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(54) **RESPIRATION RATE DETERMINING APPARATUS, RESPIRATION RATE DETERMINING METHOD, AND PROGRAM RECORDING MEDIUM**

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

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(57) **ABSTRACT**

A respiration rate determining apparatus includes: an obtaining unit which obtains accelerations in directions that are mutually different, the accelerations being obtained by an acceleration sensor measuring a body movement by respiration of a user; a transform unit which transforms the accelerations in the directions obtained by the obtaining unit, into spectrum information items in a frequency domain; a phase removing unit which transforms the spectrum information items into amplitude spectra by removing phase information from the spectrum information items; a peak detector which adds up the amplitude spectra and detects a peak frequency based on an amplitude spectrum resulting from the adding up, the peak frequency indicating a respiratory component; and a respiration rate calculator which calculates a respiration rate using the peak frequency.

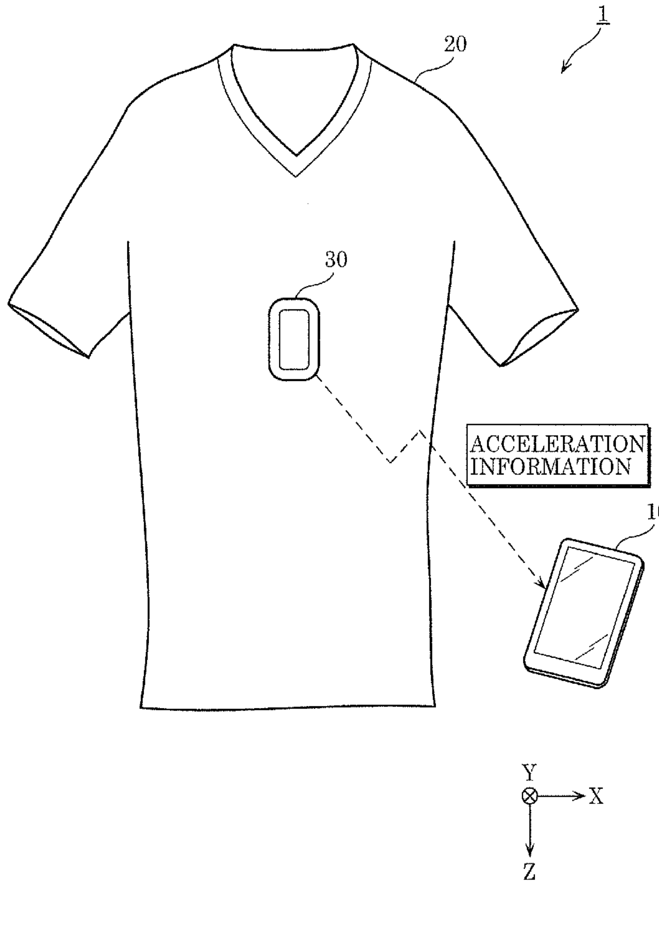


FIG. 1

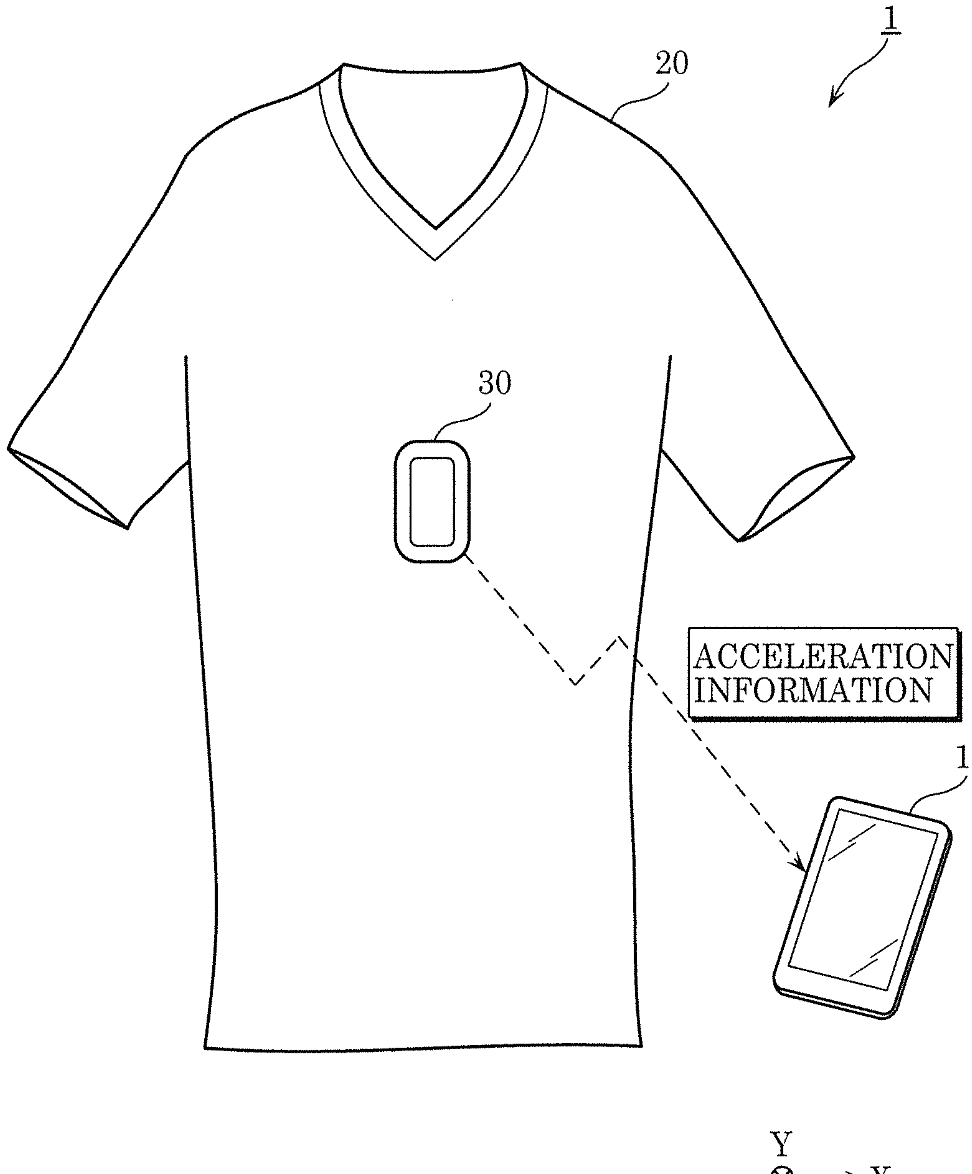


FIG. 2

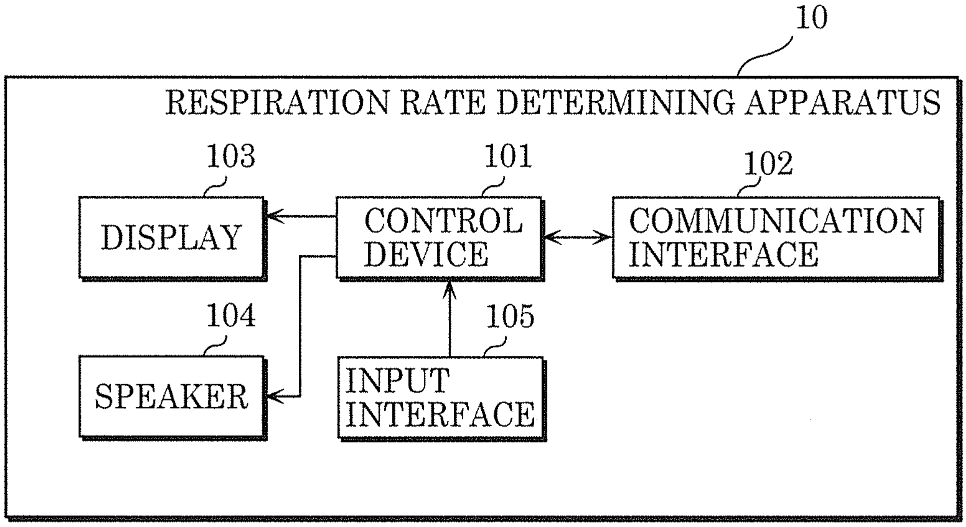

10
RESPIRATION RATE DETERMINING APPARATUS
103
DISPLAY
101
CONTROL DEVICE
102
COMMUNICATION INTERFACE
104
SPEAKER
105
INPUT INTERFACE

