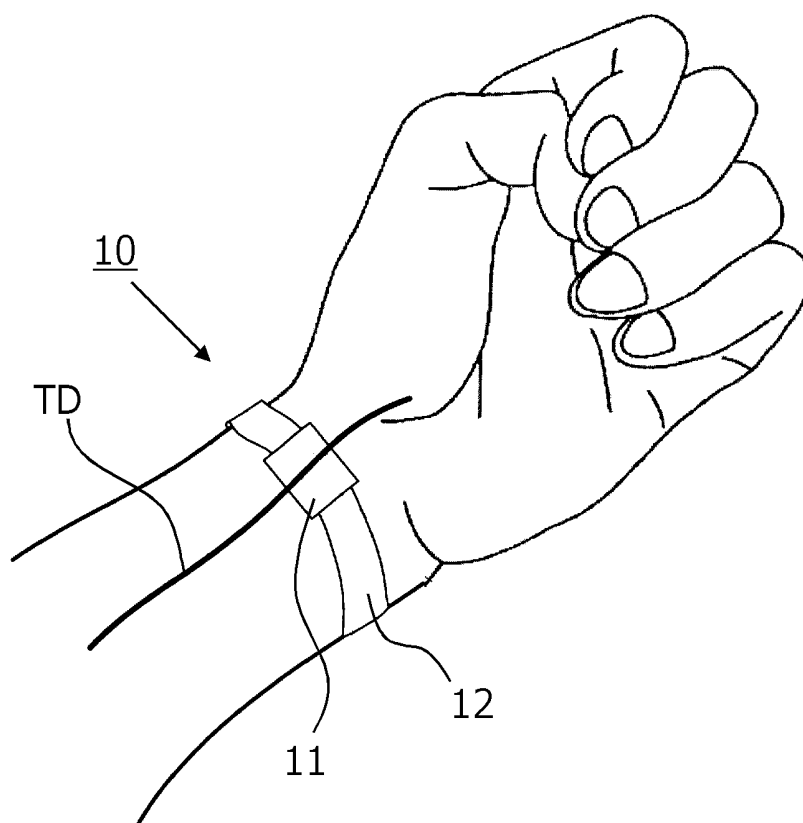


FIG. 2

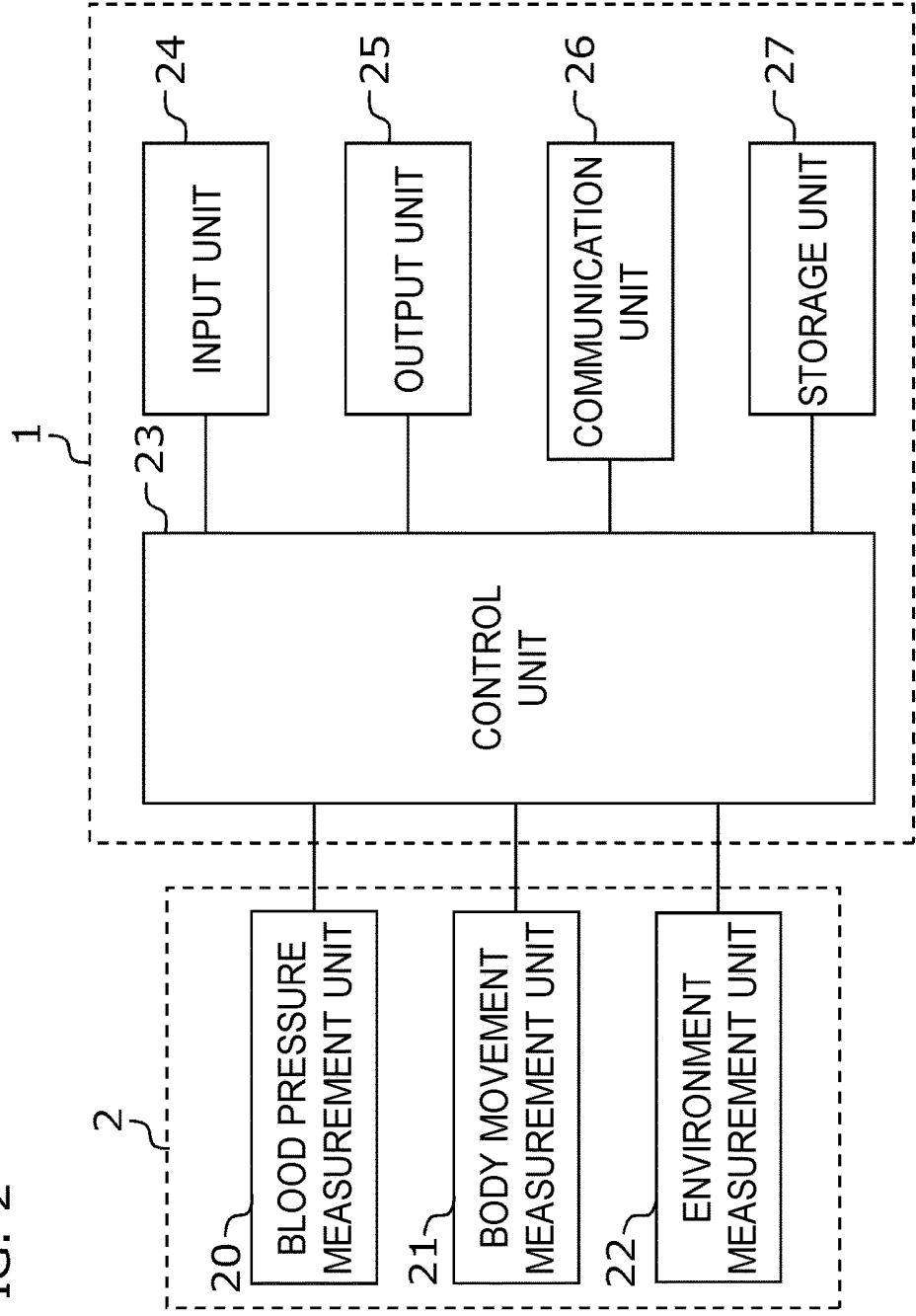


FIG. 3

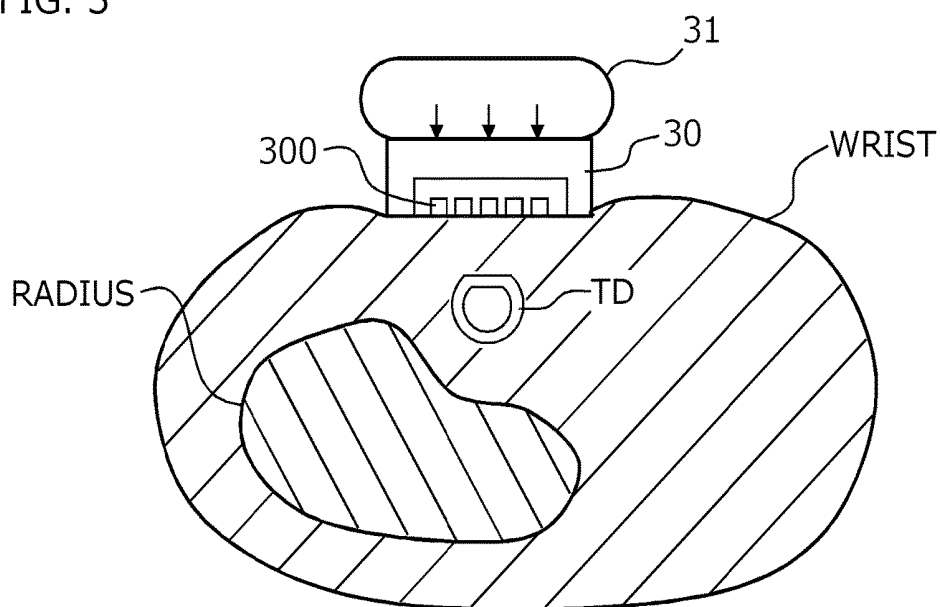


FIG. 4

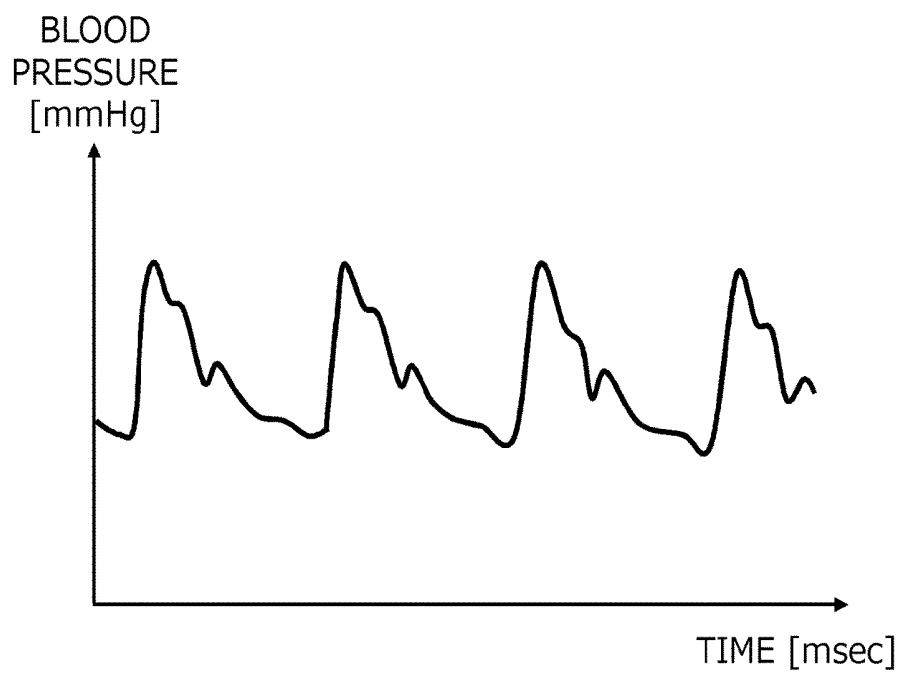
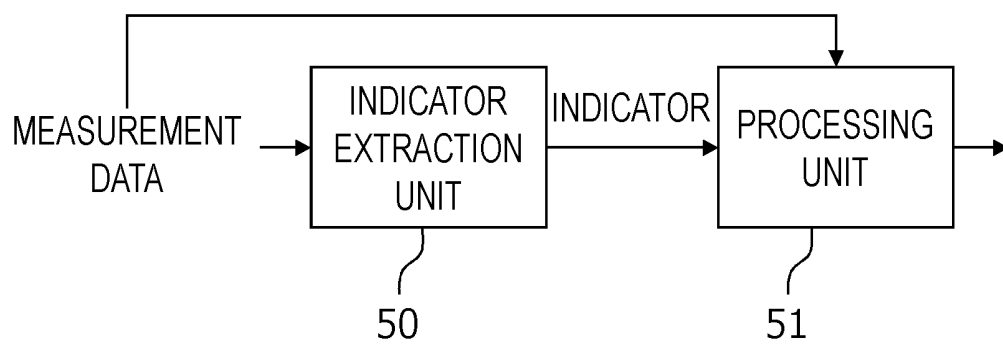


