US 20060173257A1

(19) United States

(12) Patent Application Publication (10) Pub. No.: US 2006/0173257 A1

Nagai et al. (43) Pub. Date: Aug. 3, 2006

(54) SLEEP EVALUATION METHOD, SLEEP EVALUATION SYSTEM, OPERATION PROGRAM FOR SLEEP EVALUATION SYSTEM, PULSE OXIMETER, AND SLEEP SUPPORT SYSTEM

(75) Inventors: **Yoshiroh Nagai**, Nishinomiya-shi (JP); **Kazumi Kitajima**, Higashiosaka-shi (JP)

Correspondence Address:
SIDLEY AUSTIN LLP
717 NORTH HARWOOD
SUITE 3400
DALLAS, TX 75201 (US)

(73) Assignee: **KONICA MINOLTA SENSING, INC.**

(21) Appl. No.: **11/341,326**

(22) Filed: **Jan. 27, 2006**

(30) **Foreign Application Priority Data**

Jan. 31, 2005 (JP) 2005-23674

Publication Classification

(51) **Int. Cl.**
A61B 5/00 (2006.01)
A61G 7/00 (2006.01)

(52) **U.S. Cl.** **600/323**; 5/600

(57) **ABSTRACT**

Measurement is made about a necessary evaluation parameter of a subject, the parameter being variable due to sleep apnea of the subject. A body position of the subject is detected in terms of angle information. The parameter measurement and the body angle detection are executed at a predetermined sampling frequency. These data are stored in a storage. A sleep evaluation system includes: an evaluation parameter detector for measuring an evaluation parameter of a subject, a body position detector for detecting a body position of the subject in terms of angle information; a storage for storing measurement data acquired by the evaluation parameter detector and by the body position detector therein; and a controller for causing the evaluation parameter detector to measure the evaluation parameter, and causing the body position detector to measure a body angle of the subject at a predetermined sampling frequency to store the measurement data in the storage.