FIG. 3

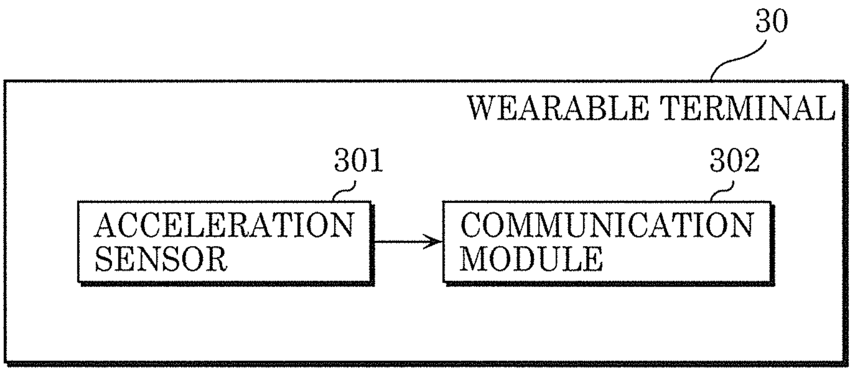

30
WEARABLE TERMINAL
301
ACCELERATION SENSOR
302
COMMUNICATION MODULE

FIG. 4

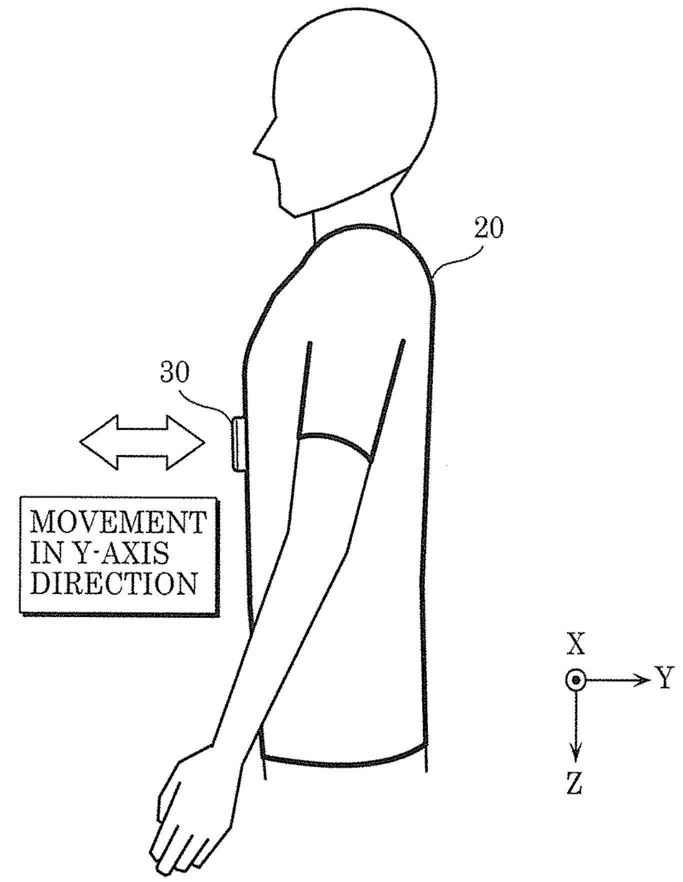

20
30
MOVEMENT IN Y-AXIS DIRECTION
X
Y
Z

FIG. 5

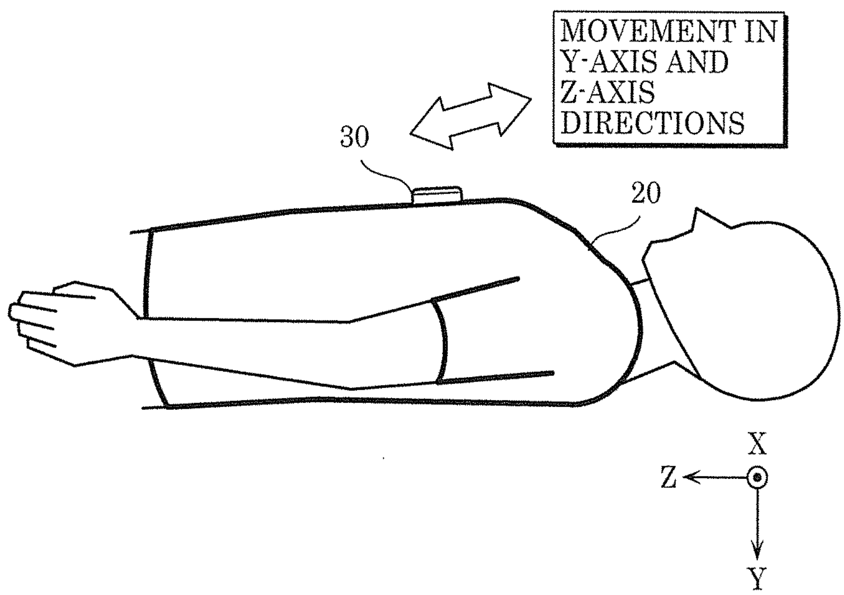

MOVEMENT IN Y-AXIS AND Z-AXIS DIRECTIONS
30
20
X
Z
Y

FIG. 6

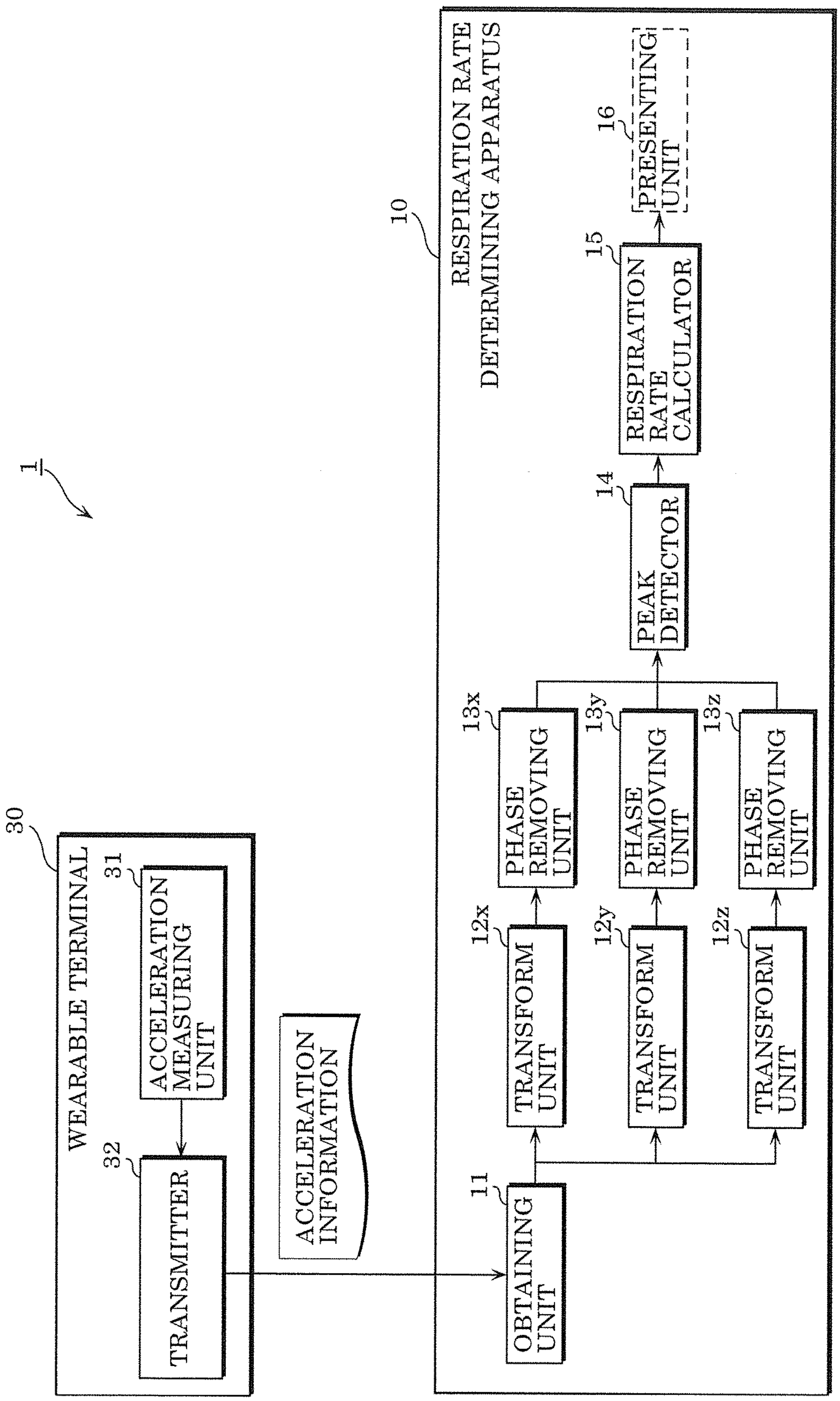

1
30
WEARABLE TERMINAL
31
ACCELERATION MEASURING UNIT
32
TRANSMITTER
ACCELERATION INFORMATION
10
RESPIRATION RATE DETERMINING APPARATUS
11
OBTAINING UNIT
12x
TRANSFORM UNIT
12y
TRANSFORM UNIT
12z
TRANSFORM UNIT
13x
PHASE REMOVING UNIT
13y
PHASE REMOVING UNIT
13z
PHASE REMOVING UNIT
14
PEAK DETECTOR
15
RESPIRATION RATE CALCULATOR
16
PRESENTING UNIT