FIG. 5



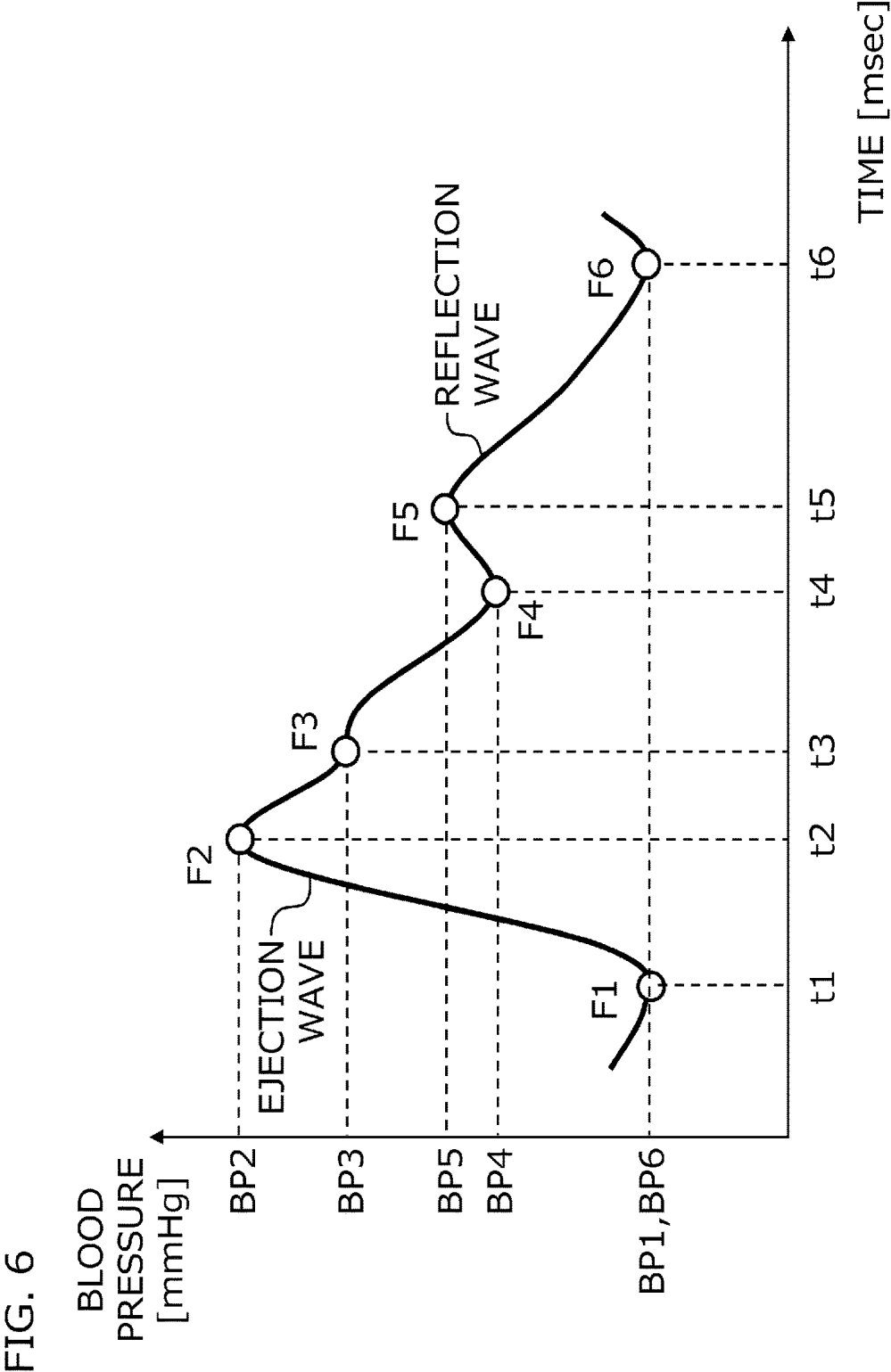


FIG. 7

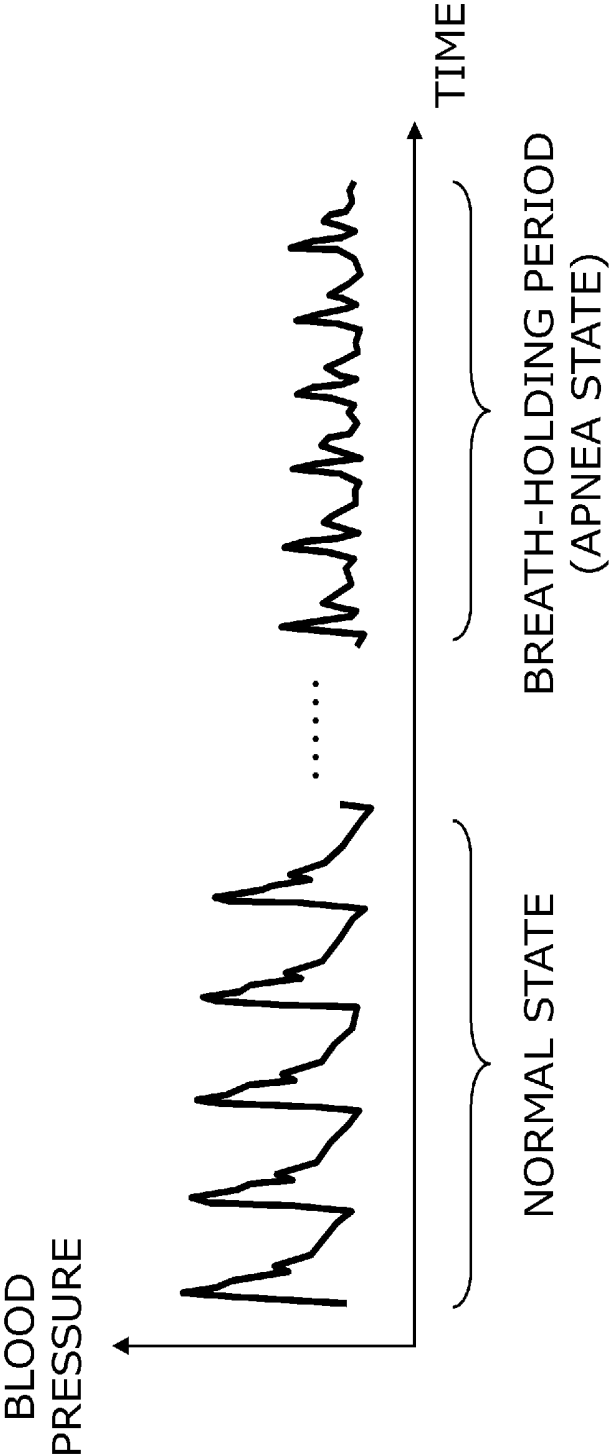


FIG. 8

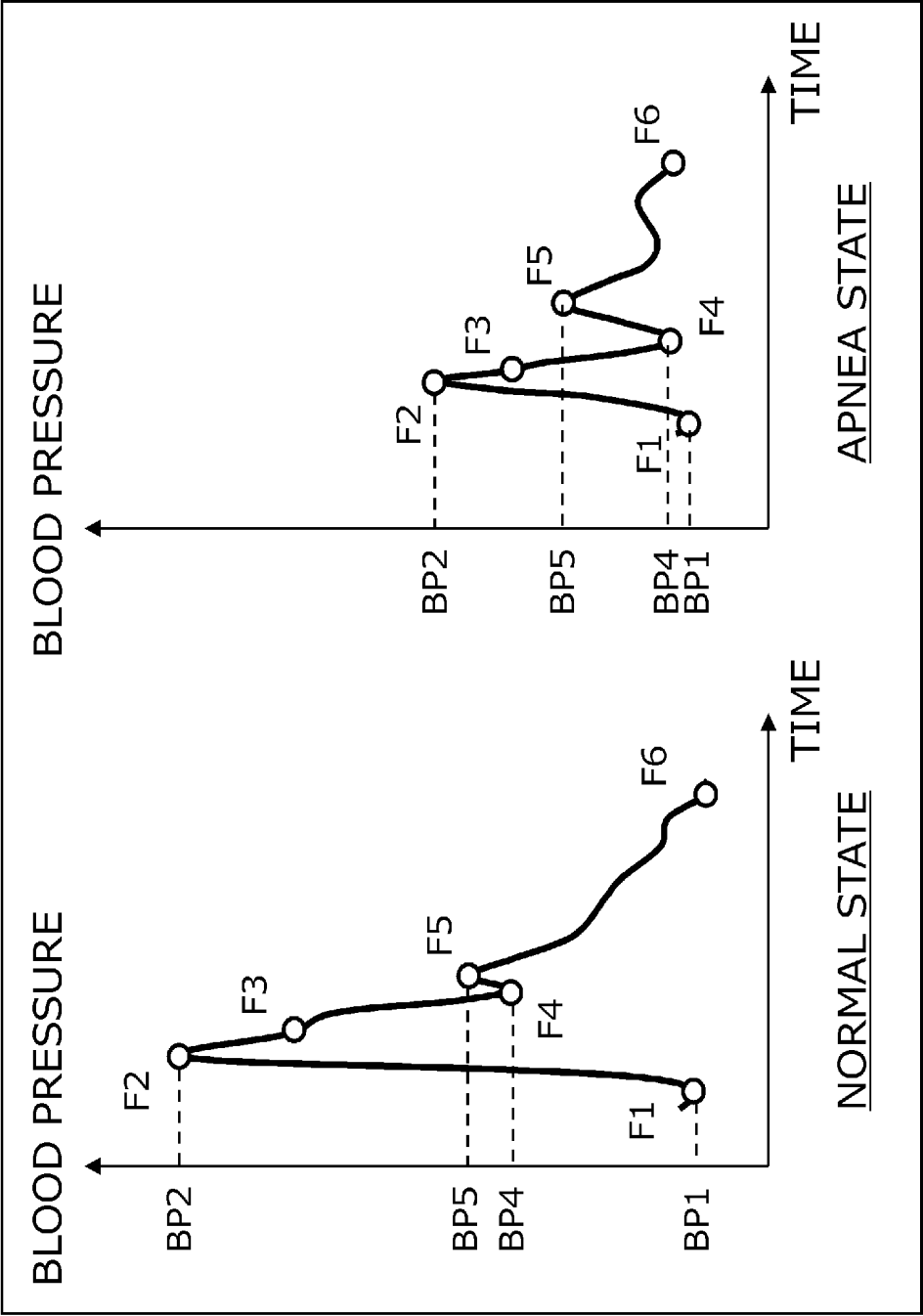