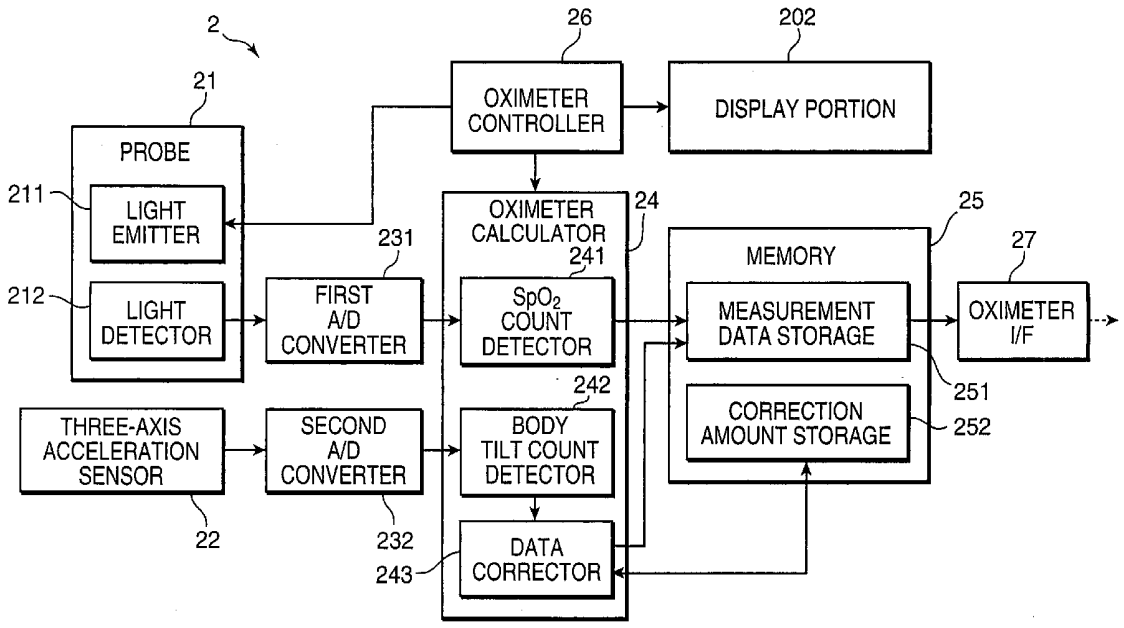


FIG.1

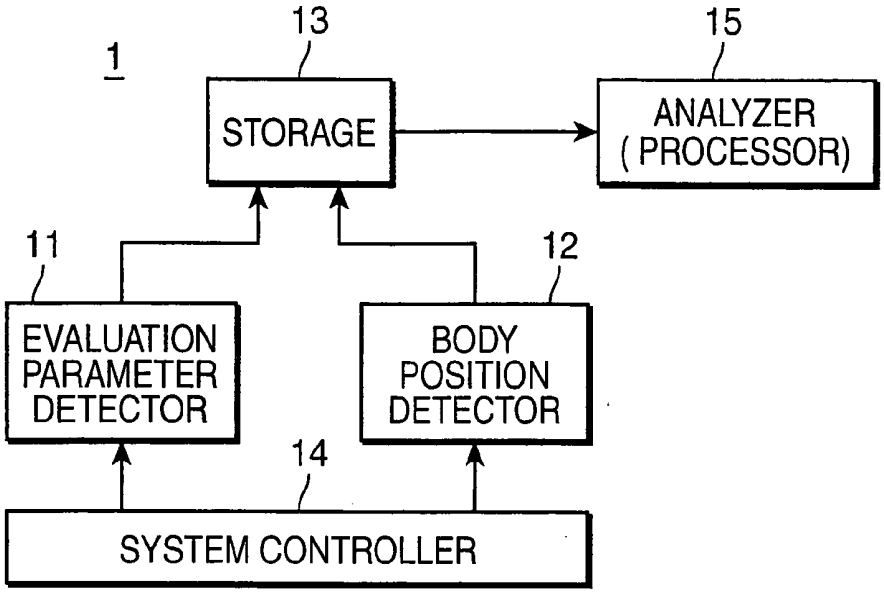

1
13
15
STORAGE
ANALYZER
(PROCESSOR)
11
12
EVALUATION
PARAMETER
DETECTOR
BODY
POSITION
DETECTOR
14
SYSTEM CONTROLLER

FIG.2

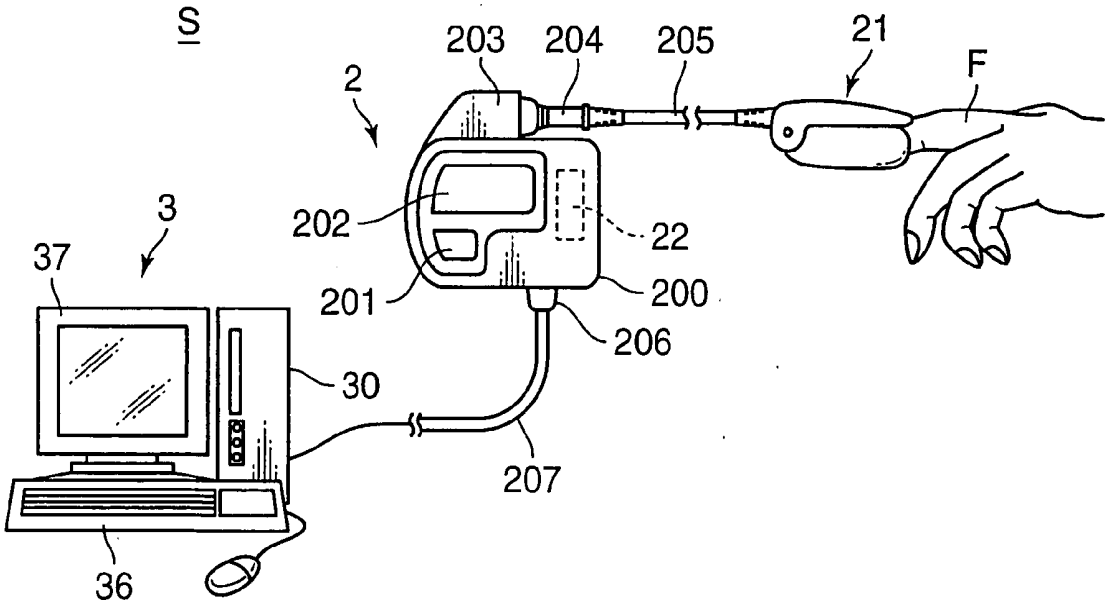

S
203
204
205
21
F
2
3
202
22
37
201
200
206
30
207
36

FIG.3

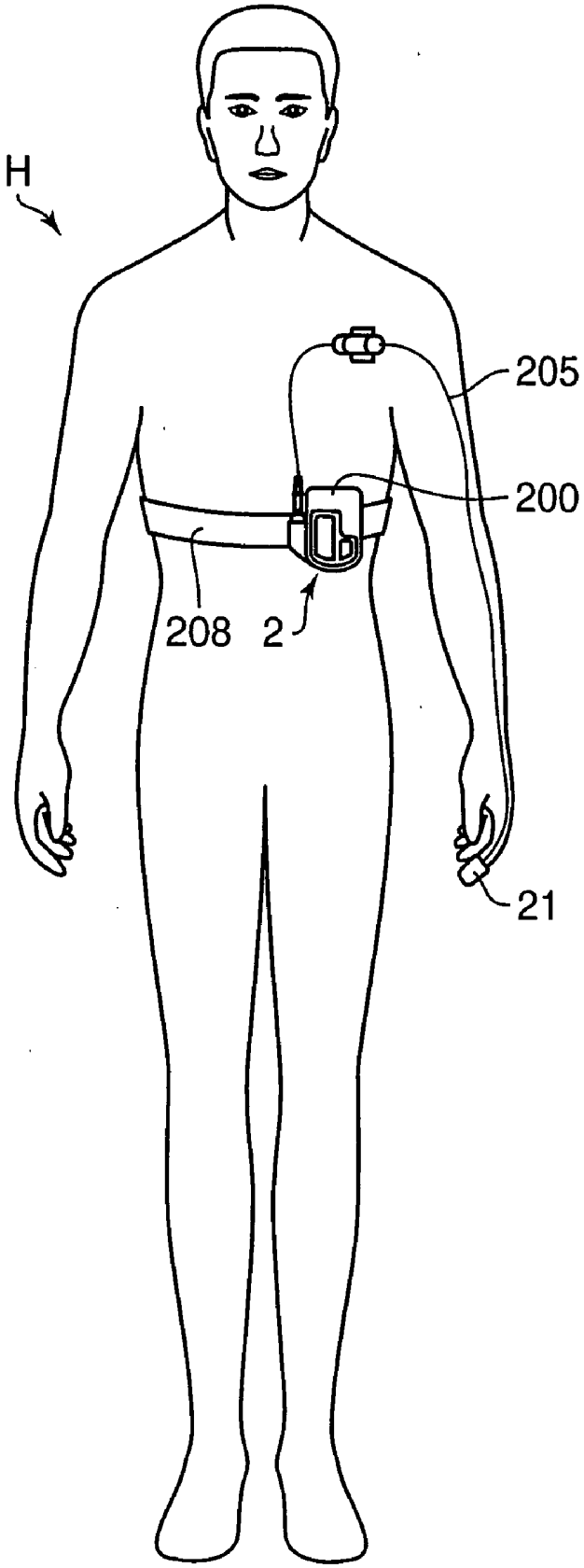


FIG.4

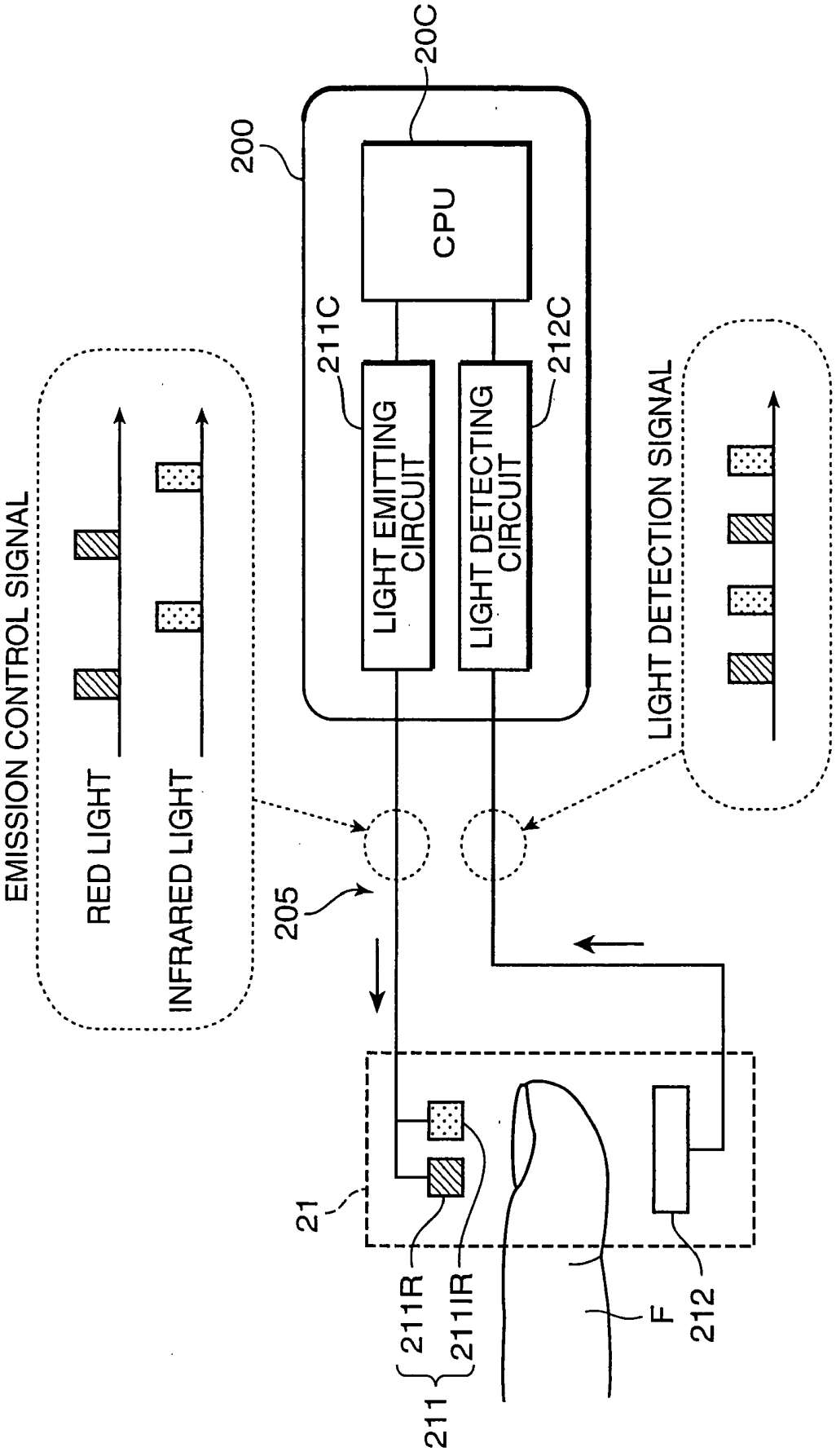

20C
200
CPU
211C
212C
LIGHT EMITTING CIRCUIT
LIGHT DETECTING CIRCUIT
EMISSION CONTROL SIGNAL
RED LIGHT
INFRARED LIGHT
LIGHT DETECTION SIGNAL
205
21
211R
211IR
211
F
212