FIG. 7

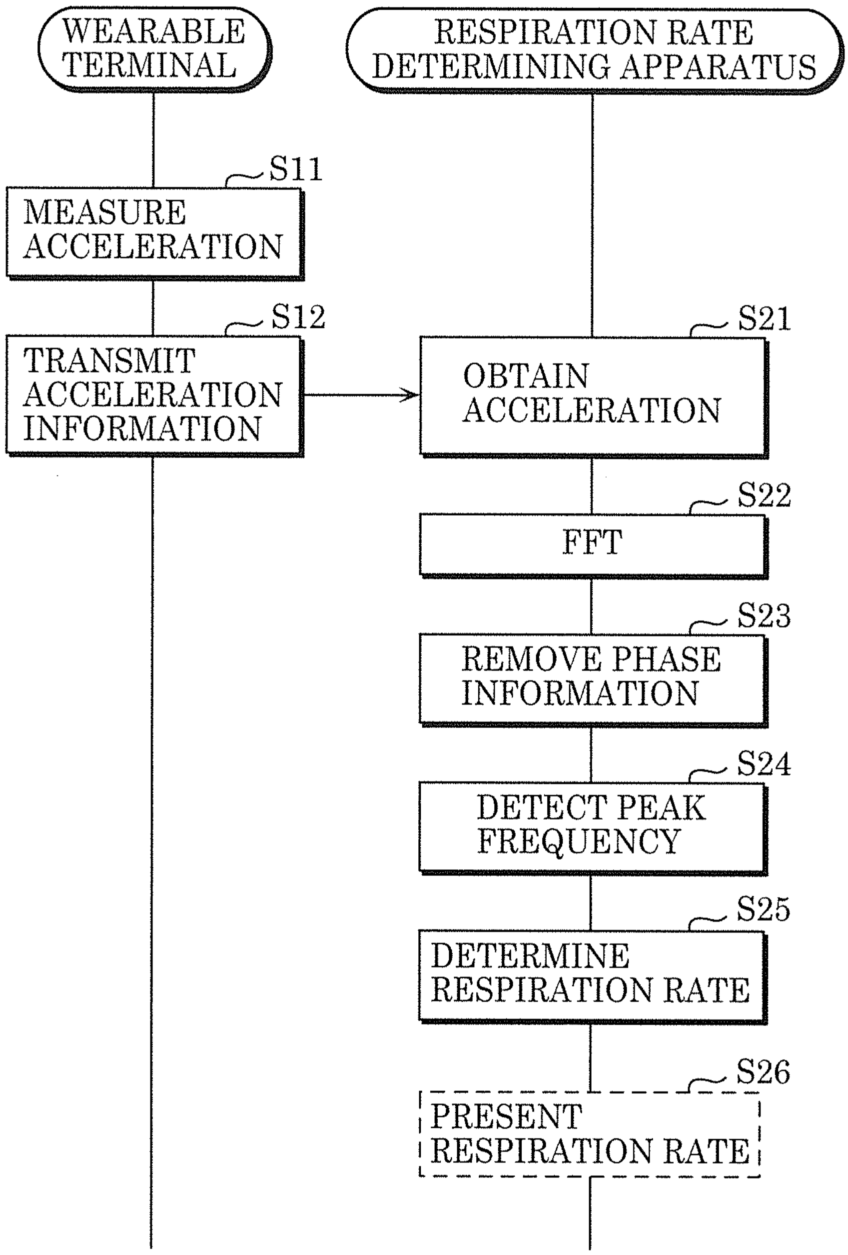

WEARABLE TERMINAL
RESPIRATION RATE DETERMINING APPARATUS
S11
MEASURE ACCELERATION
S12
TRANSMIT ACCELERATION INFORMATION
S21
OBTAIN ACCELERATION
S22
FFT
S23
REMOVE PHASE INFORMATION
S24
DETECT PEAK FREQUENCY
S25
DETERMINE RESPIRATION RATE
S26
PRESENT RESPIRATION RATE

FIG. 8

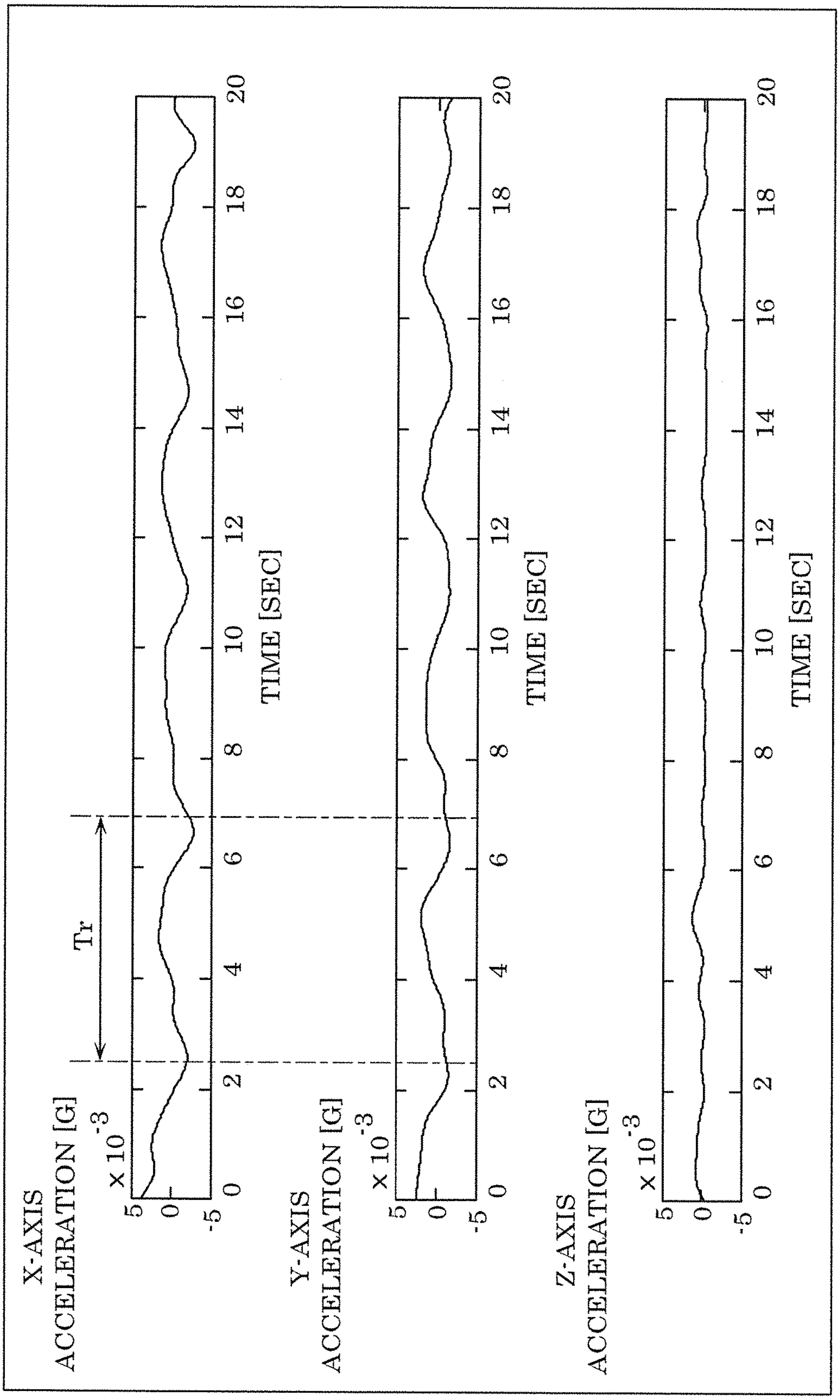

X-AXIS
ACCELERATION [G]
x 10^-3
Y-AXIS
ACCELERATION [G]
x 10^-3
Z-AXIS
ACCELERATION [G]
x 10^-3
5
0
-5
Tr
0
2
4
6
8
10
12
14
16
18
20
TIME [SEC]