FIG. 9

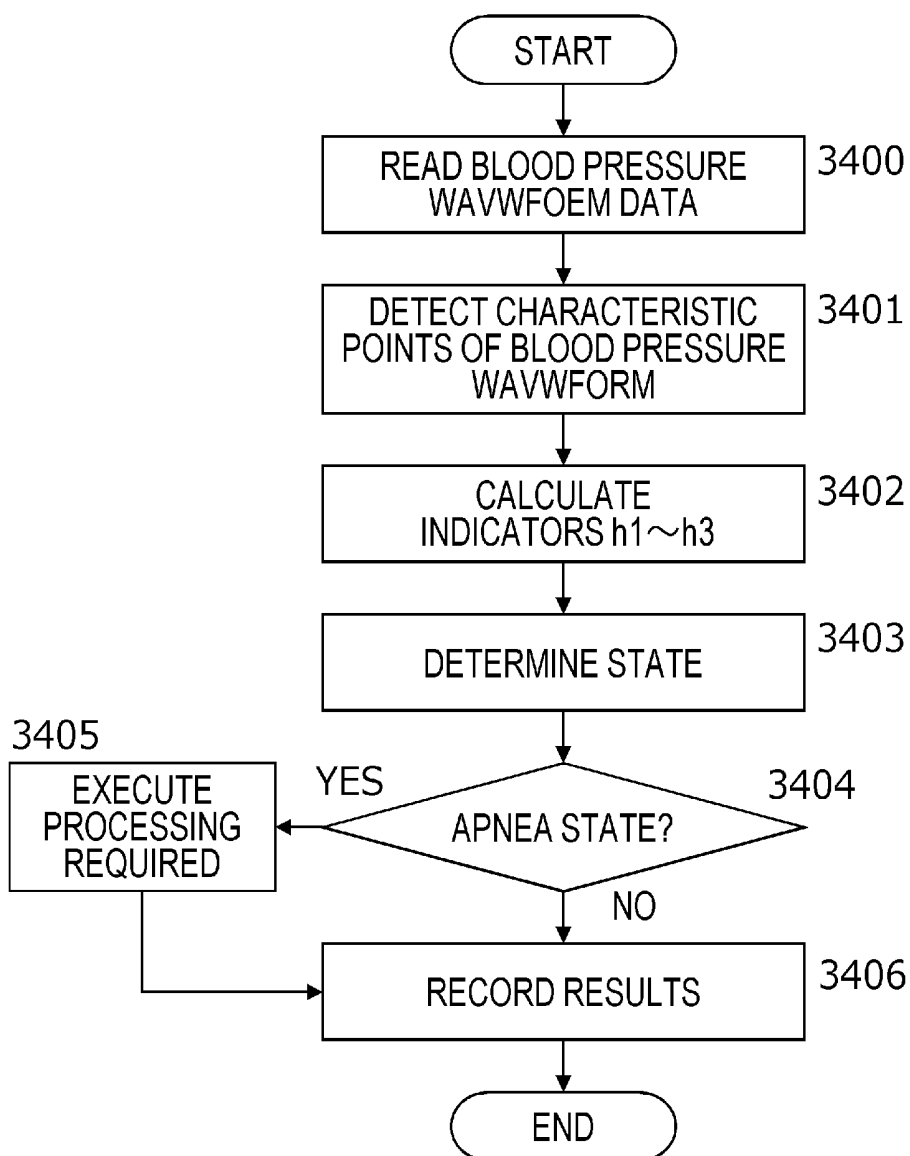


FIG. 10

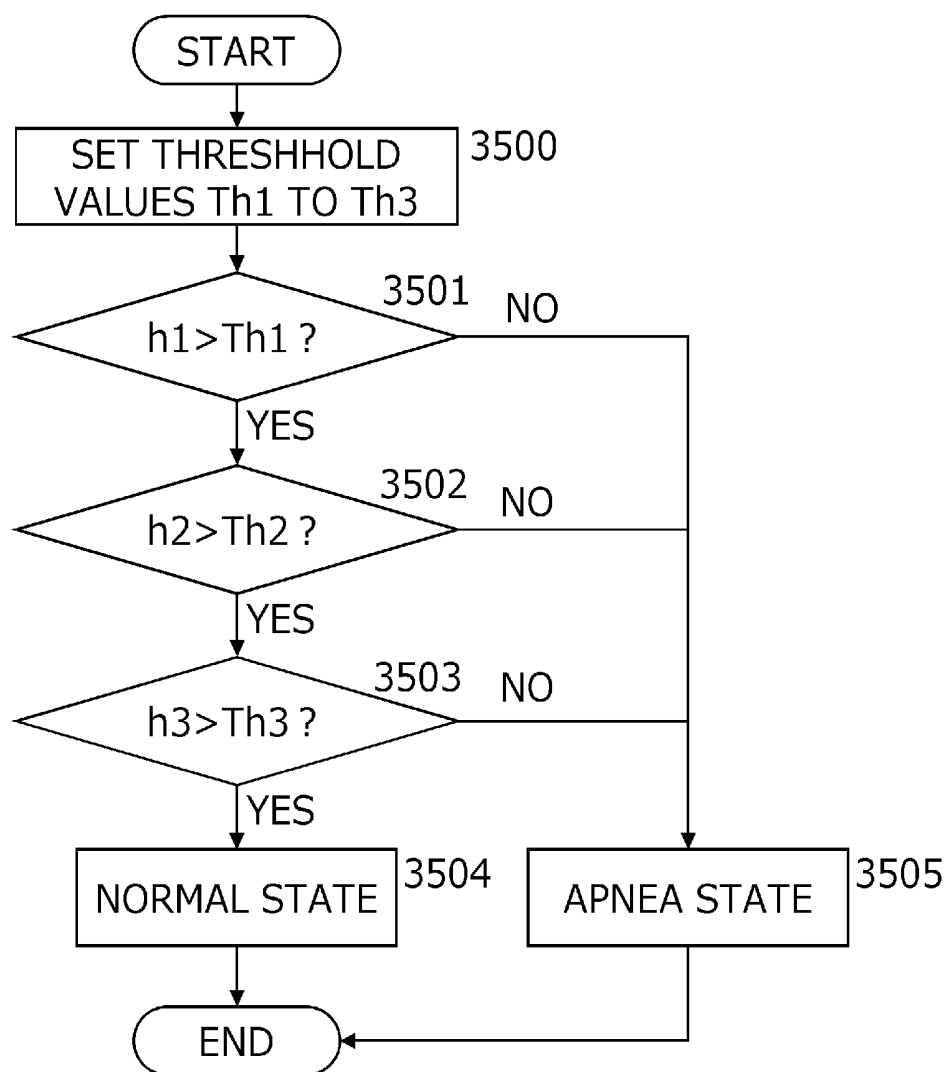
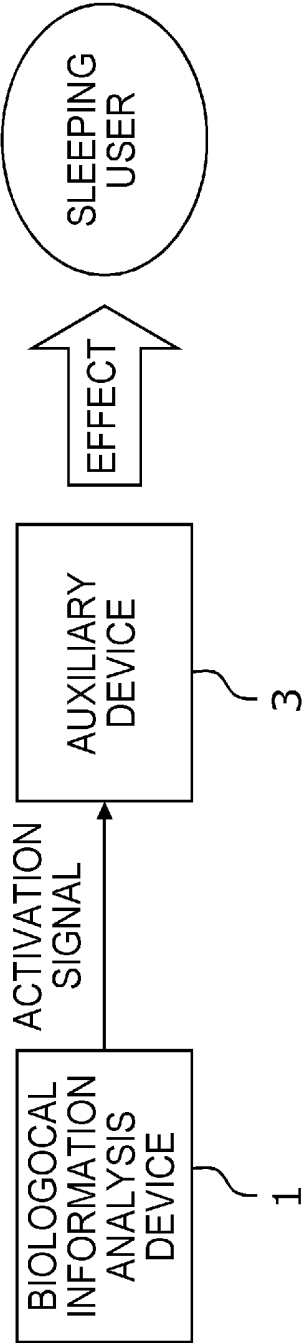