FIG.5A

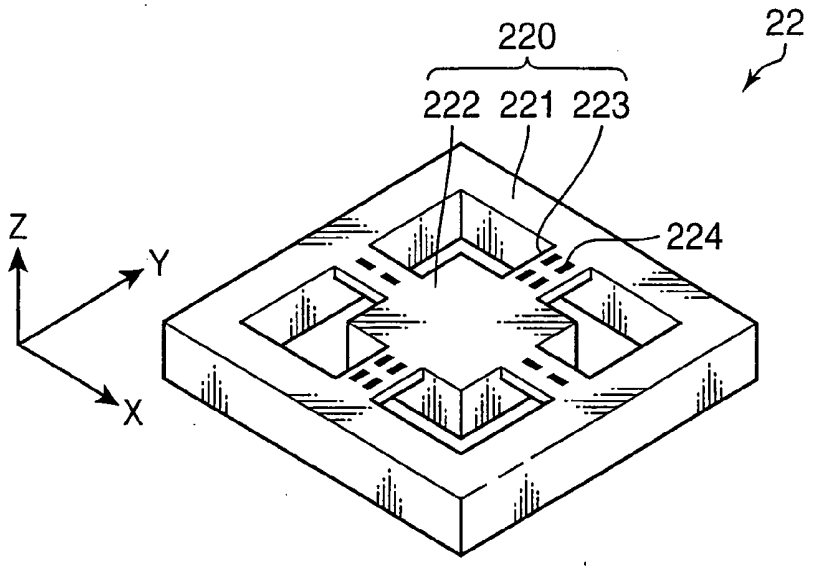


FIG.5B

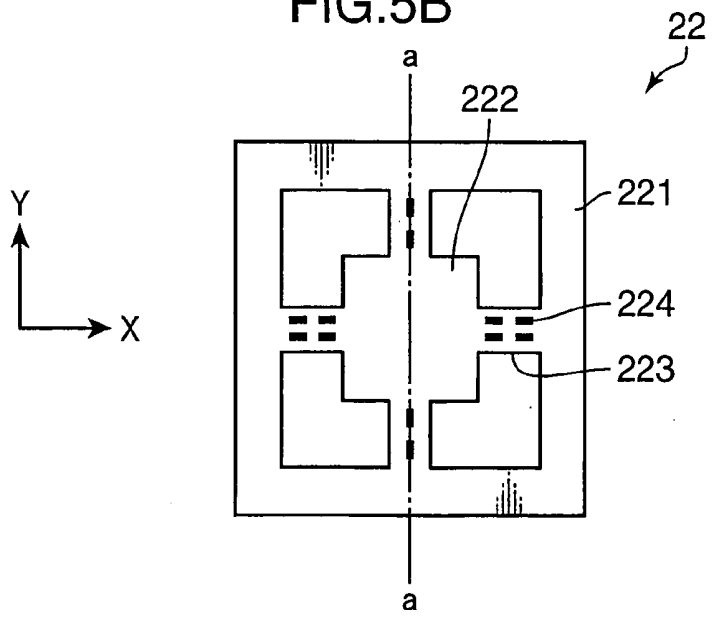


FIG.5C

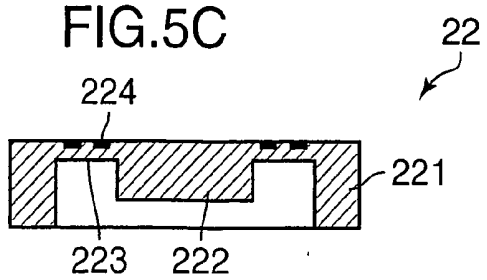


FIG.6A

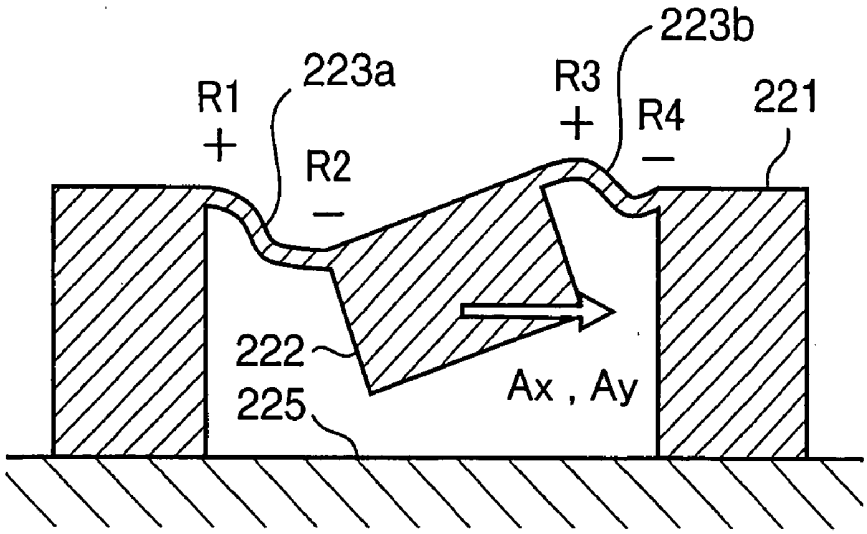


FIG.6B

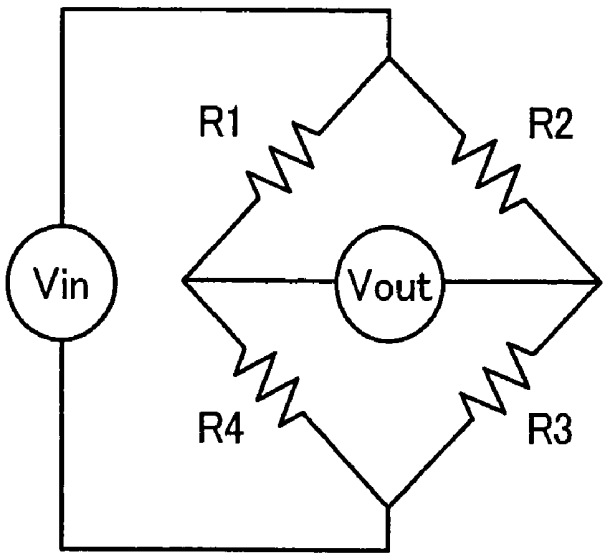


FIG.7A

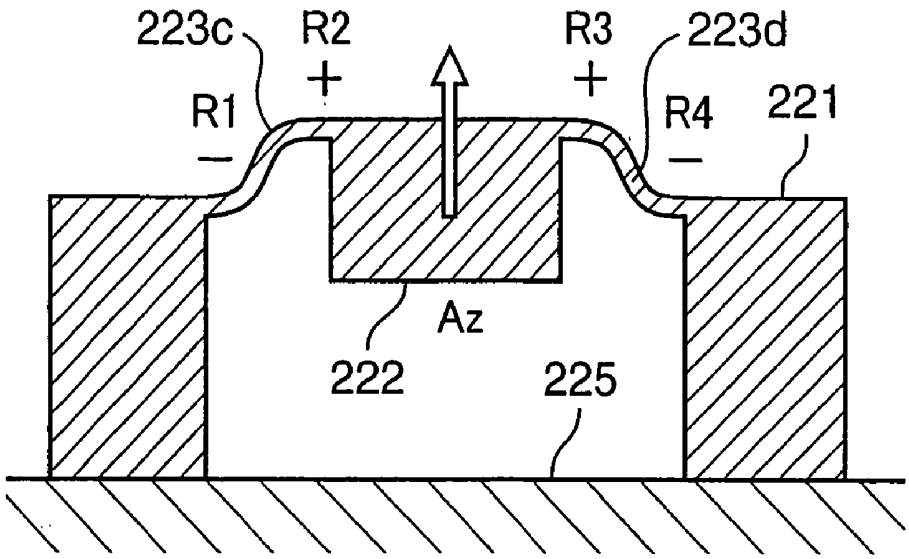


FIG.7B