FIG. 9

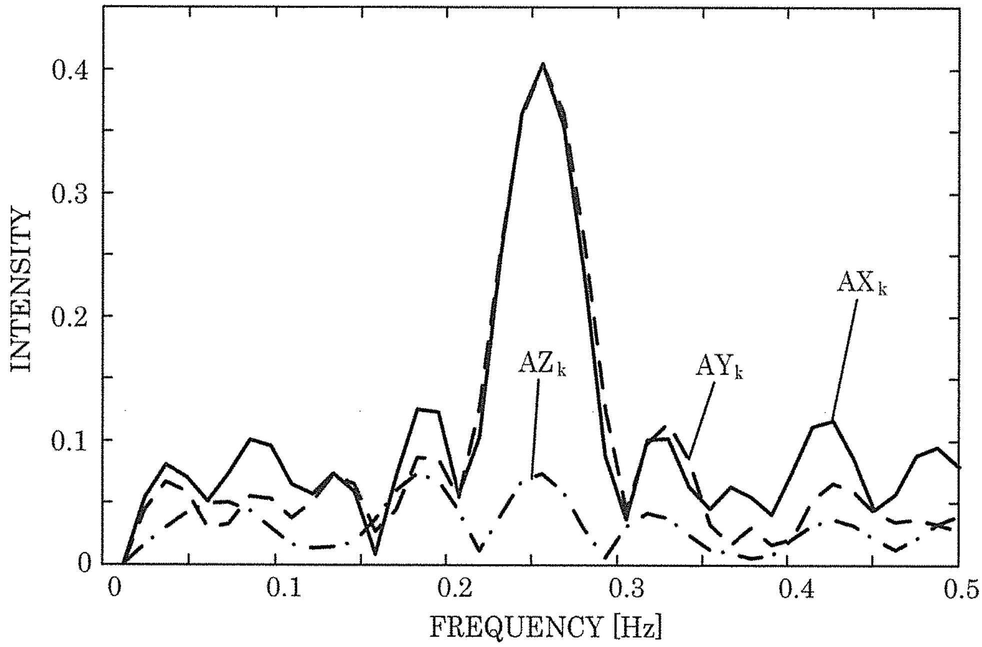

INTENSITY
FREQUENCY [Hz]
AX_k
AY_k
AZ_k
0
0.1
0.2
0.3
0.4
0.5

FIG. 10

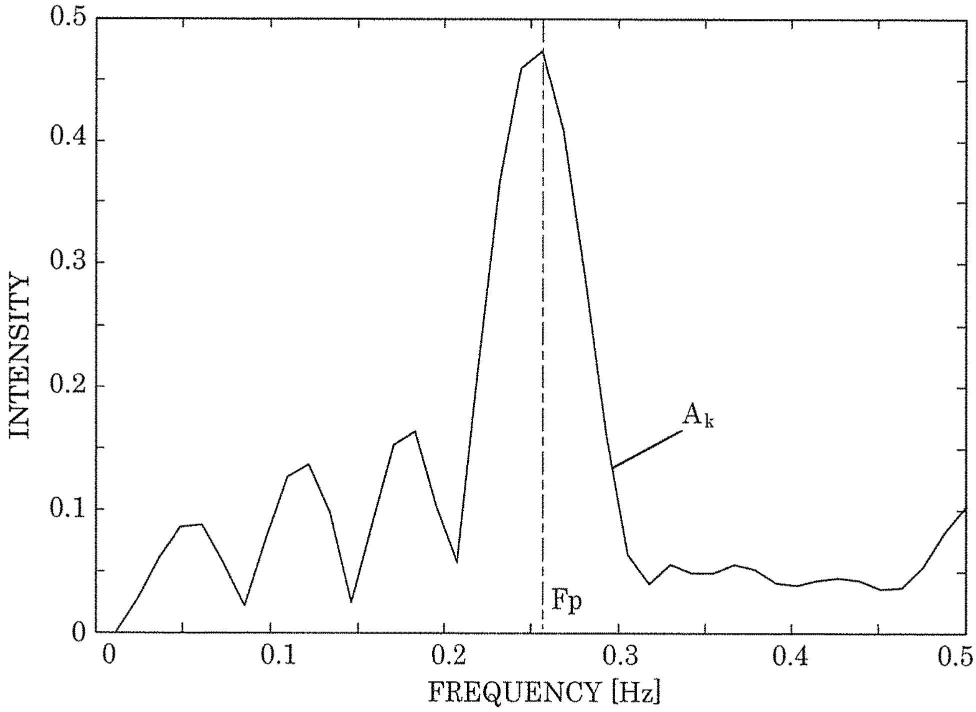

INTENSITY
FREQUENCY [Hz]
A_k
Fp
0
0.1
0.2
0.3
0.4
0.5

FIG. 11

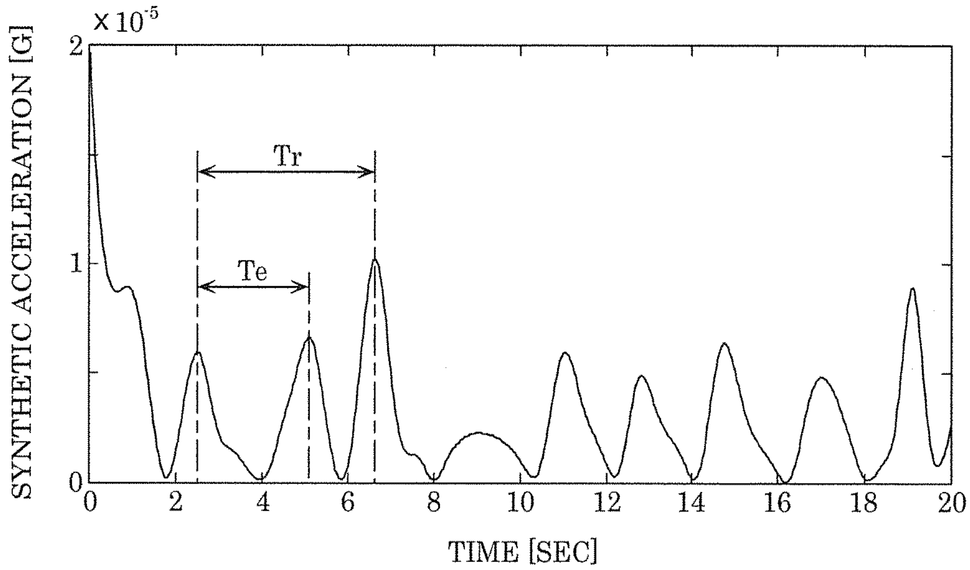

×10^-5
2
1
0
SYNTHETIC ACCELERATION [G]
Tr
Te
0
2
4
6
8
10
12
14
16
18
20
TIME [SEC]

FIG. 12

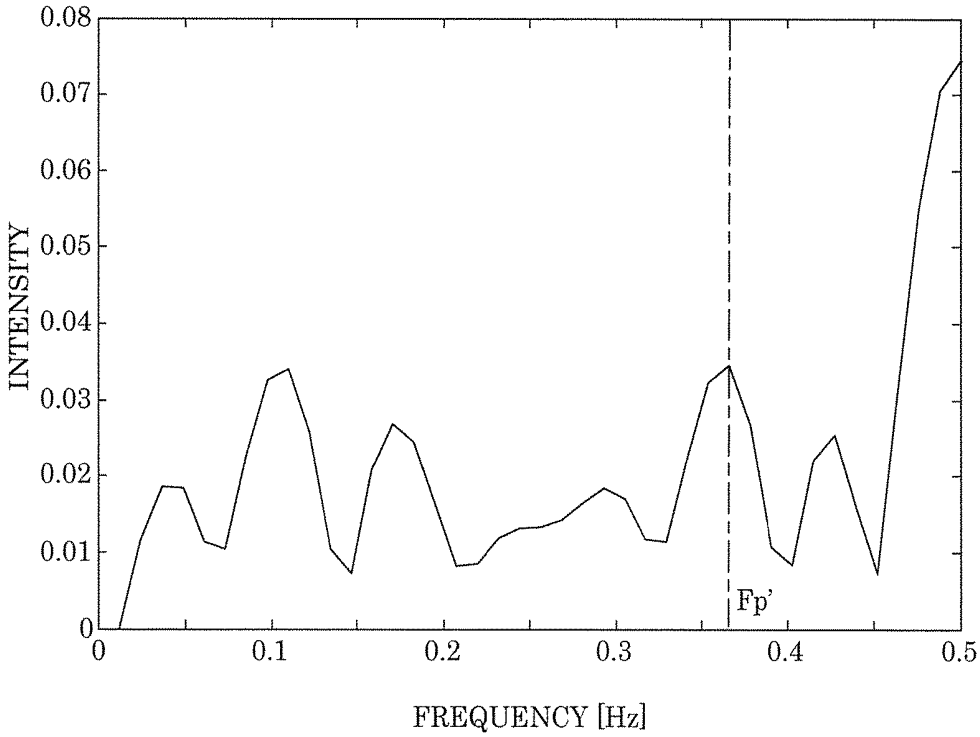

0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
INTENSITY
Fp'
0
0.1
0.2
0.3
0.4
0.5
FREQUENCY [Hz]

FIG. 13

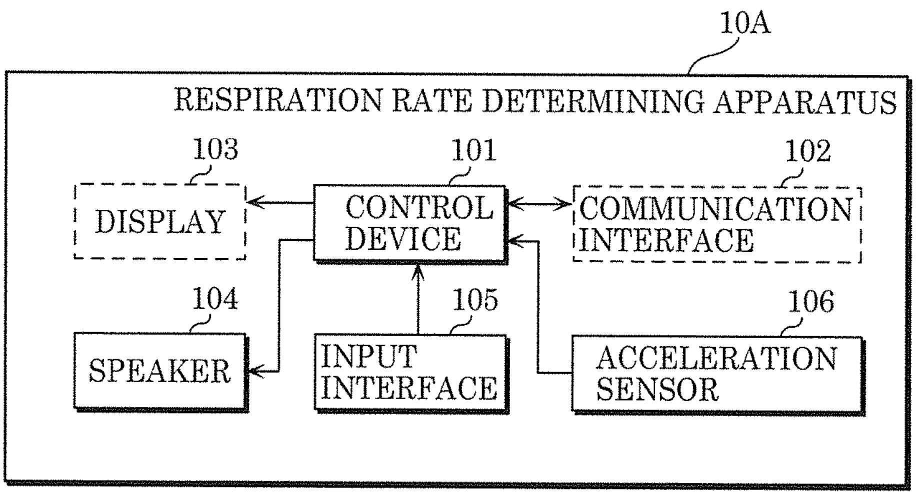

10A
RESPIRATION RATE DETERMINING APPARATUS
103
DISPLAY
101
CONTROL DEVICE
102
COMMUNICATION INTERFACE
104
SPEAKER
105
INPUT INTERFACE
106
ACCELERATION SENSOR