FIG. 11



BIOLOGICAL INFORMATION ANALYSIS DEVICE, SYSTEM, AND PROGRAM

TECHNICAL FIELD

[0001] The present invention relates to technology for acquiring useful information from a blood pressure waveform that has been measured.

RELATED ART

[0002] There is a known technology for measuring changes in the internal pressure of a radial artery and recording the shape of a pressure pulse wave (blood pressure waveform). Patent Document 1 (JP 2008-61824A) discloses that a blood pressure waveform is measured using a tonometry method, and pieces of information such as an AI (Augmentation Index) value, a pulse wave period, a baseline fluctuation rate, sharpness, and an ET (Ejection Time) are acquired from the blood pressure waveform. Also, Patent Document 2 (JP 2005-532111A) discloses that a blood pressure waveform is measured using a wristwatch-type blood pressure meter, in which a mean arterial pressure, a mean systolic pressure, a mean diastolic pressure, a mean systolic pressure indicator, and a mean diastolic pressure indicator are calculated from the blood pressure waveform, and an alert is output when any of these values deviates from a reference value.

RELATED ART DOCUMENTS

Patent Documents

Patent Document 1: JP 2008-61824A

Patent Document 2: JP 2005-532111A

SUMMARY OF THE INVENTION

Problem to be Solved by the Invention

[0003] Conventionally, a PSG (Polysomnography) examination is usually performed to diagnose sleep apnea syndrome. However, a PSG examination is costly and restrains the subject for a long period of time because the subject needs to stay in a medical institution overnight to undergo examination. In addition, in order to record the state of sleep, electrodes are attached to the head, the face, and the body of the subject at required positions, using pieces of tape. Thus, the subject is uncomfortable and a great burden is placed on the subject. Therefore, if it is possible to detect the occurrence of sleep apnea by using an easy method that places less burden on the subject, such a method would be very useful.

[0004] The inventors of the present invention have worked hard to develop a blood pressure measurement device that can accurately measure an ambulatory blood pressure waveform for each heartbeat, and to put such a device into practical use. Through experiments performed on subjects during the development phase, the inventors have found that various kinds of useful information can be extracted from data regarding ambulatory blood pressure waveforms that have been consecutively measured. For example, although conventional blood pressure meters can only acquire information regarding blood pressure, it has become more apparent that various kinds of information related to the body of a user (e.g. information regarding the functions/states of

respiratory organs and circulatory organs), in addition to information related to blood pressure, can be extracted by accurately and non-invasively monitoring ambulatory blood pressure waveforms taken every heartbeat.

[0005] Therefore, the present invention aims to provide a novel technology for acquiring information related to respiratory organs during sleep.

Means for Solving the Problems

[0006] To achieve the above-described aim, the present invention employs the following configurations.

[0007] A biological information analysis device according to the present invention is a biological information analysis device that includes: an indicator extraction unit configured to extract, from data regarding blood pressure waveforms consecutively measured by a sensor configured to be worn on a body part of a sleeping user and to be capable of non-invasively measuring a blood pressure waveform for each heartbeat, an indicator that is related to the functionality of respiratory organs of the user, based on characteristics of the blood pressure waveforms; and a processing unit configured to perform processing that is based on the indicator thus extracted.

[0008] With this configuration, it is possible to acquire information related to the functionality of respiratory organs of a sleeping user by simply monitoring the blood pressure waveform. Furthermore, the blood pressure waveform can be non-invasively measured. Therefore, this configuration is easy for the user, and places less physical or psychological burden on the user.

[0009] It is preferable that the indicator extraction unit is configured to determine whether a blood pressure waveform is a blood pressure waveform in a normal state or a blood pressure waveform in an apnea state based on the characteristics of the blood pressure waveform, and extract an indicator that indicates a normal state or an apnea state as the indicator related to the functionality of the respiratory organs.

[0010] If sleep apnea occurs, the blood pressure waveform shows significant changes compared to that in a normal state. Therefore, by focusing on the characteristics of the blood pressure waveform, it is possible to determine whether the blood pressure waveform is that in a normal state or that in an apnea state, with certain reliability.

[0011] It is preferable that the characteristics of a blood pressure waveform are characteristics of the shape of a blood pressure waveform corresponding to one heartbeat. Examples of characteristics of the shape of a blood pressure waveform include “a difference between a systolic blood pressure and a diastolic blood pressure in a blood pressure waveform corresponding to one heartbeat”, “a difference between a minimum value that appears after a systolic blood pressure, and a diastolic blood pressure, in a blood pressure waveform corresponding to one heartbeat”, and “a difference between a maximum value that appears after a minimum value that appears after a systolic blood pressure, and a diastolic blood pressure, in a blood pressure waveform corresponding to one heartbeat”. The values of these characteristics are significantly lower in an apnea state than in a normal state. Therefore, it is possible to determine whether the state is an apnea state or a normal state by performing a simple comparison using threshold values.

[0012] It is preferable that the processing unit is configured to perform processing to resolve an apnea state of the

user. For example, it is preferable that the processing includes at least one of; processing that is performed to activate a device that assists the user in breathing; processing that is performed to activate a device that wakes up the user; and processing that is performed to activate a device that changes the user's posture. If such kinds of processing can resolve an apnea state of the user, it can be expected that the risk of a serious event occurring will be reduced.

[0013] Note that the present invention can be interpreted as a biological information analysis device or system that is provided with at least one of the above-described configurations or at least one of the above-described functions. The present invention can also be interpreted as a biological information analysis method that includes at least part of the above-described processing, or a program that causes a computer to execute such a method, or a computer-readable recording medium on which such a program is recorded in a non-transitory manner. The present invention can be formed by combining the above-described configurations and the above-described kinds of processing with each other unless no technical inconsistency occurs.

Effects of the Invention

[0014] According to the present invention, it is possible to provide a novel technology for acquiring information related to respiratory organs during sleep.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] FIG. 1 shows a schematic external configuration of a biological information analysis system 10.

[0016] FIG. 2 is a block diagram showing a hardware configuration of the biological information analysis system 10.

[0017] FIG. 3 is a cross-sectional view schematically showing a configuration of a blood pressure measurement unit 20 and a state in which measurement is performed.

[0018] FIG. 4 shows a blood pressure waveform that is measured by the blood pressure measurement unit 20.

[0019] FIG. 5 is a block diagram illustrating processing that is performed by a biological information analysis device 1.

[0020] FIG. 6 shows a waveform (a blood pressure waveform) of a pressure pulse wave from a radial artery corresponding to one heartbeat.

[0021] FIG. 7 shows examples of data regarding blood pressure waveforms in a normal state and during a breath-holding period according to Example 1.

[0022] FIG. 8 shows an example of a blood pressure waveform that is observed in an apnea state and an example of a blood pressure waveform that is observed in a normal state according to Example 1.

[0023] FIG. 9 is a flowchart for apnea determination processing according to Example 1.

[0024] FIG. 10 is a flowchart for determination processing that is performed to determine whether a state is an apnea state or a normal state according to Example 1.

[0025] FIG. 11 shows an application example of the biological information analysis device 1.

EMBODIMENTS OF THE INVENTION

[0026] The following describes a preferred embodiment of the present invention with reference to the drawings. Note that the following descriptions of components may be modi-

fied as appropriate depending on the configuration of a device to which the present invention is applied, and on various conditions, and the scope of the present invention is not intended to be limited to the following descriptions.

Biological Information Analysis System

[0027] FIG. 1 shows a schematic external configuration of a biological information analysis system 10 according to an embodiment of the present invention. FIG. 1 shows a state in which the biological information analysis system 10 is worn on the left wrist. The biological information analysis system 10 includes a main body 11 and a belt 12 that is fixed to the main body 11. The biological information analysis system 10 is a so-called wearable device, and is worn such that the main body 11 is in contact with the skin on the palm side of the wrist, and the main body 11 is located over a radial artery TD that lies beneath the skin. Although the device is configured to be worn on the radial artery TD in the present embodiment, the device may be configured to be worn on another superficial artery.