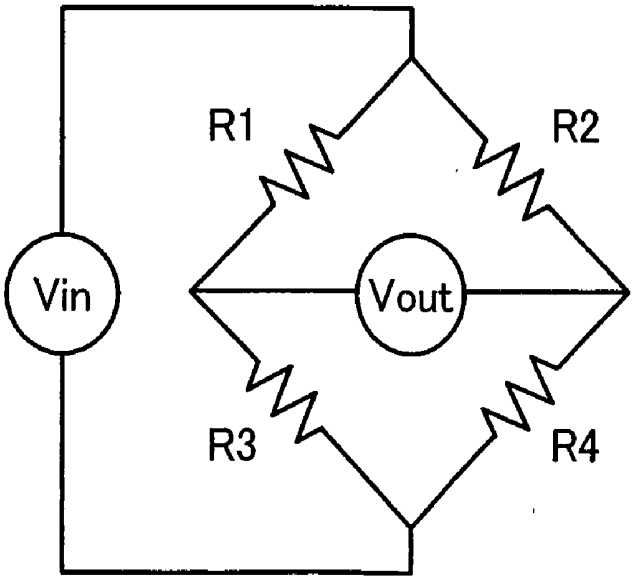


FIG.8

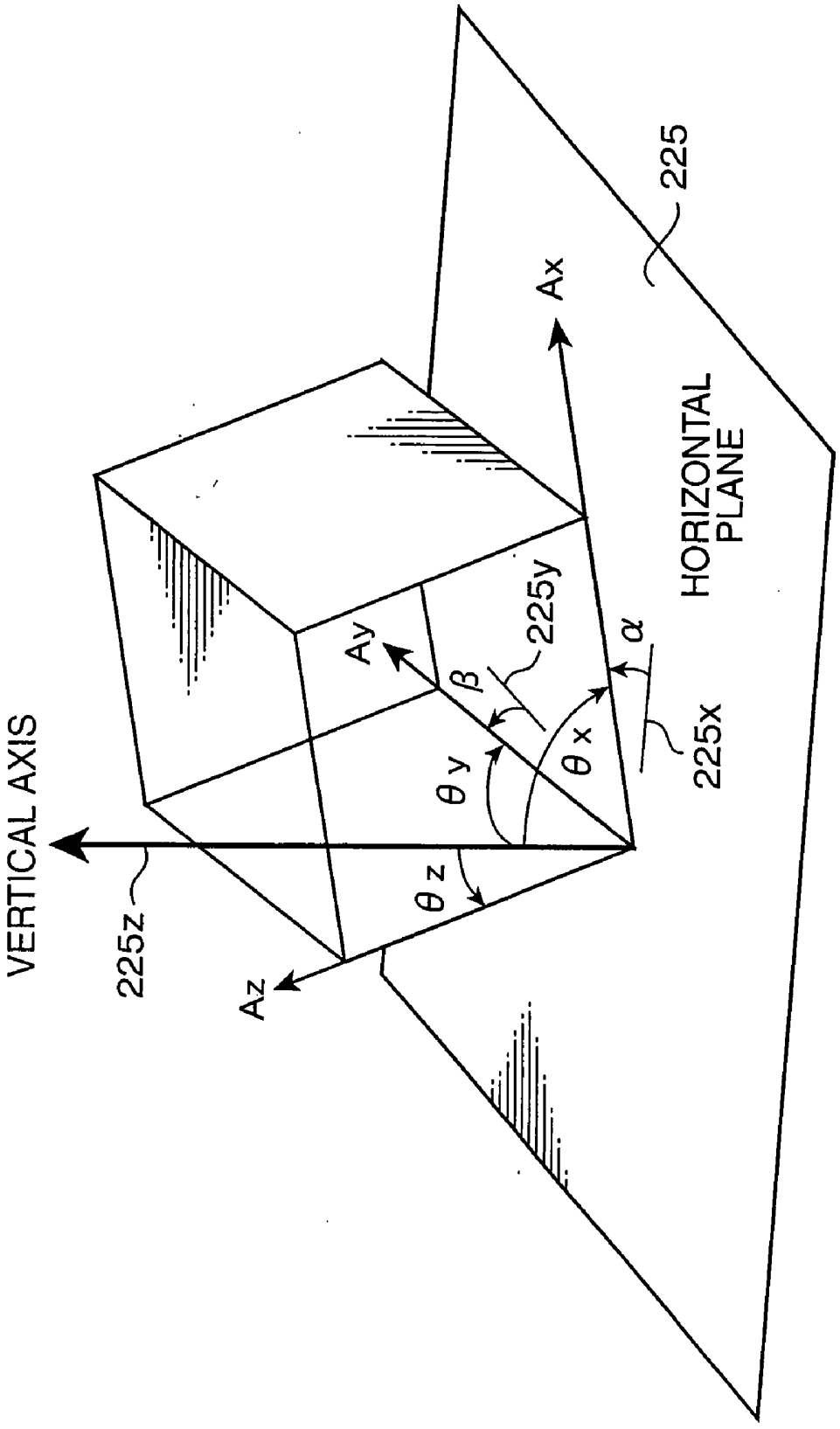

225
Ax
HORIZONTAL PLANE
Ay
225y
β
α
θ y
θ x
225x
VERTICAL AXIS
θ z
225z
Az

FIG.9

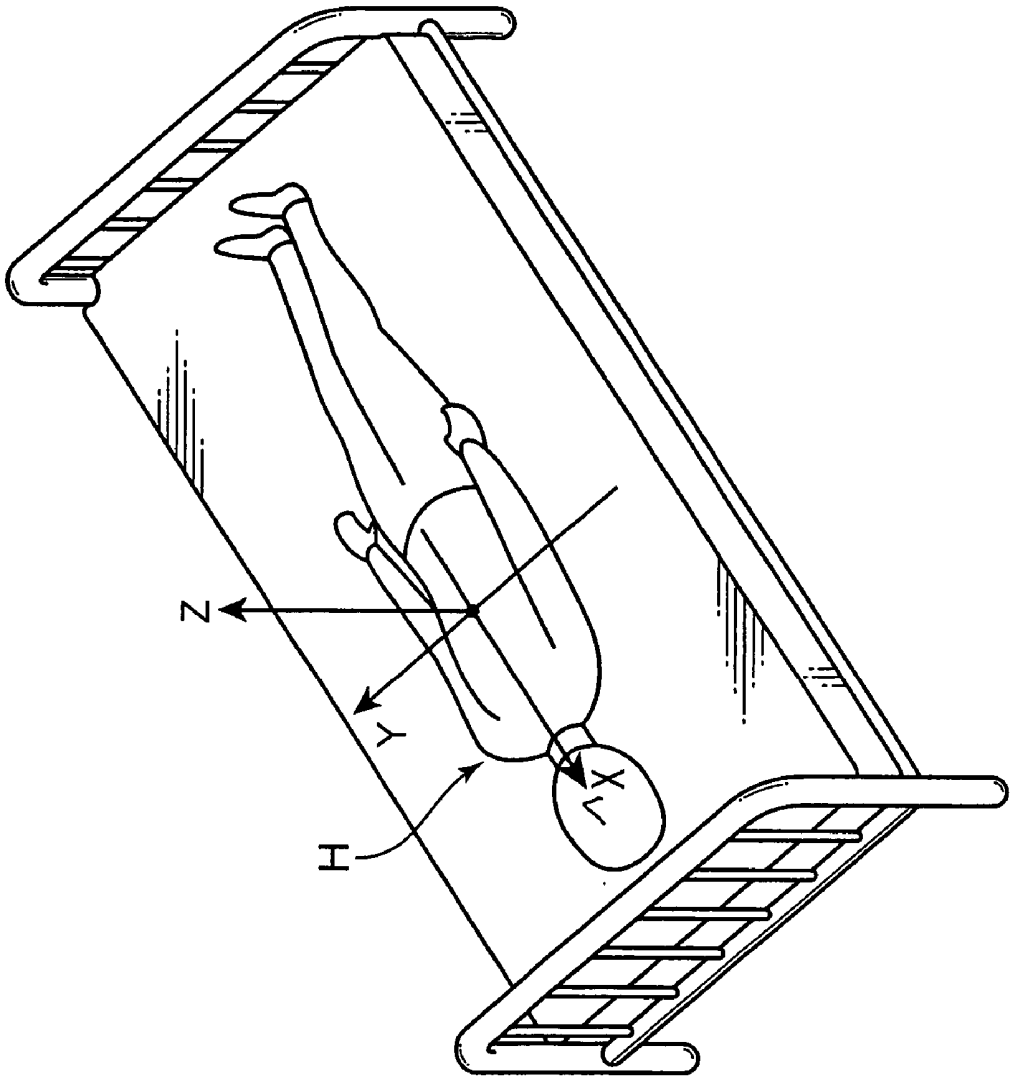


FIG.10

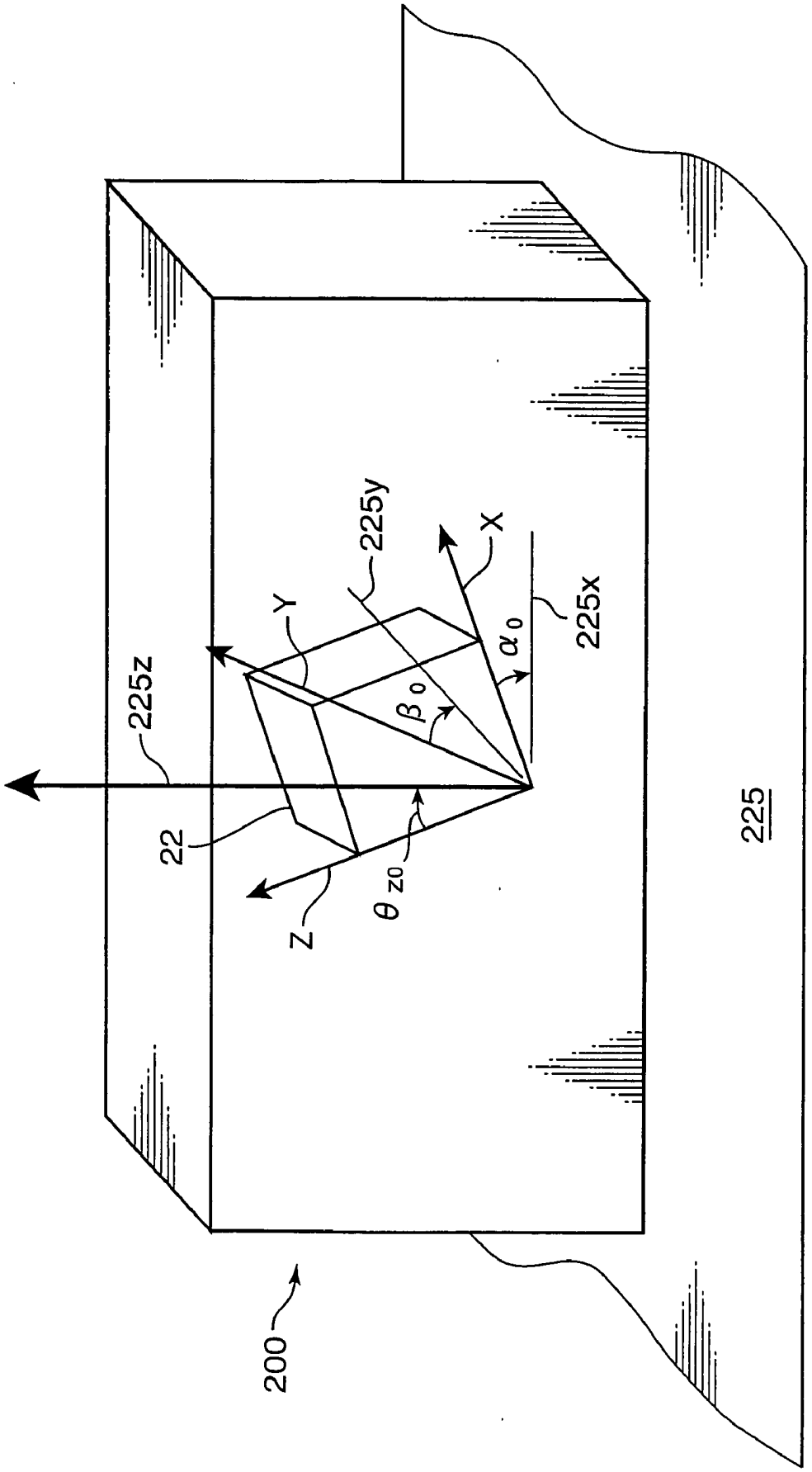
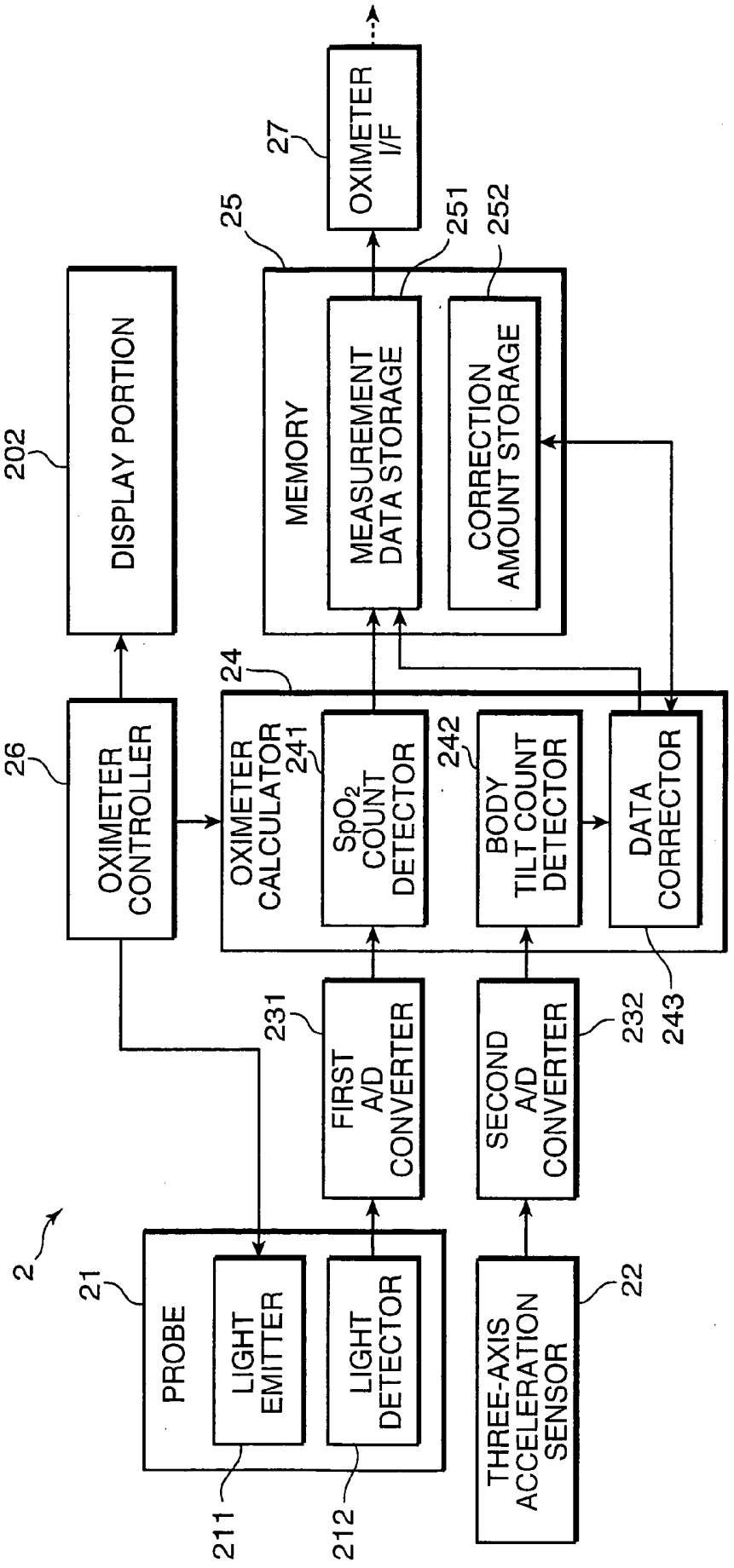