FIG. 14

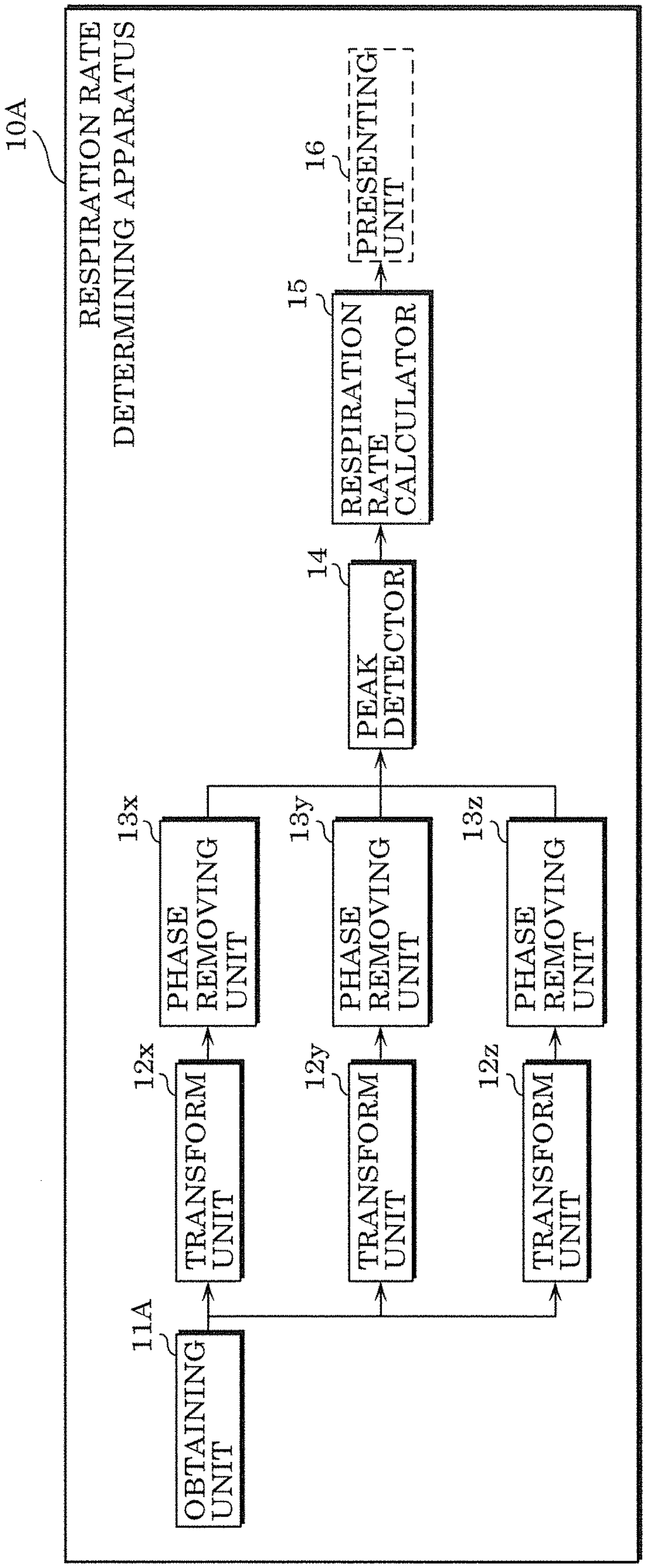
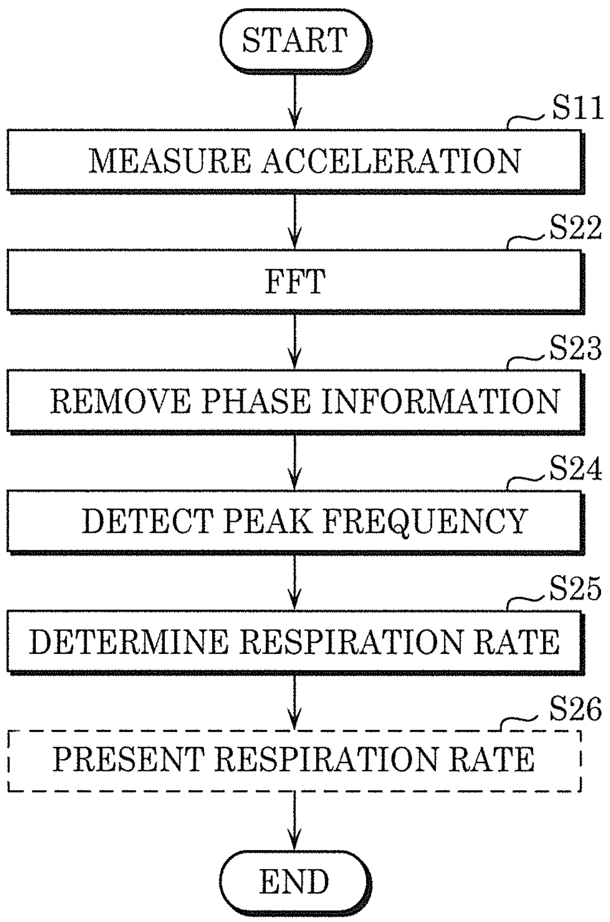

10A
RESPIRATION RATE DETERMINING APPARATUS
11A
OBTAINING UNIT
12x
TRANSFORM UNIT
12y
TRANSFORM UNIT
12z
TRANSFORM UNIT
13x
PHASE REMOVING UNIT
13y
PHASE REMOVING UNIT
13z
PHASE REMOVING UNIT
14
PEAK DETECTOR
15
RESPIRATION RATE CALCULATOR
16
PRESENTING UNIT

FIG. 15


START
S11
MEASURE ACCELERATION
S22
FFT
S23
REMOVE PHASE INFORMATION
S24
DETECT PEAK FREQUENCY
S25
DETERMINE RESPIRATION RATE
S26
PRESENT RESPIRATION RATE
END

RESPIRATION RATE DETERMINING APPARATUS, RESPIRATION RATE DETERMINING METHOD, AND PROGRAM RECORDING MEDIUM

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is a U.S. continuation application of PCT International Patent Application Number PCT/JP2016/004681 filed on Oct. 25, 2016, claiming the benefit of priority of Japanese Patent Application Number 2016-015230 filed on Jan. 29, 2016, the entire contents of which are hereby incorporated by reference.

BACKGROUND

1. Technical Field

[0002] The present disclosure relates to a respiration rate determining apparatus and a respiration rate determining method, and a program recording medium which determine a respiration rate based on measurement data of an acceleration sensor attached to the body of a person.

2. Description of the Related Art

[0003] Patent Literature (PTL) 1 (Japanese Unexamined Patent Application Publication No. 2006-247374) discloses a respiration rate determining apparatus which determines a respiration rate based on an acceleration sensor attached to the body of a person. Specifically, the respiration rate determining apparatus combines accelerations measured by a triaxial acceleration sensor attached to the body, and determines a respiration rate based on the frequency characteristics of the synthetic acceleration. This makes it possible to determine a respiration rate even when respiratory components included in the measured accelerations disperse into axes.

SUMMARY

[0004] After the acceleration sensor is attached to the chest of a user, the respiration rate determining apparatus of PTL 1 makes it possible to detect a chest movement when the user respires. Unfortunately, false detection may happen depending on a state of the user such as a posture.

[0005] The present disclosure provides a respiration rate determining apparatus capable of stably and accurately determining a respiration rate of a user regardless of a state of the user.

[0006] A respiration rate determining apparatus according to the present disclosure includes: an obtaining unit which obtains accelerations in directions that are mutually different, the accelerations being obtained by an acceleration sensor measuring a body movement by respiration of a user; a transform unit which transforms the accelerations in the directions obtained by the obtaining unit, into spectrum information items in a frequency domain; a phase removing unit which transforms the spectrum information items into amplitude spectra by removing phase information from the spectrum information items; a peak detector which adds up the amplitude spectra and detects a peak frequency based on an amplitude spectrum resulting from the adding up, the peak frequency indicating a respiratory component; and a respiration rate calculator which calculates a respiration rate using the peak frequency.

[0007] The respiration rate determining apparatus in the present disclosure is capable of accurately determining a respiration rate regardless of a state of the user such as a posture.

BRIEF DESCRIPTION OF DRAWINGS

[0008] These and other objects, advantages and features of the disclosure will become apparent from the following description thereof taken in conjunction with the accompanying drawings that illustrate a specific embodiment of the present disclosure.

[0009] FIG. **1** is a schematic view illustrating an outline of a respiration rate determining system according to Embodiment 1;

[0010] FIG. **2** is a block diagram illustrating an example of a hardware configuration of a respiration rate determining apparatus according to Embodiment 1;

[0011] FIG. **3** is a block diagram illustrating an example of a hardware configuration of a wearable terminal according to Embodiment 1;

[0012] FIG. **4** is a schematic view illustrating a direction of a chest movement accompanied by respiration in the case of a sitting or standing position;

[0013] FIG. **5** is a schematic view illustrating a direction of a chest movement accompanied by respiration in the case of a supine position;

[0014] FIG. **6** is a block diagram illustrating an example of a functional configuration of the respiration rate determining system according to Embodiment 1;

[0015] FIG. **7** is a sequence diagram illustrating an example of operation performed by the respiration rate determining system according to Embodiment 1;

[0016] FIG. **8** is a graph illustrating accelerations measured by a triaxial acceleration sensor according to Embodiment 1;

[0017] FIG. **9** is a graph illustrating an amplitude spectrum in each direction in Embodiment 1;

[0018] FIG. **10** is a graph illustrating an amplitude spectrum combined in Embodiment 1;

[0019] FIG. **11** is a graph illustrating a synthetic acceleration according to a comparative example;

[0020] FIG. **12** is a graph illustrating an amplitude spectrum based on the synthetic acceleration according to the comparative example;

[0021] FIG. **13** is a block diagram illustrating an example of a hardware configuration of a respiration rate determining apparatus according to Embodiment 2;

[0022] FIG. **14** is a block diagram illustrating an example of a functional configuration of the respiration rate determining apparatus according to Embodiment 2; and

[0023] FIG. **15** is a flow chart illustrating operation performed by the respiration rate determining apparatus according to Embodiment 2.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0024] Hereinafter, embodiments will be described in detail with reference to the drawings. However, unnecessarily detailed descriptions may be omitted. For example, detailed descriptions of well-known matters or descriptions of components that are substantially the same as components previously described may be omitted. This is to avoid unnecessary redundancy and provide easily read descriptions for a person skilled in the art.

[0025] It should be noted that the appended drawings and the following descriptions are provided to facilitate sufficient understanding of the present disclosure for a person skilled in the art, and are not intended to limit the subject matter of the claims.

Embodiment 1

[0026] Hereinafter, Embodiment 1 will be described with reference to FIG. **1** through FIG. **12**.

1-1. Configuration

[0027] FIG. **1** is a schematic view illustrating an outline of a respiration rate determining system according to Embodiment 1.

[0028] Specifically, FIG. **1** illustrates respiration rate determining apparatus **10**, garment **20**, and wearable terminal **30**. For example, respiration rate determining system **1** include, among these structural elements, respiration rate determining apparatus **10** and wearable terminal **30**. As illustrated in FIG. **1**, respiration rate determining apparatus **10** and wearable terminal **30** are separate structurally.

[0029] Respiration rate determining system **1** determines a respiration rate of a user by measuring a user's body (chest) movement by the user's respiration.

(1-1-1. Respiration Rate Determining Apparatus)

[0030] The following describes a hardware configuration of a respiration rate determining apparatus with reference to FIG. **2**.