[0028] FIG. 2 is a block diagram showing a hardware configuration of the biological information analysis system 10. In general, the biological information analysis system 10 includes a measurement unit 2 and the biological information analysis device 1. The measurement unit 2 is a device that performs measurement to acquire information that is used to analyze biological information, and includes a blood pressure measurement unit 20, a body movement measurement unit 21, and an environment measurement unit 22. However, note that the configuration of the measurement unit 2 is not limited to that shown in FIG. 2. For example, a unit that measures biological information other than blood pressure or a body movement (e.g. body temperature, blood-sugar level, or brain waves) may be added. Also, any unit that is not used in the example described below is not an essential component, and may be omitted from the biological information analysis system 10. The biological information analysis device 1 is a device that analyzes biological information based on information acquired from the measurement unit 2, and includes a control unit 23, an input unit 24, an output unit 25, a communication unit 26, and a storage unit 27. The units 20 to 27 are connected to each other so that signals can be exchanged between them via a local bus or other signal lines. The biological information analysis system 10 also includes a power supply (a battery), which is not shown.

[0029] The blood pressure measurement unit 20 measures a pressure pulse wave from the radial artery TD by using a tonometry method. The tonometry method is for forming a flat area in the artery TD by pressing the artery from the skin with appropriate pressure, adjusting the balance between the internal pressure and the external pressure of the artery, and non-invasively measuring the pressure pulse wave using a pressure sensor.

[0030] The body movement measurement unit 21 includes a tri-axis acceleration sensor, and measures the movement of the user's body (body movement) using this sensor. The body movement measurement unit 21 may include a circuit that converts the format of an output from the tri-axis acceleration sensor into a format that is readable to the control unit 23.

[0031] The environment measurement unit 22 measures environmental information that may affect mental and physical conditions of the user (in particular the blood pressure).

The environment measurement unit **22** may include, for example, an atmospheric temperature sensor, a humidity sensor, an illuminance sensor, an altitude sensor, a position sensor, and so on. The environment measurement unit **22** may include a circuit that converts the format of outputs from these sensors and so on into a format that is readable to the control unit **23**.

[0032] The control unit **23** performs various kinds of processing, such as controlling each unit of the biological information analysis system **10**, acquiring data from the measurement unit **2**, storing the acquired data in the recording unit **27**, processing and analyzing data, and inputting and outputting data. The control unit **23** includes a hardware processor (hereinafter referred to as the “CPU”) a ROM (Read Only Memory), a RAM (Random Access Memory), and so on. Processing that is performed by the control unit **23**, which will be described later, is realized by the CPU reading and executing a program stored in the ROM or the storage unit **27**. The RAM functions as a work memory that is used by the control unit **23** when performing various kinds of processing. Although acquisition of data from the measurement unit **2** and the storing of data in the storage unit **27** are performed by the control unit **23** in the present embodiment, it is possible to employ a configuration in which the measurement unit **2** directly stores (writes) data in the storage unit **27**.

[0033] Each of the constituent components of the embodiment such as a measurement unit, an indicator extraction unit, a processing unit, a determination unit, a risk database, an input unit, an output unit, a case database, and so on may be implemented as pieces of hardware in the biological information analysis system **10**. The indicator extraction unit, the processing unit, and the determination unit may receive an executable program stored in the storage unit **27**, and execute the program. The indicator extraction unit, the processing unit, and the determination unit may receive data from the blood pressure measurement unit **20**, the body movement measurement unit **21**, the environment measurement unit **22**, the input unit **24**, the output unit **25**, the communication unit **26**, the storage unit **27**, and so on as required. Databases such as the risk database and the case database may be implemented using the storage unit **27** and so on, and store pieces of information that are arranged such that a data search and data accumulation can be easily performed. Here, for example, the configuration, operations, and so on of the biological information analysis system **10** are disclosed in JP 2016-082069A. The contents of this disclosure are incorporated herein by reference. Also, the configuration, operations, and so on of the blood pressure measurement unit are disclosed in JP 2016-087003A. The contents of this disclosure are incorporated herein by reference.

[0034] The input unit **24** provides an operation interface for the user. For example, an operation button, a switch, a touch panel, and so on may be used.

[0035] The output unit **25** provides an interface that outputs information to the user. For example, a display device (such as a liquid crystal display) that outputs information using images, an audio output device or a beeper that outputs information using audio, an LED that outputs information by blinking, a vibration device that outputs information by vibrating, and so on may be used.

[0036] The communication unit **26** performs data communication with another device. Any data communication method such as a wireless LAN or Bluetooth (registered trademark) may be used.

[0037] The storage unit **27** is a storage medium that can store data and from which data can be read out, and stores programs that are to be executed by the control unit **23**, pieces of measurement data acquired from the measurement units, and various kinds of data acquired by processing the pieces of measurement data, and so on. The storage unit **27** is a medium that accumulates pieces of information that are to be stored, through an electrical, magnetic, optical, mechanical, or chemical action. For example, a flash memory is used. The storage unit **27** may be a portable unit such as a memory card, or built into the biological information analysis system **10**.

[0038] At least one unit or all units out of the body movement measurement unit **21**, environment measurement unit **22**, the control unit **23**, the input unit **24**, the output unit **25**, and the storage unit **27** may be configured as a device that is separate from the main body **11**. That is, as long as the blood pressure measurement unit **20** and the main body **11** that incorporates a circuit that controls the blood pressure measurement unit **20** are configured to be wearable on a wrist, the configurations of other units can be freely designed. If this is the case, the main body **11** cooperates with another unit via the communication unit **26**. Various configurations can be conceived of. For example, the functions of the control unit **23**, the input unit **24**, and the output unit **25** may be realized using a smartphone application, and required data may be acquired from an activity monitor that has the functions of the body movement measurement unit **21** and the environment measurement unit **22**. Also, a sensor that measures biological information other than blood pressure may be provided. For example, a sleep sensor, a pulse oximeter (an SpO₂ sensor), a respiration sensor (a flow sensor), a blood-sugar level sensor, and the like may be combined.

[0039] Although the sensor (the blood pressure measurement unit **20**) that measures blood pressure and the component (including the control unit **23** and so on) that performs processing to analyze blood pressure waveform data are provided in one device in the present embodiment, they may be provided in separate members. In the present embodiment, the component (including the control unit **23** and so on) that performs processing to analyze biological information is referred to as a biological information analysis device, and the device that includes the combination of the measurement unit and the biological information analysis device is referred to as a biological information analysis system. However, these names are given for descriptive purposes, and the measurement unit and the component that performs processing to analyze biological information may be referred to as a biological information analysis device as a whole, or other names may be used.

Measurement of Blood Pressure Waveform

[0040] FIG. **3** is a cross-sectional view schematically showing the configuration of the blood pressure measurement unit **20** and a state in which measurement is performed. The blood pressure measurement unit **20** includes a pressure sensor **30** and a pressurizing mechanism **31** for pressing the pressure sensor **30** against a wrist. The pressure sensor **30** includes a plurality of pressure detection elements **300**. The

pressure detection elements **300** detect pressure and convert the pressure into an electrical signal. For example, elements that utilize a piezoresistive effect may be preferably used. The pressurizing mechanism **31** includes, for example, an air bag and a pump that adjusts the internal pressure of the air bag. As a result of the control unit **23** controlling the pump to increase the internal pressure of the air bag, the air bag expands and the pressure sensor **30** is pressed against the surface of the skin. Note that the pressurizing mechanism **31** may be any mechanism as long as it can adjust the pressing force of the pressure sensor **30** applied to the surface of the skin, and is not limited to a mechanism that uses an air bag.

[0041] Upon the biological information analysis system **10** being worn on a wrist and activated, the control unit **23** controls the pressurizing mechanism **31** of the blood pressure measurement unit **20** to keep the pressing force of the pressure sensor **30** in an appropriate state (a tonometry state). Then, pressure signals detected by the pressure sensor **30** are sequentially acquired by the control unit **23**. Pressure signals acquired from the pressure sensor **30** are generated by digitizing analogue physical amounts (e.g. voltage values) output by the pressure detection elements **300**, through an A/D converter circuit or the like that employs a well-known technology. Preferable analogue values such as current values or resistance values may be employed as the analogue physical amounts, depending on the type of the pressure detection elements **300**. Signal processing such as the aforementioned A/D conversion may be performed using a predetermined circuit provided in the blood pressure measurement unit **20**, or performed by another unit (not shown) provided between the blood pressure measurement unit **20** and the control unit **23**. Each pressure signal acquired by the control unit **23** corresponds to an instantaneous value of the internal pressure of the radial artery TD. Therefore, it is possible to acquire time-series data regarding blood pressure waveforms by acquiring pressure signals with time granularity and continuity that make it possible to ascertain a blood pressure waveform for each heartbeat. The control unit **23** stores the pressure signals sequentially acquired from the pressure sensor **30**, in the storage unit **27**, together with information regarding points in time at which the pressure signals were measured. The control unit **23** may store the acquired pressure signals in the storage unit **27** without change, or store the pressure signals in the storage unit **27** after performing required signal processing on the pressure signals. Required signal processing includes, for example, processing that is performed to calibrate each pressure signal such that the amplitude of the pressure signal matches the blood pressure value (e.g. the brachial blood pressure), processing that is performed to reduce or remove noise in each pressure signal, and so on.