FIG.11


2
21
PROBE
LIGHT EMITTER
LIGHT DETECTOR
211
212
THREE-AXIS ACCELERATION SENSOR
22
FIRST A/D CONVERTER
231
SECOND A/D CONVERTER
232
243
OXIMETER CONTROLLER
26
OXIMETER CALCULATOR
24
SpO_2 COUNT DETECTOR
241
BODY TILT COUNT DETECTOR
242
DATA CORRECTOR
DISPLAY PORTION
202
MEMORY
25
MEASUREMENT DATA STORAGE
251
CORRECTION AMOUNT STORAGE
252
OXIMETER I/F
27

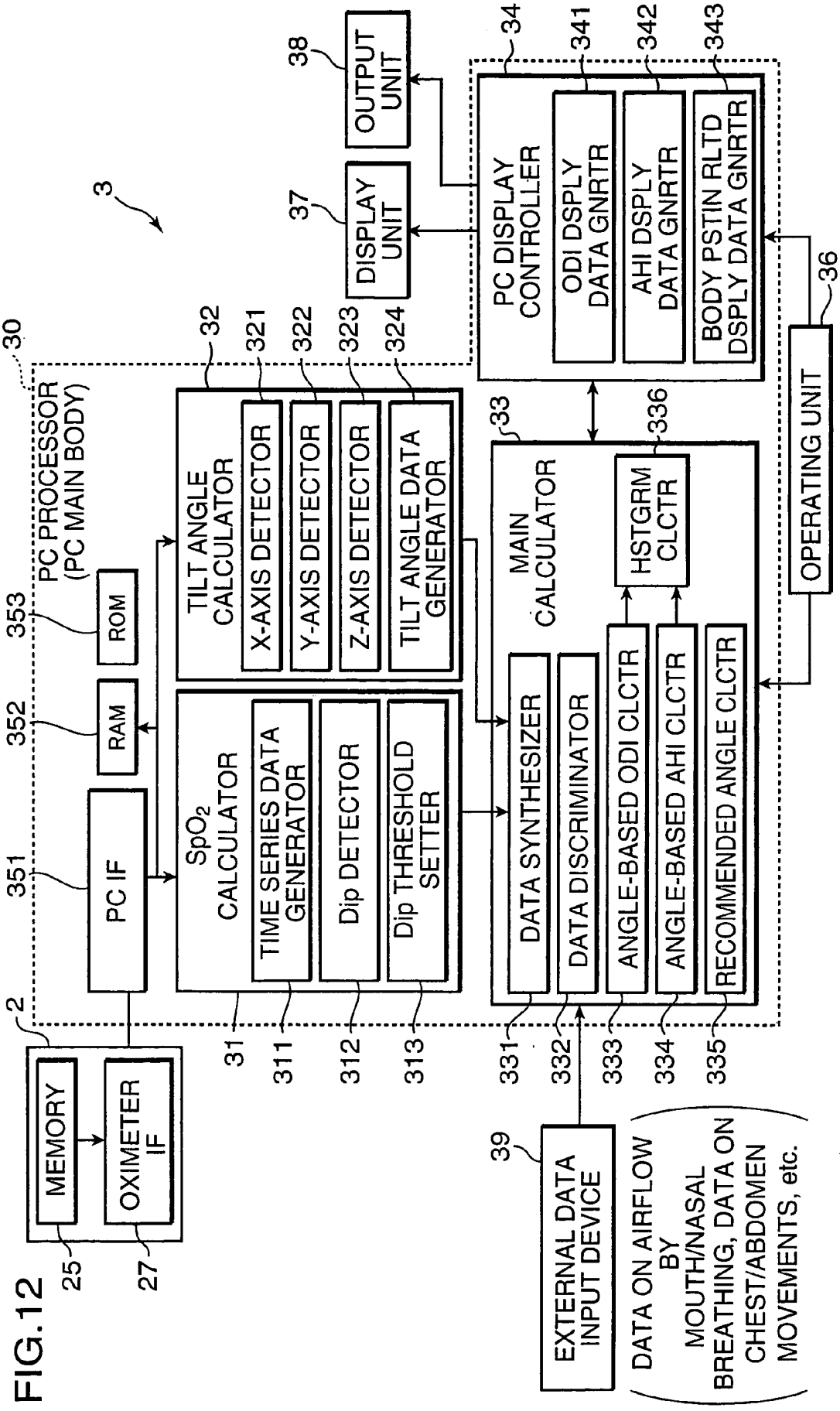

3
2
30
PC PROCESSOR
(PC MAIN BODY)
MEMORY
OXIMETER IF
PC IF
ROM
RAM
SpO_2 CALCULATOR
TIME SERIES DATA GENERATOR
Dip DETECTOR
Dip THRESHOLD SETTER
TILT ANGLE CALCULATOR
X-AXIS DETECTOR
Y-AXIS DETECTOR
Z-AXIS DETECTOR
TILT ANGLE DATA GENERATOR
MAIN CALCULATOR
DATA SYNTHESIZER
DATA DISCRIMINATOR
ANGLE-BASED ODI CLCTR
ANGLE-BASED AHI CLCTR
RECOMMENDED ANGLE CLCTR
HSTGRM CLCTR
PC DISPLAY CONTROLLER
ODI DSPLY DATA GNRTR
AHI DSPLY DATA GNRTR
BODY PSTN RLTD DSPLY DATA GNRTR
OUTPUT UNIT
DISPLAY UNIT
OPERATING UNIT
EXTERNAL DATA INPUT DEVICE
DATA ON AIRFLOW BY MOUTH/NASAL BREATHING, DATA ON CHEST/ABDOMEN MOVEMENTS, etc.
25
27
31
311
312
313
32
321
322
323
324
33
331
332
333
334
335
336
34
341
342
343
35
351
352
353
36
37
38
39