[0031] FIG. **2** is a block diagram illustrating an example of a hardware configuration of a respiration rate determining apparatus according to Embodiment 1.

[0032] As illustrated in FIG. **2**, respiration rate determining apparatus **10** includes control device **101**, communication interface (I/F) **102**, display **103**, speaker **104**, and input I/F **105**. Respiration rate determining apparatus **10** is, for example, a communicable portable terminal such as a smartphone and a table terminal. It should be noted that although respiration rate determining apparatus **10** is a portable terminal, respiration rate determining apparatus **10** may be a communicable apparatus or an information terminal such as a personal computer (PC).

[0033] Control device **101** includes: a processor which executes a control program for causing respiration rate determining apparatus **10** to operate; a volatile storage area (main storage) which is used as a work area when the control program is executed; and an nonvolatile storage area (auxiliary storage) which stores the control program, contents, and so on. Examples of the volatile storage area include a random-access memory (RANI). Examples of the nonvolatile storage area include a read-only memory (ROM), a flash memory, and a hard disk drive (HDD).

[0034] Communication I/F **102** communicates with wearable terminal **30**. Communication I/F **102** may correspond to communication module **302** (to be described later) included in wearable terminal **30**. In other words, communication I/F **102** is, for example, a wireless communication interface compatible with the Bluetooth™ standards. It should be noted that communication I/F **102** may be a wireless local area network (LAN) interface compatible with standards such as IEEE802.11a, IEEE802.11b, IEEE802.11g, and IEEE802.11n, or a wireless communication interface compatible with communications standards used in mobile telecommunications technology such as the third generation of wireless mobile telecommunications technology (3G), the fourth generation of wireless telecommunications technology (4G), and LTE (registered trademark).

[0035] Display **103** displays processing results by control device **101**. Examples of display **103** include a liquid crystal display and an organic electroluminescence (EL) display.

[0036] Speaker **104** outputs sound decoded from audio information.

[0037] Input I/F **105** is, for example, a touch panel which is disposed in the surface of display **103** and receives an input to an user interface (UI) displayed on display **103**, from a user. Moreover, input I/F **105** may be, for example, an input device such as a numeric keypad and a keyboard.

(1-1-2. Wearable Terminal)

[0038] FIG. **3** is a block diagram illustrating an example of a hardware configuration of a wearable terminal according to Embodiment 1.

[0039] As illustrated in FIG. **3**, wearable terminal **30** includes acceleration sensor **301** and communication module **302**. Wearable terminal **30** is a small terminal which, as illustrated in FIG. **1**, is fixed to a location on garment **20** corresponding to the chest of the user, by a snap button, a double-sided tape, an adhesive, a thread, etc. In consequence, wearable terminal **30** is disposed to the chest of the user when the user wears garment **20**.

[0040] Acceleration sensor **301** measures an acceleration of wearable terminal **30**. Specifically, acceleration sensor **301** measures an acceleration of wearable terminal **30** in a direction of each of three axes (X-axis, Y-axis, and Z-axis) orthogonal to one another. It should be noted that in Embodiment 1, a right-left direction, a front-back direction, and an up-down direction relative to the body of the user when the user is in a standing position are defined as the X-axis direction, the Y-axis direction, and the Z-axis direction, respectively. In addition, a positive side of the X-axis direction corresponds to the left side of the right-left direction, a positive side of the Y-axis direction corresponds to the back side of the front-back direction, and a positive side of the Z-axis direction corresponds to the down side of the up-down direction. It should be noted that the directions of the axes are not limited to the above, and it is sufficient that directions make it possible to measure a body movement.

[0041] Acceleration sensor **301** detects, as an acceleration, a chest movement by respiration of the user because wearable terminal **30** is disposed to the chest of the user. Wearable terminal **30** measures accelerations along directional axes using acceleration sensor **301** because the chest movement during respiration varies depending on a posture of the user etc. It should be noted that the directional axes need not always be three axes orthogonal to each other, and may be at least two axes in predetermined directions. In other words, acceleration sensor **301** may measure accelerations in directions of at least two axes.

[0042] FIG. **4** is a schematic view illustrating a direction of a chest movement accompanied by respiration when the user is in a sitting or standing position.

[0043] As illustrated in FIG. **4**, when the user is in the sitting or standing position, a chest movement of the user is likely to be in the front-back direction (Y-axis direction) relative to the user. For this reason, when the user is in the sitting or standing position, acceleration sensor **301** detects the chest movement accompanied by respiration, using an acceleration in the Y-axis direction.

[0044] FIG. **5** is a schematic view illustrating a direction of a chest movement accompanied by respiration when the user is in a supine position.

[0045] As illustrated in FIG. **5**, when the user is in the supine position, the chest movement of the user includes many motions in the up-down direction (Z-axis direction) relative to the user in addition to motions in the front-back direction (Y-axis direction) relative to the user. For this reason, when the user is in the supine position, acceleration sensor **301** detects the chest movement accompanied by respiration, using accelerations in the Y-axis direction and the Z-axis direction.

[0046] Acceleration sensor **301** of wearable terminal **30** measures accelerations along directional axes because the chest movement accompanied by the user's respiration differs depending on the user's posture as stated above.

[0047] Communication module **302** communicates with respiration rate determining apparatus **10**. Communication module **302** may include, for example, a wireless communication interface compatible with the Bluetooth™ standards or a wireless local area network (LAN) interface compatible with standards such as IEEE802.11a, IEEE802.11b, IEEE802.11g, and IEEE802.11n.

1-2. Functional Configuration of Respiration Rate Determining System

[0048] The following describes a functional configuration of respiration rate determining system **1** with reference to FIG. **6**.

[0049] FIG. **6** is a block diagram illustrating an example of a functional configuration of a respiration rate determining system according to Embodiment 1.

[0050] First, a functional configuration of wearable terminal **30** will be described.

[0051] Wearable terminal **30** includes, as functional elements, acceleration measuring unit **31** and transmitter **32**.

[0052] Acceleration measuring unit **31** measures a body movement by the user's respiration, in accelerations in mutually different directions. Acceleration measuring unit **31** measures accelerations in directions using a predetermined sampling frequency, and generates acceleration information indicating a time series variation in acceleration in each direction. Acceleration measuring unit **31** is implemented by, for example, acceleration sensor **301**.

[0053] Transmitter **32** transmits the generated acceleration information to respiration rate determining apparatus **10**. It should be noted that transmitter **32** transmits acceleration information stored in a memory not shown to respiration rate determining apparatus **10** on a predetermined cycle. Transmitter **32** is implemented by, for example, communication module **302**. In other words, transmitter **32** transmits acceleration information to respiration rate determining apparatus **10** connected for communication based on, for example, Bluetooth™.

[0054] Next, a functional configuration of respiration rate determining apparatus **10** will be described.

[0055] Respiration rate determining apparatus **10** includes obtaining unit **11**, transform units **12***x*, **12***y*, and **12***z*, phase removing units **13***x*, **13***y*, and **13***z*, peak detector **14**, and respiration rate calculator **15**. Respiration rate determining apparatus **10** may further include presenting unit **16**.

[0056] Obtaining unit **11** receives acceleration information transmitted by transmitter **32** of wearable terminal **30**. In other words, obtaining unit **11** communicates with wearable terminal **30** including acceleration sensor **301** and attached to the user's body. Consequently, obtaining unit **11** obtains acceleration information indicating accelerations in mutually different directions obtained by acceleration sensor **301** measuring a body movement by the user's respiration. Obtaining unit **11** is implemented by, for example, control device **101** and communication I/F **102**.

[0057] Transform units **12***x*, **12***y*, and **12***z* transform the accelerations in the directions indicated in the acceleration information obtained by obtaining unit **11**, into spectrum information items. Transform unit **12***x* performs the transformation on the acceleration in the X-axis direction. Transform unit **12***y* performs the transformation on the acceleration in the Y-axis direction. Transform unit **12***z* performs the transformation on the acceleration in the Z-axis direction. Transform units **12***x*, **12***y*, and **12***z* transform, using the fast Fourier transform (FFT), acceleration values in respective directions into spectrum information items in a frequency domain of the respective directions. In other words, the transformation makes it possible to obtain the spectrum information items in the respective directions, that is, three spectrum information items.

[0058] Transform units **12***x*, **12***y*, and **12***z* are not particularly limited, and may perform the FFT for a duration (approximately from two to twenty seconds) of, for example, approximately one to ten respiration periods. It should be noted that the duration indicates a period in which the FFT is repeated. Here, when the duration in which the FFT is performed is reduced, conformity to a variation in respiration rate is enhanced, but sensitivity to noise such as a body movement other than respiration is increased. In contrast, when the duration is extended, the sensitivity to noise such as a body movement other than respiration is decreased, but the conformity to the variation in respiration rate is reduced. Accordingly, it is desirable that the duration in which the FFT is performed be appropriately adjusted. Moreover, it is desirable that a window function such as a hanning window be used when the FFT is performed.

[0059] Transform units **12***x*, **12***y*, and **12***z* are implemented by, for example, control device **101**.

[0060] Phase removing units **13***x*, **13***y*, and **13***z* extract amplitude spectra by removing phase information from spectrum information items transform units **12***x*, **12***y*, and **12***z* transformed into a frequency domain. Phase removing unit **13***x* transforms the spectrum information in the X-axis direction into an amplitude spectrum by removing phase information from the spectrum information in the X-axis direction. Phase removing unit **13***y* transforms the spectrum information in the Y-axis direction into an amplitude spectrum by removing phase information from the spectrum information in the Y-axis direction. Phase removing unit **13***z* transforms the spectrum information in the Z-axis direction into an amplitude spectrum by removing phase information from the spectrum information in the Z-axis direction. In other words, phase removing units **13***x*, **13***y*, and **13***z* transform the spectrum information items in the respective directions into the amplitude spectra in the respective directions by removing the phase information from the spectrum information items in the frequency domain in the respective directions. The transformation makes it possible to obtain the amplitude spectra in the respective directions, that is, three amplitude spectra. Accordingly, it is possible to remove a phase difference among the movement components of respiration included in the accelerations in the respective directions. Phase removing units **13**x, **13**y, and **13**z are implemented by, for example, control device **101**.