[0042] FIG. 4 shows a blood pressure waveform measured by the blood pressure measurement unit **20**. The horizontal axis indicates time and the vertical axis indicates blood pressure. Although the sampling frequency may be set to any value, it is preferably set to be no less than 100 Hz so that characteristics of the shape of a waveform corresponding to one heartbeat can be reproduced. Typically, the period of one heartbeat is approximately one second, and therefore approximately one hundred or more data points can be acquired on a waveform corresponding to one heartbeat.

[0043] The blood pressure measurement unit **20** according to the present embodiment is advantageous in terms of the following.

[0044] The blood pressure measurement unit **20** can measure a blood pressure waveform for each heartbeat. As a result, it is possible to acquire various indicators related to blood pressure, the state of the heart, cardiovascular risks, and so on, based on the characteristics of the shape of the blood pressure waveform. In addition, it is possible to monitor for instantaneous values of blood pressure. Therefore, it is possible to instantaneously detect a blood pressure surge (a sudden rise in the blood pressure value), and to detect changes in blood pressure and irregularities in a blood pressure waveform that may occur in a very short period of time (corresponding to one to several heartbeats) without missing them.

[0045] As a portable blood pressure meter, a blood pressure meter that is to be worn on a wrist or an upper arm and employs an oscillometric method to measure blood pressure has come into practical use. However, a conventional portable blood pressure meter can only measure the mean value of blood pressure based on changes in the internal pressure of a cuff during a period of several seconds to a dozen or so seconds corresponding to a plurality of heartbeats, and cannot acquire time-series data regarding a blood pressure waveform for each heartbeat, unlike the blood pressure measurement unit **20** according to the present embodiment.

[0046] The blood pressure measurement unit **20** can record time-series data regarding blood pressure waveforms. By acquiring time-series data regarding blood pressure waveforms, and, for example, discerning characteristics of the blood pressure waveform related to temporal changes, or performing a frequency analysis on the time-series data to extract a specific frequency component, it is possible to acquire various indicators related to blood pressure, the state of the heart, cardiovascular risks, and so on.

[0047] The device employs a portable (wearable) type configuration, and less burden is placed on the user during measurement. Therefore, continuous measurement for a long time, and even 24-hour blood pressure monitoring, can be relatively easily performed. Also, since the device is of a portable type, changes in not only blood pressure under resting conditions, but also an ambulatory blood pressure (for example, during daily life or exercise) can be measured. As a result, it is possible to grasp how blood pressure is affected by behaviours in daily life (such as sleeping, eating, commuting, working, and taking medicine) and exercise, for example.

[0048] Conventional products are types of devices that measure blood pressure under resting conditions, with an arm or a wrist fixed to a blood pressure measurement unit, and cannot measure changes in blood pressure in daily life or during exercise, unlike the biological information analysis system **10** according to the present embodiment.

[0049] The blood pressure measurement unit **20** can be easily combined or linked with other sensors. For example, it is possible to make an evaluation of a cause-effect relationship or a composite evaluation with information that can be acquired by other sensors (e.g. a body movement, environmental information such as an atmospheric temperature, biological information such as an SpO2 and respiration information).

Biological Information Analysis Device

[0050] FIG. 5 is a block diagram illustrating processing that is performed by the biological information analysis device **1**. As shown in FIG. 5, the biological information

analysis device 1 includes an indicator extraction unit 50 and a processing unit 51. In the present embodiment, processing performed by the indicator extraction unit 50 and the processing unit 51 may be realized by the control unit 23 executing a program that is required for the processing. The program may be stored in the storage unit 27. When the control unit 23 executes the required program, the subject program stored in the ROM or storage unit 27 is loaded to the RAM. Then, the control unit 23 interprets and executes the program loaded to the RAM, using the CPU, to control each constituent component. Note that at least one or all of the processing procedures executed by the indicator extraction unit 50 and the processing unit 51 may be realized using a circuit such as an ASIC or an FPGA. Alternatively, at least one or all of the processing procedures executed by the indicator extraction unit 50 and the processing unit 51 may be realized using a computer (e.g. a smartphone, a tablet terminal, a personal computer, or a cloud server) that is separate from the main body 11.

[0051] The indicator extraction unit 50 acquires time-series data regarding blood pressure waveforms, which have been consecutively measured by the blood pressure measurement unit 20, from the storage unit 27. The indicator extraction unit 50 extracts, from the acquired time-series data regarding blood pressure waveforms, indicators that are related to characteristics of the blood pressure waveforms. Here, characteristics of a blood pressure waveform include, for example, characteristics of the shape of a blood pressure waveform corresponding to one heartbeat, temporal changes in a blood pressure waveform, and frequency components of a blood pressure waveform. However, characteristics of a blood pressure waveform are not limited to those listed above. The extracted indicators are output to the processing unit 51. There are various characteristics and indicators regarding a blood pressure waveform, and the characteristics and indicators that are to be extracted may be designed or selected as appropriate according to the purpose of processing that is to be performed by the processing unit 51. Characteristics and indicators that can be extracted from measurement data regarding blood pressure waveforms according to the present embodiment will be described later in detail.

[0052] When obtaining indicators, the indicator extraction unit 50 may use measurement data that has been acquired by the body movement measurement unit 21 and/or measurement data that has been acquired by the environment measurement unit 22, in addition to measurement data regarding blood pressure waveforms. Also, although not shown in the drawings, pieces of measurement data that have been acquired by a sleep sensor, an SpO₂ sensor, a respiration sensor (a flow sensor), a blood-sugar level sensor, and the like may be combined with one another. By performing complex analysis on a plurality of kinds of measurement data acquired by a plurality of sensors, it is possible to perform more advanced information analysis of a blood pressure waveform. For example, it is possible to extract information regarding the influence of body movement, an activity amount, activity intensity, a change in an atmospheric temperature, etc. on blood pressure, and thus evaluate the cause-effect relationship, the correlation, etc. between pieces of measurement data.

[0053] The processing unit 51 receives the indicators extracted by the indicator extraction unit 50. The processing unit 51 performs processing that is based on the received

indicators. Various kinds of processing can be conceived of as processing that is based on the indicators. For example, the processing unit 51 may provide the values of the extracted indicators or changes in the values to a user, a doctor, a public health nurse, or the like to prompt the utilization of the indicators in the fields of health care, treatment, health guidance, and so on. Alternatively, the processing unit 51 may estimate respiratory risks from the extracted indicators, or provide guidelines for health maintenance or risk mitigation. Furthermore, the processing unit 51 may notify the user or his/her doctor of the indicators, or perform control to activate another device.

Information Acquired from Blood Pressure Waveform

[0054] FIG. 6 shows a waveform (a blood pressure waveform) of a pressure pulse wave from a radial artery corresponding to one heartbeat. The horizontal axis indicates time t (msec) and the vertical axis indicates blood pressure BP (mmHg).

[0055] A blood pressure waveform is the waveform of a composite wave constituted by an “ejection wave” that is generated when the heart contracts and pumps out blood, and a “reflection wave” that is generated when an ejection wave is reflected at a branch point of a peripheral vessel or an artery. The following shows examples of characteristic points that can be extracted from a blood pressure waveform corresponding to one heartbeat.

[0056] A point F1 is the rising point of the pressure pulse wave. The point F1 corresponds to the ejection start point of the heart, i.e. the point at which the aortic valve opens.

[0057] A point F2 is a point at which the amplitude (the pressure) of the ejection wave is at the maximum (a first peak).

[0058] A point F3 is an inflection point that appears midway in a drop in the ejection wave, due to a reflection wave being superimposed.

[0059] A point F4 is the minimum point, which appears between the ejection wave and the reflection wave, and is also referred to as a notch. This point corresponds to the point at which the aortic valve closes.

[0060] A point F5 is the peak of the reflection wave (a second peak), which appears after the point F4.

[0061] A point F6 is the end point of one heartbeat, and corresponds to the ejection start point of the next heartbeat, i.e. the start point of the next heartbeat.

[0062] The indicator extraction unit 50 may use any algorithm to detect the above-described characteristic points. For example, the indicator extraction unit 50 may perform computations to obtain an n^{th} order differential waveform of a blood pressure waveform, and detect the zero-crossing points to extract the characteristic points (the inflection points) of the blood pressure waveform (the points F1, F2, F4, F5, and F6 can be detected from the first order differential waveform, and the point F3 can be detected from the second order differential waveform or the fourth order differential waveform). Alternatively, the indicator extraction unit 50 may read out, from the storage unit 27, a waveform pattern on which the characteristic points have been arranged in advance, and perform fitting of the waveform pattern to the target blood pressure waveform to specify the respective positions of the characteristic points.

[0063] The indicator extraction unit 50 performs computations based on time t and pressure BP of each of the above-described characteristic points F1 to F6, and can thus

obtain various kinds of information (values, characteristic amounts, indicators, etc.) from the blood pressure waveform of one heartbeat. The following are typical examples of information that can be acquired from a blood pressure waveform. Note that t_x and BP_x respectively represent time and blood pressure corresponding to a characteristic point F_x .