FIG. 12

FIG. 13

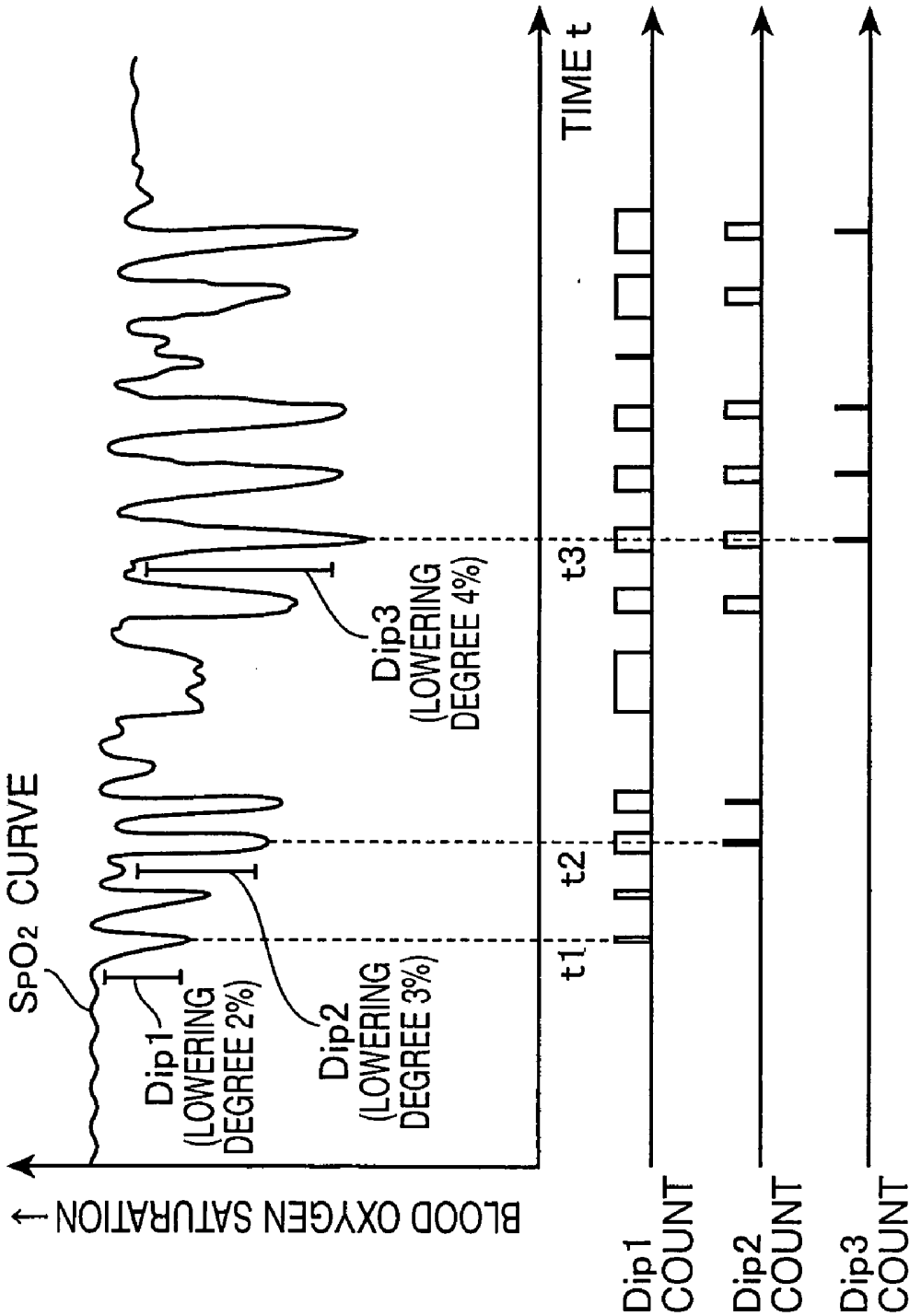

BLOOD OXYGEN SATURATION
TIME t
SpO2 CURVE
Dip1 (LOWERING DEGREE 2%)
Dip2 (LOWERING DEGREE 3%)
Dip3 (LOWERING DEGREE 4%)
t1
t2
t3
Dip1 COUNT
Dip2 COUNT
Dip3 COUNT