[0061] Peak detector **14** superimposes, on one another, the respiratory components in the respective directions by adding up the three amplitude spectra from which phase removing units **13**x, **13**y, and **13**z removed the phase information. Subsequently, peak detector **14** detects, as peak frequency Fp, a frequency having a peak value of an amplitude spectrum resulting from the superimposition, based on the amplitude spectrum. Peak detector **14** may detect peak frequency Fp of the amplitude spectrum in a frequency band that is preset as a detection range. For example, assuming that the number of breaths per minute is 5 to 30, peak detector **14** may detect peak frequency Fp in a detection range of from 0.08 (Hz) to 0.5 (Hz), inclusive. By setting the detection range in which peak frequency Fp is detected as above, peak detector **14** is capable of preventing false detection when noise is found outside of the detection range. Peak detector **14** is implemented by, for example, control device **101**.

[0062] Respiration rate calculator **15** calculates respiration rate Rc (breaths per minute: bpm) using peak frequency Fp (Hz) of the amplitude spectrum of the accelerations detected by peak detector **14**. Respiration rate calculator **15** is implemented by, for example, control device **101**.

[0063] Presenting unit **16** displays an image or character information indicating the respiration rate calculated by respiration rate calculator **15**. Presenting unit **16** may output voice indicating the calculated respiration rate. Presenting unit **16** may be implemented by, for example, control device **101** and display **103** or control device **101** and speaker **104**.

1-3. Operation

[0064] The following describes operation performed by respiration rate determining system **1** thus configured with reference to FIG. **7**. Specifically, a respiration rate determining method performed by respiration rate determining system **1** will be described.

[0065] FIG. **7** is a sequence diagram illustrating an example of a respiration rate determining method performed by the respiration rate determining system according to Embodiment 1.

[0066] Wearable terminal **30** attached to the user's body as illustrated in FIG. **4** and FIG. **5** causes acceleration measuring unit **31** to measure a chest movement of the user as triaxial accelerations (S**11**).

[0067] FIG. **8** is a graph illustrating an example of the triaxial accelerations (acceleration information) measured by the acceleration measuring unit. In FIG. **8**, the horizontal axis represents time, and the vertical axis represents acceleration. In FIG. **8**, movement components by respiration are mainly included in the acceleration in the X-axis direction and the acceleration in the Y-axis direction. It is clear from FIG. **8** that cycle Tr is approximately four seconds (0.25 (Hz)).

[0068] Next, wearable terminal **30** causes transmitter **32** to transmit the acceleration information to respiration rate determining apparatus **10** (S**12**).

[0069] Subsequently, respiration rate determining apparatus **10** obtains the accelerations in the respective directions indicated by the acceleration information, by causing obtaining unit **11** to receive the acceleration information from transmitter **32** of wearable terminal **30** (S**21**).

[0070] Next, transform units **12**x, **12**y, and **12**z transform, using the FFT, the obtained accelerations in the respective directions into spectrum information items in a frequency domain (S**22**). Specifically, transform unit **12**x transforms, using the FFT, acceleration x_n in the X-axis direction into spectrum information X_k in a frequency domain, using Equation 1a. Transform unit **12**y transforms, using the FFT, acceleration y_n in the Y-axis direction into spectrum information Y_k in a frequency domain, using Equation 1b. Transform unit **12**z transforms, using the FFT, acceleration z_n in the Z-axis direction into spectrum information Z_k in a frequency domain, using Equation 1c.

[Math. 1]

$$X_k = \sum_{n=0}^{N-1} x_n e^{-i\frac{2\pi nk}{N}} \quad \text{(Equation 1a)}$$

$$Y_k = \sum_{n=0}^{N-1} y_n e^{-i\frac{2\pi nk}{N}} \quad \text{(Equation 1b)}$$

$$Z_k = \sum_{n=0}^{N-1} z_n e^{-i\frac{2\pi nk}{N}} \quad \text{(Equation 1c)}$$

[0071] In Equation 1a to Equation 1c, N denotes the number of points at which the FFT is performed, n denotes a sample number, and k denotes an index of the FFT.

[0072] Next, phase removing units **13**x, **13**y, and **13**z remove phase information from the spectrum information items X_k, Y_k, and Z_k in the frequency domain in the respective directions (S**23**). Specifically, phase removing unit **13**x calculates amplitude spectrum AX_k that is an absolute value, by removing phase information from spectrum information X_k obtained by transforming acceleration x_n in the X-axis direction into a frequency domain using Equation 2a. Phase removing unit **13**y calculates amplitude spectrum AY_k that is an absolute value, by removing phase information from spectrum information Y_k obtained by transforming acceleration y_n in the Y-axis direction into a frequency domain using Equation 2b. Phase removing unit **13**z calculates amplitude spectrum AZ_k that is an absolute value, by removing phase information from spectrum information Z_k obtained by transforming acceleration z_n in the Z-axis direction into a frequency domain using Equation 2c.

[Math. 2]

$$AX_k = |X_k| \quad \text{(Equation 2a)}$$

$$AY_k = |Y_k| \quad \text{(Equation 2b)}$$

$$AZ_k = |Z_k| \quad \text{(Equation 2c)}$$

[0073] FIG. **9** is a graph illustrating amplitude spectra in respective directions calculated from the accelerations in the respective directions illustrated in FIG. **8**. In FIG. **9**, the horizontal axis represents frequency, and the vertical axis represents intensity. In FIG. **9**, a solid line, a broken line, and a dashed line represent amplitude spectrum AX_k in the X-axis direction, amplitude spectrum AY_k in the Y-axis direction, and amplitude spectrum AZ_k in the Z-axis direction, respectively. It is clear from FIG. **9** that many respiratory components in the proximity of frequency 0.25 (Hz) are included in, among amplitude spectra AX_k, AY_k, and AZ_k in the respective directions, amplitude spectrum AX_k in the X-axis direction and amplitude spectrum AY_k in the Y-axis direction.

[0074] Next, peak detector **14** adds up amplitude spectra AX_k, AY_k, and AZ_k in the respective directions as indicated in Equation 3, and calculates peak frequency Fp having a peak value of amplitude spectrum A_k resulting from the adding up, using Equation 4 and Equation 5 (S**24**).

[Math. 3]

$$A_k = AX_k + AY_k + AZ_k \quad \text{(Equation 3)}$$

[Math. 4]

$$\hat{k} = argmax_k\, A_k \quad \text{(Equation 4)}$$

[Math. 5]

$$Fp = \frac{\hat{k}}{N} Fs[\text{Hz}] \quad \text{(Equation 5)}$$

[0075] Here, argmax_k denotes a function that calculates k maximizing A_k, and Fs denotes a sampling frequency for measurement by acceleration sensor **301**.

[0076] Sampling frequency Fs is not particularly limited, but it is desirable that sampling frequency Fs be sufficiently greater than the upper limit (several Hz) of a respiratory frequency.

[0077] FIG. **10** is a graph illustrating amplitude spectrum A_k resulting from combining (adding up) the amplitude spectra in the respective directions. In FIG. **10**, the horizontal axis represents frequency, and the vertical axis represents intensity. Combined amplitude spectrum A_k has peak frequency Fp in the proximity of 0.25 Hz that is a respiratory frequency. It is possible to accurately determine a respiration rate of the user by calculating peak frequency Fp.

[0078] Next, respiration rate calculator **15** calculates respiration rate Rc per minute (bpm) using calculated peak frequency Fp and Equation 6 (S**25**).

[Math. 6]

$$Rc = Fp \times 60[\text{bpm}] \quad \text{(Equation 6)}$$

In the example of FIG. **10**, respiration rate Rc is approximately 15 (times/minute) because peak frequency Fp is in the proximity of 0.25 (Hz).

[0079] Accordingly, when the accelerations including the respiratory components measured by acceleration sensor **301** are added up and the respiration rate is calculated, even if a phase difference among the respiratory components caused by the user's posture or the like is present, it is possible to reduce the influence of the phase difference, thereby stably determining the respiration rate.

[0080] As a comparative example, a case will be described in which synthetic acceleration G of accelerations along directional axes at a time is calculated using Equation 7, and a respiration rate is calculated from synthetic acceleration G.

[Math. 7]

$$G = \sqrt{x^2 + y^2 + z^2}[G] \text{(Equation 7)}$$

[0081] Here, x, y, and z denote accelerations in the X-axis, Y-axis, and Z-axis directions at a time, respectively, and G denotes an acceleration resulting from combining x, y, and z.

[0082] It is possible to combine respiratory components included in the respective directions using synthetic acceleration G. However, when a phase difference among movement components of respiration included in accelerations in respective directions arises from the user's posture, a state of respiration, etc., synthetic acceleration G may indicate a movement other than the respiratory components.

[0083] An example in which synthetic acceleration G of the accelerations in the X-axis, Y-axis, and Z-axis directions illustrated in FIG. **8** is calculated using Equation 7 will be described with reference to FIG. **11**.

[0084] FIG. **11** is a graph illustrating a synthetic acceleration according to the comparative example. In FIG. **11**, the horizontal axis represents time, and the vertical axis represents synthetic acceleration G.