[0064] Pulse Wave Interval (Period of Heartbeat)
 $TA = t_6 - t_1$

[0065] Heart Rate $PR = 1/TA$

[0066] Pulse Wave Rising Time $UT = t_2 - t_1$

[0067] Systole $TS = t_4 - t_1$

[0068] Diastole $TD = t_6 - t_4$

[0069] Reflection Wave Delay Time $= t_3 - t_1$

[0070] Maximum Blood Pressure (Systolic Blood Pressure) $SBP = BP_2$

[0071] Minimum Blood Pressure (Diastolic Blood Pressure) $DBP = BP_1$

[0072] Mean Blood Pressure $MAP = (\text{Area of Blood Pressure Waveform from } t_1 \text{ to } t_6) / \text{Period of Heartbeat } TA$

[0073] Mean Blood Pressure during Systole $= (\text{Area of Blood Pressure Waveform from } t_1 \text{ to } t_4) / \text{Systole } TS$

[0074] Mean Blood Pressure during Diastole $= (\text{Area of Blood Pressure Waveform from } t_4 \text{ to } t_6) / \text{Diastole } TD$

[0075] Pulse Pressure $PP = \text{Maximum Blood Pressure } SBP - \text{Minimum Blood Pressure } DBP$

[0076] Late Systolic Pressure $SBP_2 = BP_3$

[0077] AI (Augmentation Index) $= (\text{Late Systolic Pressure } SBP_2 - \text{Minimum Blood Pressure } DBP) / \text{Pulse Pressure } PP$

[0078] Basic statistics of these pieces of information (values, characteristic amounts, and indicators) can also be used as indicators. Basic statistics include, for example, representative values (a mean value, a median value, a mode value, the maximum value, the minimum value, and so on) and the degree of scatter (dispersion, a standard deviation, a coefficient of variation, and so on). Temporal changes in these pieces of information (values, characteristic values, and indicators) can also be used as indicators.

[0079] In addition, the indicator extraction unit 50 can also acquire an indicator called BRS (Baroreflex Sensitivity) by performing computations on pieces of beat information. This indicator indicates the ability to regulate blood pressure to be constant. Examples of methods for calculating the indicator include a spontaneous sequence method. This is a method for only extracting a sequence in which the maximum blood pressure SBP and the pulse wave interval TA consecutively rise or fall over the period of three or more beats in synchronization with each other, plotting the maximum blood pressure SBP and the pulse wave interval TA onto a two-dimensional plane, and defining the inclination of the regression line obtained through a least squares method as the BRS.

[0080] As described above, the use of the biological information analysis system 10 according to the present embodiment makes it possible to acquire various kinds of information from blood pressure waveform data. However, the biological information analysis system 10 need not implement all of the functions that are required to acquire all of the kinds of information described above. The biological information analysis system 10 need only implement functions that are required to acquire necessary information, depending on the configuration of the biological information

analysis system 10, who the user is, the purpose of use, the location of use, and so on. Also, each function may be provided as a program module (a piece of application software), and the biological information analysis system 10 may employ a mechanism with which a function can be added by installing a necessary program module on the biological information analysis system 10.

[0081] The following illustrates an example, which is a specific application, of the biological information analysis system 10.

Example 1

[0082] During an experiment on the subject, the inventors performed a Valsalva test, which is equivalent to creating an apnea state, and observed the data shown in FIG. 7 regarding a blood pressure waveform. The data on the left shows a blood pressure waveform in a normal state, and the data on the right shows a blood pressure waveform during a breath-holding period (equivalent to an apnea state). It can be seen that there is a significant difference between the blood pressure waveform in the normal state and that in the apnea state. Based on such findings, the present example proposes an algorithm that makes it possible to easily detect the occurrence of sleep apnea in real time by monitoring the blood pressure waveform of a sleeping user, based on characteristics of the shape of the blood pressure waveform. [0083] FIG. 8 shows an example of a blood pressure waveform that is observed in an apnea state, and an example of a blood pressure waveform that is observed in a normal state. The characteristic points shown in the drawing are the same as those defined in FIG. 6. That is: the point F1 is the rising point of the pressure pulse wave; the point F2 is a point at which the amplitude of the ejection wave is the maximum (the first peak); the point F3 is an inflection point that appears midway in a drop in the ejection wave, due to a reflection wave being superimposed; the point F4 is the minimum value (the notch), which occurs between the ejection wave and the reflection wave; the point F5 is the peak of the reflection wave (the second peak), which appears after the point F4; and the point F6 is the end point of one heartbeat.

[0084] When the two blood pressure waveforms are compared with each other, there are the following two remarkable differences between them in terms of shape characteristics, for example. (1) In the apnea state, the pulse pressure (the difference between the systolic blood pressure and the diastolic blood pressure) is significantly smaller than that in the normal state. (2) In the apnea state, the overlap between the ejection wave and the reflection wave is small, and there is a deep valley at the point F4.

[0085] Therefore, in the present example, the following three characteristic amounts h_1 to h_3 are used to discern between a blood pressure waveform in an apnea state and a blood pressure waveform in a normal state.

[0086] The first characteristic amount h_1 is an indicator that indicates a pulse pressure PP, and is defined as follows. Note that BP_x indicates the value of amplitude (the blood pressure value) at a characteristic point F_x .

[0087] $h_1 = \text{Systolic Blood Pressure } SBP - \text{Diastolic Blood Pressure } DBP = BP_2 - BP_1$

[0088] Both the second characteristic amount h_2 and the third characteristic amount h_3 are characteristic amounts for estimating the degree of overlap between the ejection wave and the reflection wave, and are defined as follows.

[0089] $h2 = \text{Amplitude at Point F4} - \text{Diastolic Blood Pressure DBP} = \text{BP4} - \text{BP1}$

[0090] $h3 = h2 / (\text{Amplitude at Point F5} - \text{Diastolic Blood Pressure DBP}) = (\text{BP4} - \text{BP1}) / (\text{BP5} - \text{BP1})$

[0091] All of these characteristic amounts $h1$ to $h3$ are significantly smaller in an apnea state than in a normal state. Therefore, it is possible to easily detect the occurrence of obstructive apnea by setting threshold values $Th1$ to $Th3$ in advance, which are used to determine whether a blood pressure waveform is that in a normal state or that in an apnea state, with respect to the characteristic amounts $h1$ to $h3$ respectively, and performing threshold value determination using the characteristic amounts $h1$ to $h3$, each time a blood pressure waveform is acquired.

[0092] FIG. 9 shows an example of a flowchart for apnea determination processing according to the present example. This processing is repeatedly executed while the user is sleeping (e.g. once every heartbeat). Whether or not the user is sleeping may be automatically determined using the result of body movement detection performed by the body movement measurement unit 21, for example. Alternatively, the user may set his/her sleep start time (bedtime) and sleep end time (wakeup time) himself/herself.

[0093] The indicator extraction unit 50 acquires data regarding blood pressure waveforms from the blood pressure measurement unit 20 (step 3400), and detects the characteristic points F1 to F6 of a blood pressure waveform corresponding to one heartbeat by performing characteristic point detection processing (step 3401). A specific method for performing characteristic point detection processing is as described with reference to FIG. 6. Next, the indicator extraction unit 50 calculates the values of the characteristic amounts $h1$ to $h3$, using the blood pressure values BP1, BP2, BP4, and BP5 at the characteristic points F1, F2, F4, and F5 (step 3402). Then, based on the values of the characteristic amounts $h1$ to $h3$, the indicator extraction unit 50 determines whether the blood pressure waveform is a blood pressure waveform in a normal state or a blood pressure waveform in an apnea state, and outputs an indicator that indicates a normal state or an apnea state (e.g. a binary indicator that takes 1 in a normal state and takes 0 in an apnea state) to the processing unit 51 (step 3403). If the blood pressure waveform is determined as a blood pressure waveform in a normal state (YES in step 3404), the processing unit 51 executes processing that is required in order to resolve the apnea state of the user (step 3405). The processing unit 51 records measurement values of blood pressure and the apnea state determination indicator to the storage unit 27 together with time information (step 3406). These records can be used as information for ascertaining the presence or absence and the frequency of sleep apnea, or reference information for examination or treatment of sleep apnea syndrome (SAS).

[0094] FIG. 10 shows details of the logic of the determination performed in step 3403.

[0095] First, the indicator extraction unit 50 sets the threshold values $Th1$ to $Th3$ for determination (step 3500). The threshold values $Th1$ to $Th3$ may be fixed values, or changed according to the user's attributes. For example, it is preferable that threshold values have been prepared in advance for each set of attributes (the gender, the age, the height, the weight, and the SAS level), and threshold values that correspond to the user's attributes are used. Alternatively, appropriate thresholds may be set based on data

regarding a blood pressure waveform in a normal state, measured from the user (e.g. the threshold values $Th1$ to $Th3$ are set with reference to the characteristic amounts $h1$ to $h3$ obtained based on data regarding a blood pressure waveform measured immediately after the user has woken up). The indicator extraction unit 50 may read the threshold values $Th1$ to $Th3$ from the storage unit 27, or from another storage such as a cloud server.

[0096] Then, the indicator extraction unit 50 compares the characteristic amounts $h1$ to $h3$ with the threshold values $Th1$ to $Th3$, respectively (steps 3501 to 3503). If an affirmative determination has been made for all of the three characteristic amounts $h1$ to $h3$, the indicator extraction unit 50 determines that the state is "normal" (step 3504), and if a negative determination has been made for any of the characteristic amounts, the indicator extraction unit 50 determines that the state is "apnea" (step 3505).

[0097] In the present example, $h1$, $h2$, and $h3$ are used as characteristic amounts for determination. However, the AI, the value at the peak of the reflection wave (Amplitude at Point F5–Diastolic Blood Pressure DBP), or characteristic amounts obtained by combining these values using the four arithmetic operations may be used for determination. Furthermore, characteristic amounts in the time direction, e.g. the period of time from the point F2 to the point F3 (Point in Time $t3$ at Point F3–Point in Time $t2$ at Point F2) may be used for determination. Also, although the state is determined as "normal" only when an affirmative determination has been made for all of the characteristic amounts in the present example, the state may be determined as "normal" when an affirmative determination has been made for any of the characteristic amounts, or an affirmative determination has been made for at least two of the characteristic amounts. Alternatively, an integrated score $f(h1, h2, h3)$, which is defined as a function of the three characteristic amounts $h1$ to $h3$, may be defined, and apnea determination processing may be performed based on the value of the integrated score f .