FIG.14

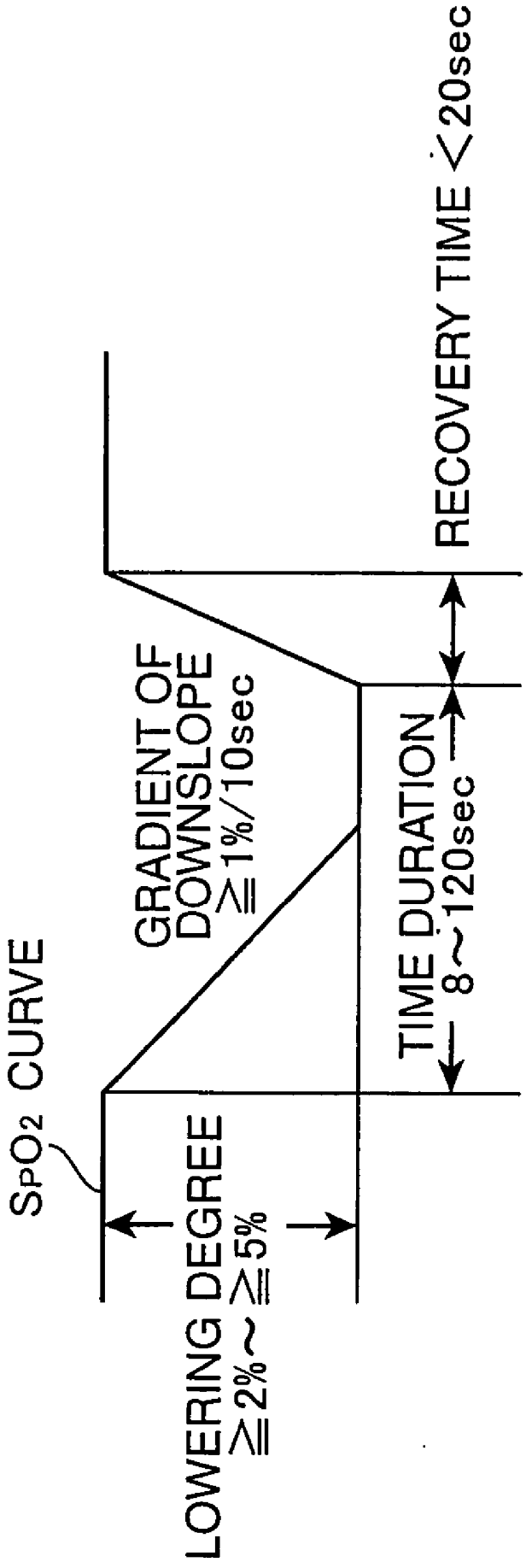

RECOVERY TIME <20sec
GRADIENT OF DOWNSLOPE ≧1%/10sec
TIME DURATION 8~120sec
SpO2 CURVE
LOWERING DEGREE ≧2%~≧5%

FIG.15

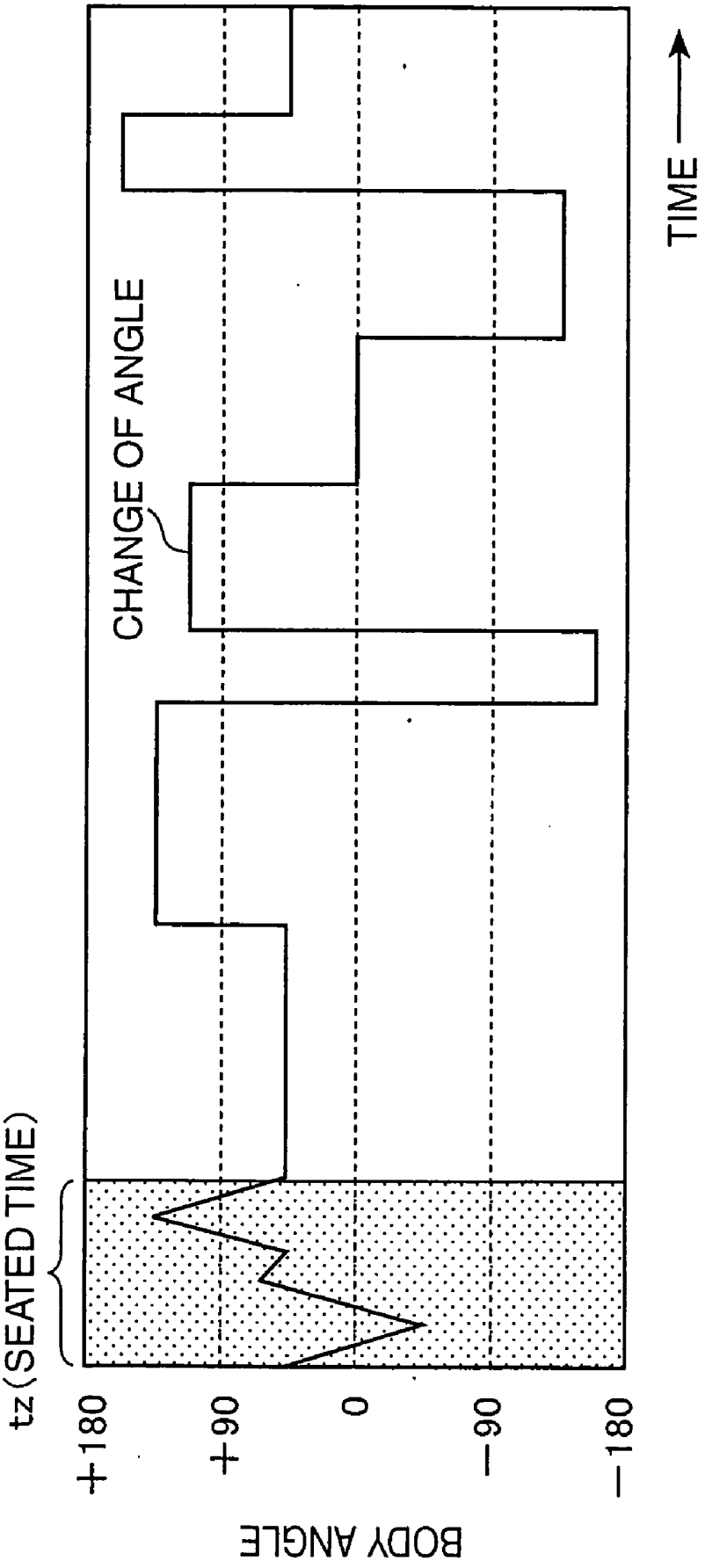


FIG.16

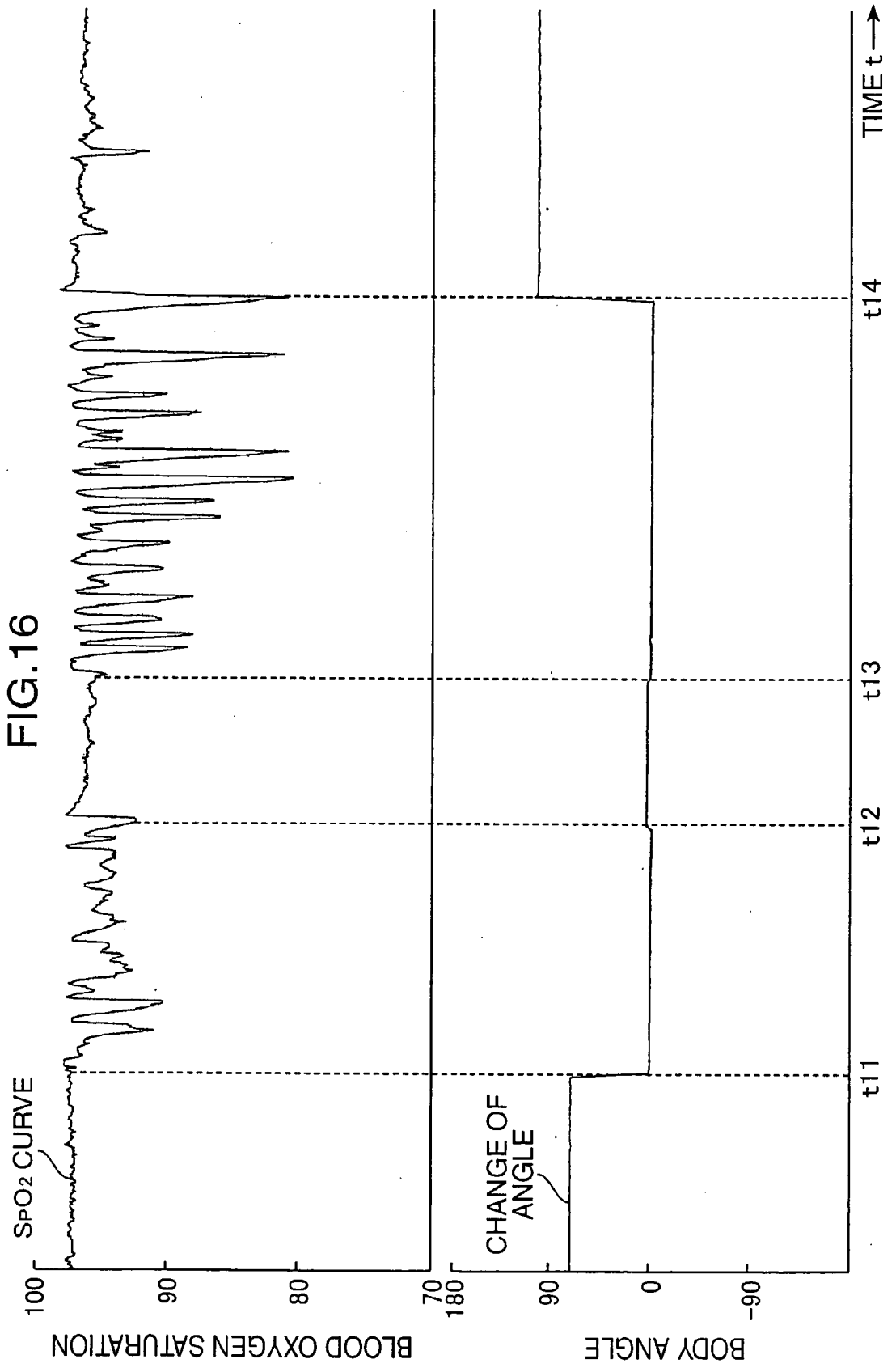

SpO2 CURVE
100
90
80
70
BLOOD OXYGEN SATURATION
CHANGE OF ANGLE
180
90
0
-90
BODY ANGLE
t11
t12
t13
t14
TIME t

FIG.17

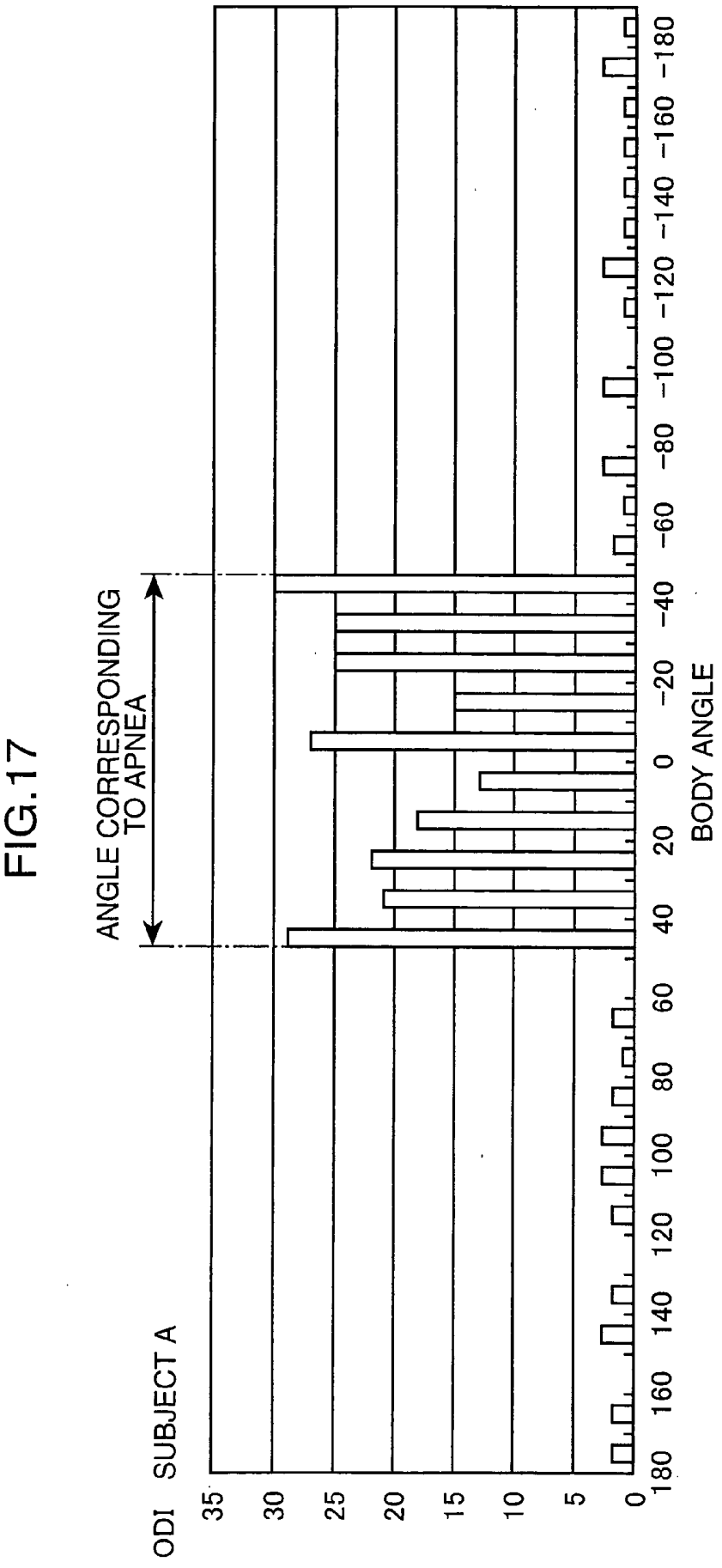

ODI SUBJECT A
35
30
25
20
15
10
5
0
ANGLE CORRESPONDING TO APNEA
180 160 140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -120 -140 -160 -180
BODY ANGLE

FIG.18

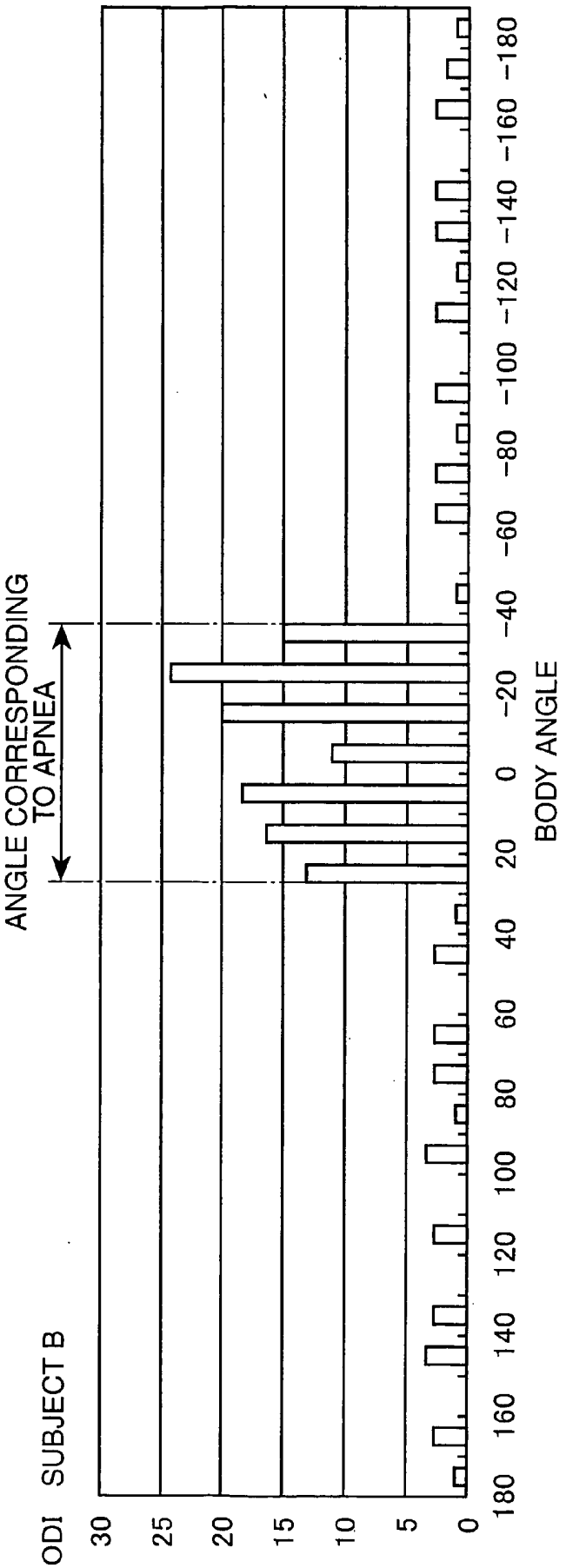
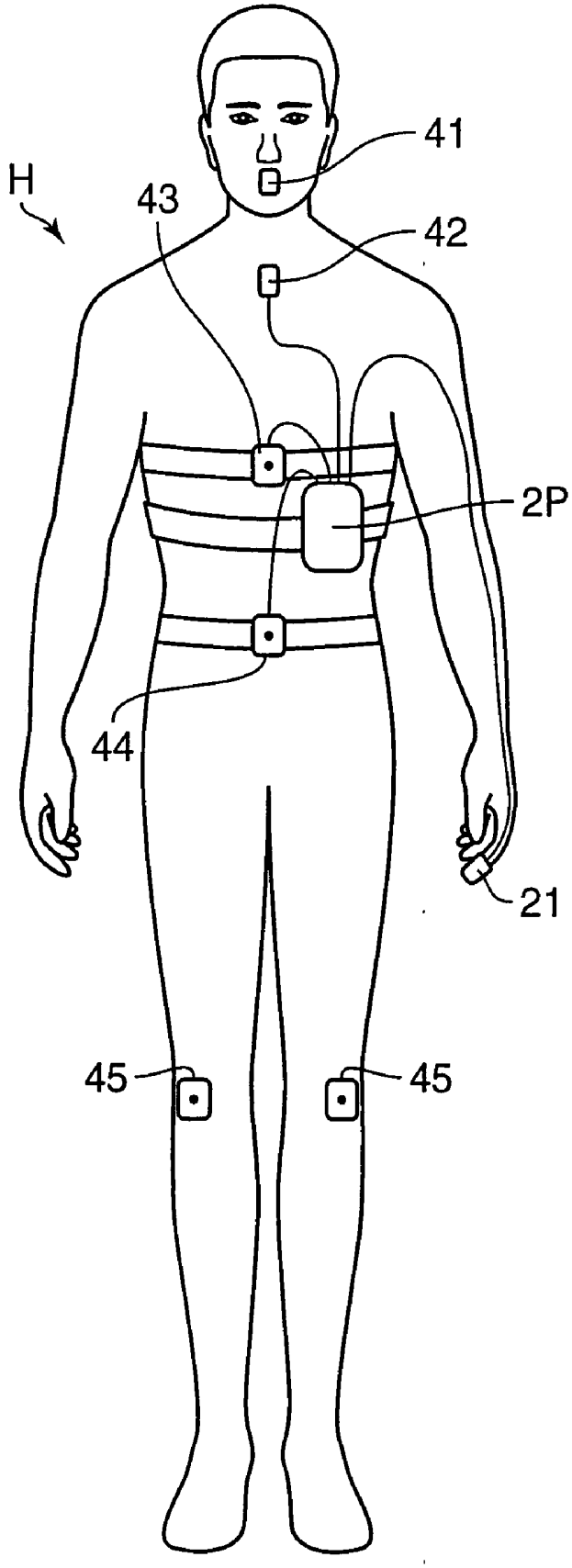