[0085] As illustrated in FIG. **11**, synthetic acceleration G indicates cycle Tr of the respiratory components included in the accelerations in the X-axis, Y-axis, and Z-axis directions, and cycle Te of components. As above, when synthetic acceleration G is used in Equation 7, fake peaks other than the respiratory components may appear because the influence of the posture etc. makes a phase of a variation in acceleration in each direction different.

[0086] An amplitude spectrum of synthetic acceleration G indicated in Equation 7 will be further examined with reference to FIG. **12**.

[0087] FIG. **12** is a graph illustrating an amplitude spectrum based on the synthetic acceleration according to the comparative example. In FIG. **12**, the horizontal axis represents frequency, and the vertical axis represents intensity. The amplitude spectrum of synthetic acceleration G has peak frequency Fp' in the proximity of 0.37 Hz. In addition, the amplitude spectrum of synthetic acceleration G has no clear peak in the proximity of 0.25 Hz that is the natural respiratory frequency.

[0088] According to Equation 6, respiration rate Rc' is approximately 22 (times/minute) because peak frequency Fp' is in the proximity of 0.37 (Hz). As above, when synthetic acceleration G calculated by Equation 7 is used, there are cases where a respiratory frequency is falsely detected because a phase difference occurs in time series data of accelerations in respective directions due to the user's posture or the like.

1-4. Advantageous Effects Etc.

[0089] As described above, respiration rate determining apparatus **10** includes obtaining unit **11**, transform processors **12***x*, **12***y*, and **12***z*, phase removing units **13***x*, **13***y*, and **13***z*, peak detector **14**, and respiration rate calculator **15**. Obtaining unit **11** obtains accelerations in directions that are mutually different, the accelerations being obtained by acceleration sensor **301** measuring a body movement by respiration of a user. Transform units **12***x*, **12***y*, and **12***z* transform the accelerations in the directions obtained by obtaining unit **11**, into spectrum information items in a frequency domain. Phase removing units **13***x*, **13***y*, and **13***z* transform the spectrum information items into amplitude spectra by removing phase information from the spectrum information items. Peak detector **14** adds up the amplitude spectra and detects peak frequency Fp based on an amplitude spectrum resulting from the adding up, peak frequency Fp indicating a respiratory component. Respiration rate calculator **15** calculates a respiration rate using peak frequency Fp.

[0090] With this, even if a phase difference among respiratory components caused by a user's posture or the like is present in accelerations including the respiratory components measured by acceleration sensor **301**, it is possible to stably determine a respiration rate.

[0091] It should be noted that although wearable terminal **30** is fixed to the chest of garment **20** in Embodiment 1, the present disclosure is not limited to this, and wearable terminal **30** may be fixed to a position at which a body movement accompanied by person's respiration can be measured, such as the abdominal region of the person.

Embodiment 2

[0092] Hereinafter, Embodiment 2 will be described with reference to FIG. **13** through FIG. **15**.

2-1. Configuration

[0093] FIG. **13** is a block diagram illustrating an example of a hardware configuration of a respiration rate determining apparatus according to Embodiment 2.

[0094] As illustrated in FIG. **13**, unlike Embodiment 1, respiration rate determining apparatus **10**A performs all steps in a respiration rate determining method in Embodiment 2. In other words, respiration rate determining apparatus **10**A according to Embodiment 2 differs from respiration rate determining apparatus **10** according to Embodiment 1 in further including acceleration sensor **106**. Acceleration sensor **106** has the same configuration as acceleration sensor **301**. Since the other structural elements are the same as in Embodiment 1, the same reference signs are assigned thereto, and descriptions thereof are omitted.

[0095] In Embodiment 2, respiration rate determining apparatus **10**A needs not include display **103** and communication I/F **102**. In addition, respiration rate determining apparatus **10**A is implemented by a small terminal fixed to garment **20** illustrated in FIG. **1**.

[0096] FIG. **14** is a block diagram illustrating an example of a functional configuration of the respiration rate determining apparatus according to Embodiment 2.

[0097] As illustrated in FIG. **14**, unlike Embodiment 1, obtaining unit **11**A is implemented by acceleration sensor **106** in Embodiment 2. In other words, obtaining unit **11**A measures a body movement by the user's respiration, in accelerations in mutually different directions.

[0098] Since structural elements other than obtaining unit **11**A are the same as in Embodiment 1, the same reference signs are assigned thereto, and descriptions thereof are omitted.

2-2. Operation

[0099] FIG. **15** is a flow chart illustrating an example of the respiration rate determining method performed by the respiration rate determining apparatus according to Embodiment 2.

[0100] As illustrated in FIG. **15**, the operation of respiration rate determining apparatus **10**A according to Embodiment 2 differs from the operation of respiration rate determining system **1** according to Embodiment 1 in that respiration rate determining apparatus **10**A completes an entire process. In other words, steps S**12** and S**21** are omitted from the sequence diagram illustrated in FIG. **7**.

[0101] To put it differently, respiration rate determining apparatus **10**A performs step S**22** after performing step S**11**. Accordingly, respiration rate determining apparatus **10**A obtains accelerations, performs transformation (the FFT), removes phase information, detects a peak frequency, and calculates a respiration rate.

[0102] It should be noted that the above embodiments are examples of the techniques of the present disclosure, and thus various modifications, permutations, additions, omissions, etc. are possible within the scope of the appended claims or the equivalents thereof.

[0103] It should be noted that transformation into a frequency domain is not limited to the FFT, and may be the discrete Fourier transform (DFT), the discrete cosine transform (DCT), wavelet transform, etc.

[0104] Respiration rate Rc thus calculated may be transmitted via a network to a server not shown. Alternatively, respiration rate Rc thus calculated may be accumulated in a storage not shown.

[0105] Although only some exemplary embodiments of the present disclosure have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of the present disclosure. Accordingly, all such modifications are intended to be included within the scope of the present disclosure.

INDUSTRIAL APPLICABILITY

[0106] A respiration rate determining apparatus, a respiration rate determining method, and a program recording medium according to the present disclosure make it possible to accurately determine a respiration rate regardless of a state of a user such as a posture, and thus are useful as a respiration rate determining apparatus, a respiration rate determining method, a program recording medium, etc. which determine a respiration rate from measured data of an acceleration sensor attached to the user's body.

What is claimed is:

1. A respiration rate determining apparatus, comprising:

an obtaining unit which obtains accelerations in directions that are mutually different, the accelerations being obtained by an acceleration sensor measuring a body movement by respiration of a user;

a transform unit which transforms the accelerations in the directions obtained by the obtaining unit, into spectrum information items in a frequency domain;

a phase removing unit which transforms the spectrum information items into amplitude spectra by removing phase information from the spectrum information items;

a peak detector which adds up the amplitude spectra and detects a peak frequency based on an amplitude spectrum resulting from the adding up, the peak frequency indicating a respiratory component; and

a respiration rate calculator which calculates a respiration rate using the peak frequency.

2. The respiration rate determining apparatus according to claim **1**,

wherein the transform unit transforms each of the accelerations in the directions into a corresponding one of the spectrum information items, using fast Fourier transform.

3. The respiration rate determining apparatus according to claim **1**,

wherein the transform unit performs the transformation for a duration of one to ten respiration periods.

4. The respiration rate determining apparatus according to claim **1**,

wherein the peak detector detects the peak frequency in a detection range of from 0.08 Hz to 0.5 Hz, inclusive.

5. The respiration rate determining apparatus according to claim **1**,

wherein the obtaining unit obtains the accelerations in the directions from a terminal attached to a body of the user and including the acceleration sensor, by communicating with the terminal, and

the respiration rate determining apparatus is structurally separate from the terminal.

6. The respiration rate determining apparatus according to claim **1**,

wherein the obtaining unit includes the acceleration sensor, and

the respiration rate determining apparatus obtains the accelerations, performs the transformation, removes the phase information, detects the peak frequency, and calculates the respiration rate.

7. A respiration rate determining method, comprising:

obtaining accelerations in directions that are mutually different, the accelerations being obtained by an acceleration sensor measuring a body movement by respiration of a user;

transforming the accelerations in the directions that are obtained, into spectrum information items in a frequency domain;

transforming the spectrum information items into amplitude spectra by removing phase information from the spectrum information items;

adding up the amplitude spectra and detecting a peak frequency based on an amplitude spectrum resulting from the adding up, the peak frequency indicating a respiratory component; and

calculating a respiration rate using the peak frequency.

8. A non-transitory computer-readable recording medium for use in a computer, the recording medium having a computer program recorded thereon for causing the computer to execute:

obtaining accelerations in directions that are mutually different, the accelerations being obtained by an acceleration sensor measuring a body movement by respiration of a user;

transforming the accelerations in the directions that are obtained, into spectrum information items in a frequency domain;

transforming the spectrum information items into amplitude spectra by removing phase information from the spectrum information items;

adding up the amplitude spectra and detecting a peak frequency based on an amplitude spectrum resulting from the adding up, the peak frequency indicating a respiratory component; and

calculating a respiration rate using the peak frequency.

* * * * *

patsnap

专利名称(译)	呼吸率确定装置，呼吸率确定方法和程序记录介质		
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摘要(译)

呼吸率确定装置包括：获取单元，其获得相互不同的方向上的加速度，所述加速度通过加速度传感器通过用户的呼吸来测量身体运动来获得;变换单元，将获取单元获得的方向上的加速度变换为频域中的频谱信息项;相位去除单元，通过从频谱信息项中去除相位信息，将频谱信息项变换为幅度谱;峰值检测器，它将振幅谱相加，并根据加起来产生的振幅谱检测峰值频率，峰值频率表示呼吸成分;以及使用峰值频率计算呼吸率的呼吸率计算器。