[0098] Also, in order to avoid a case in which the result of determination often changes for each beat like "normal"→"apnea"→"normal" . . . , the final determination may be made based on the results of determination corresponding to a plurality of beats. For example, the indicator extraction unit 50 or the processing unit 51 may hold the results of determination corresponding to the previous n beats (n is an integer no less than 2), and if the results of determination corresponding to the n beats and the current result of determination are all "apnea", it may be determined that an "apnea" state was started at the n^{th} beat from the current beat in reverse chronological order. Alternatively, as it is unlikely that a normal state or an apnea state changes to the other in the period of a few beats, sections that each correspond to m beats (m is an integer no less than 5, and is 10 or so, for example) may be defined, and determination as to whether the state is "normal" or "apnea" may be performed for each section. For example, in a given section, if the number of beats determined as "normal" out of m beats is greater than the number of other beats, the section is determined as a "normal" section, and if the number of beats determined as "apnea" is greater than the number of other beats, the section is determined as an "apnea" section.

[0099] In addition, the threshold values may be dynamically changed according to the period of time for which the same state continues. For example, it can be considered that

the longer an apnea state continues, the more likely it is the state returns to the normal state. Therefore, it is preferable that the threshold values decrease seamlessly or stepwise as the period of time for which an apnea state continues increases.

[0100] The processing performed in step 3405 to resolve an apnea state may be any kind of processing. For example, the output unit 25 may emit sound, light, vibrations, or the like to wake up the user. As shown in FIG. 11, the biological information analysis device 1 may be connected to an auxiliary device 3 that can affect the user's respiratory state, and the biological information analysis device 1 may transmit an activation signal to the auxiliary device 3. Examples of the auxiliary device 3 include a device that assists the user in breathing (such as a ventilator used for CPAP (Continuous Positive Airway Pressure)), and a device that secures the airway by changing the user's posture (such as a device that changes the angle of the upper body, the positions of the neck and the chin, or the like by adjusting the recline angle of the bed or the height of the pillow).

[0101] With the above-described configuration according to the present example, it is possible to easily detect the occurrence of sleep apnea in real time by only monitoring a blood pressure waveform. In addition, the biological information analysis system 10 only needs to be worn on a wrist, which is easy and places less physical or psychological burden on the user. If the occurrence of sleep apnea is detected, it is possible to resolve the apnea state by performing the required processing.

[0102] The configurations according to the above-described embodiment and example are no more than specific examples of configurations according to the present invention, and are not intended to limit the scope of the present invention. The present invention may employ various specific configurations without departing from the technical idea thereof. For example, although the above-described example shows a case in which an apnea state (the occurrence of apnea) is detected in real time, the apnea determination algorithm according to the above-described example may be applied to offline apnea determination processing. That is, pieces of measurement data regarding blood pressure waveforms obtained in one night are accumulated in the storage unit 27, and thereafter the indicator extraction unit 50 reads pieces of data regarding blood pressure waveforms from the storage unit 27, one waveform at a time, and sequentially performs apnea determination. As a result, it is possible to obtain information regarding an overnight sleeping period, such as points in time at which apnea occurred, the number of times apnea occurred, and the temporal frequency distribution of apnea.

[0103] The technical idea disclosed in the present description can be specified as the following aspects of the present invention.

Supplementary Note 1

[0104] A biological information analysis device comprising:

[0105] a hardware processor; and a memory configured to store a program,

[0106] wherein the hardware processor is configured to execute the program to

[0107] extract, from data regarding blood pressure waveforms consecutively measured by a sensor that is configured to be worn on a body part of a sleeping user and to be

capable of non-invasively measuring a blood pressure waveform for each heartbeat, an indicator that is related to the functionality of respiratory organs of the user, based on characteristics of the blood pressure waveforms, and

[0108] perform processing that is based on the indicator thus extracted.

Supplementary Note 2

[0109] A biological information analysis system comprising:

[0110] a sensor configured to be worn on a body part of a user and to be capable of non-invasively measuring a blood pressure waveform for each heartbeat; a hardware processor; and a memory configured to store a program,

[0111] wherein the hardware processor is configured to execute the program to

[0112] extract, from data regarding blood pressure waveforms consecutively measured by a sensor configured to be worn on a body part of a sleeping user and to be capable of non-invasively measuring a blood pressure waveform for each heartbeat, an indicator that is related to the functionality of respiratory organs of the user, based on characteristics of the blood pressure waveforms, and

[0113] perform processing that is based on the indicator thus extracted.

Supplementary Note 3

[0114] A biological information analysis method comprising:

[0115] a step of extracting, from data regarding blood pressure waveforms consecutively measured by a sensor configured to be worn on a body part of a sleeping user and to be capable of non-invasively measuring a blood pressure waveform for each heartbeat, an indicator that is related to the functionality of respiratory organs of the user, based on characteristics of the blood pressure waveforms, using at least one hardware processor; and

[0116] a step of performing processing that is based on the indicator thus extracted, using at least one hardware processor.

INDEX TO THE REFERENCE NUMERALS

[0117] 1 . . . biological information analysis device, 2 . . . measurement unit

[0118] 10 . . . biological information analysis system, 11 . . . main body, 12 . . . belt

[0119] 20 . . . blood pressure measurement unit, 21 . . . body movement measurement unit,

[0120] 22 . . . environment measurement unit, 23 . . . control unit, 24 . . . input unit, 25 . . . output unit, 26 . . . communication unit, 27 . . . storage unit

[0121] 30 . . . pressure sensor, 31 . . . pressurizing mechanism, 300 . . . pressure detection element

[0122] 50 . . . indicator extraction unit, 51 . . . processing unit

[0123] 3 . . . auxiliary device

1. A biological information analysis device comprising:
an indicator extraction unit configured to extract, from data regarding blood pressure waveforms consecutively measured by a sensor configured to be worn on a body part of a user and to be capable of non-invasively measuring a blood pressure waveform for each heartbeat, an indicator that is related to the func-

tionality of respiratory organs of the user, based on characteristics of the blood pressure waveforms; and a processing unit configured to perform processing that is based on the indicator thus extracted.

2. The biological information analysis device according to claim 1,

wherein the indicator extraction unit is configured to determine whether a blood pressure waveform is a blood pressure waveform in a normal state or a blood pressure waveform in an apnea state based on the characteristics of the blood pressure waveform, and extract an indicator that indicates a normal state or an apnea state as the indicator related to the functionality of the respiratory organs.

3. The biological information analysis device according to claim 2,

wherein the characteristics of a blood pressure waveform are characteristics of the shape of a blood pressure waveform corresponding to one heartbeat.

4. The biological information analysis device according to claim 3,

wherein the characteristics of a blood pressure waveform include a difference between a systolic blood pressure and a diastolic blood pressure in a blood pressure waveform corresponding to one heartbeat.

5. The biological information analysis device according to claim 3,

wherein the characteristics of a blood pressure waveform include a difference between a minimum value that appears after a systolic blood pressure, and a diastolic blood pressure, in a blood pressure waveform corresponding to one heartbeat.

6. The biological information analysis device according to claim 3,

wherein the characteristics of a blood pressure waveform include a difference between a maximum value that appears after a minimum value that appears after a systolic blood pressure, and a diastolic blood pressure, in a blood pressure waveform corresponding to one heartbeat.

7. The biological information analysis device according to claim 3,

wherein the indicator extraction unit is configured to determine that a blood pressure waveform is in an apnea state when values of the characteristics of the blood pressure waveform are respectively no greater than predetermined threshold values.

8. The biological information analysis device according to claim 3,

wherein the processing unit is configured to perform processing to resolve an apnea state of the user.

9. The biological information analysis device according to claim 8,

wherein the processing includes at least one of: processing that is performed to activate a device that assists the user in breathing; processing that is performed to activate a device that wakes up the user; and processing that is performed to activate a device that changes the user's posture.

10. A biological information analysis system comprising: a sensor configured to be worn on a body part of a user and to be capable of non-invasively measuring a blood pressure waveform for each heartbeat; and

the biological information analysis device according to claim 1, the biological information analysis device being configured to analyze biological information, using data regarding blood pressure waveforms consecutively measured by the sensor.

11. A non-transitory computer-readable medium storing a program that causes a processor to function as the indicator extraction unit and the processing unit of the biological information analysis device according to claim 1.

12. A biological information analysis method comprising: a step of extracting, from data regarding blood pressure waveforms consecutively measured by a sensor configured to be worn on a body part of a user and to be capable of non-invasively measuring a blood pressure waveform for each heartbeat, an indicator that is related to the functionality of respiratory organs of the user, based on characteristics of the blood pressure waveforms; and

a step of performing processing that is based on the indicator thus extracted.

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摘要(译)

一种生物信息分析装置，包括：指示器提取单元，被配置为从关于由配置成佩戴在睡眠用户的身体部位上的传感器连续测量的血压波形的数据中提取并且能够非侵入性地测量血压。每个心跳的波形，一个与用户呼吸器官功能相关的指标，基于血压波形的特征;处理单元，被配置为执行基于如此提取的指示符的处理。