ODI SUBJECT B
30
25
20
15
10
5
0
180 160 140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -120 -140 -160 -180
BODY ANGLE
ANGLE CORRESPONDING TO APNEA

FIG.19



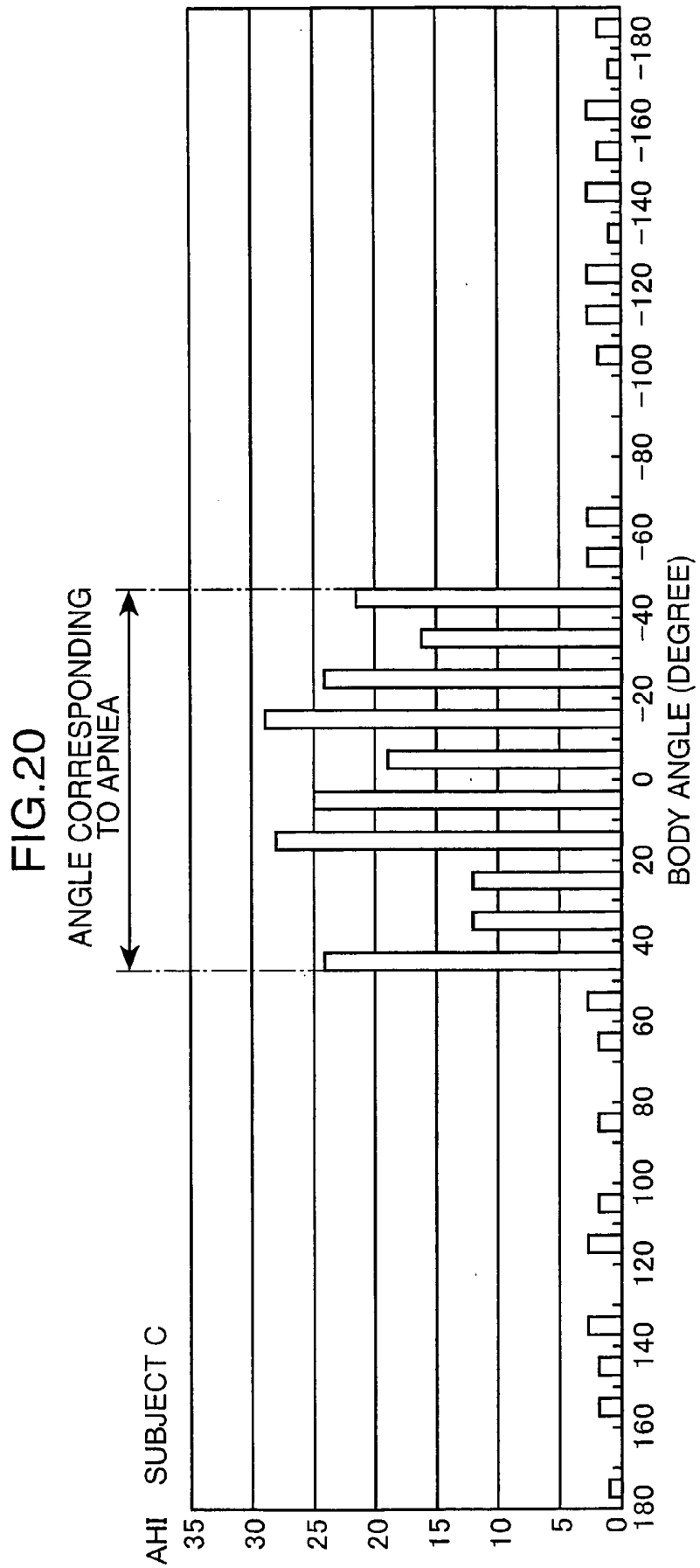

AHI SUBJECT C
35
30
25
20
15
10
5
0
180 160 140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -120 -140 -160 -180
BODY ANGLE (DEGREE)
ANGLE CORRESPONDING TO APNEA

FIG.20

FIG.21A

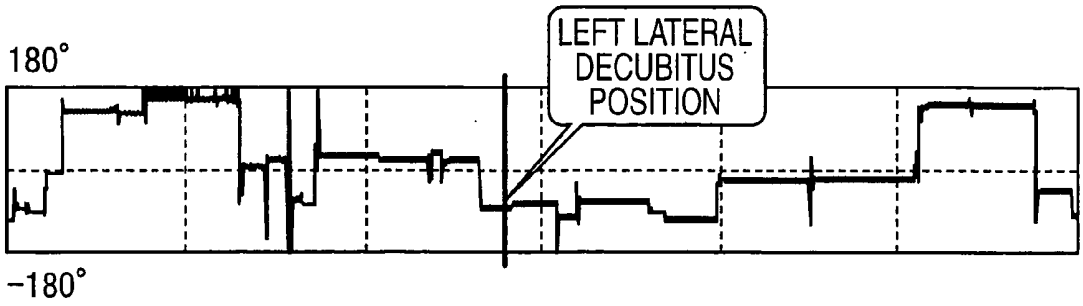


FIG.21B

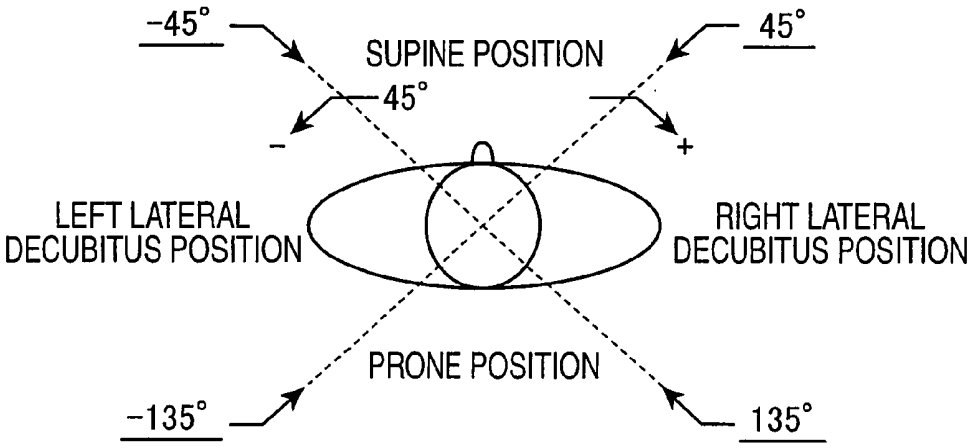


FIG.21C

RELATION BETWEEN BODY POSITION AND BODY ANGLE

PRONE POSITION	-135° TO -180° OR 135° TO 180°
RIGHT LATERAL DECUBITUS POSITION	-45° TO -135°
SUPINE POSITION	-45° TO 45°
LEFT LATERAL DECUBITUS POSITION	45° TO 135°

FIG.22

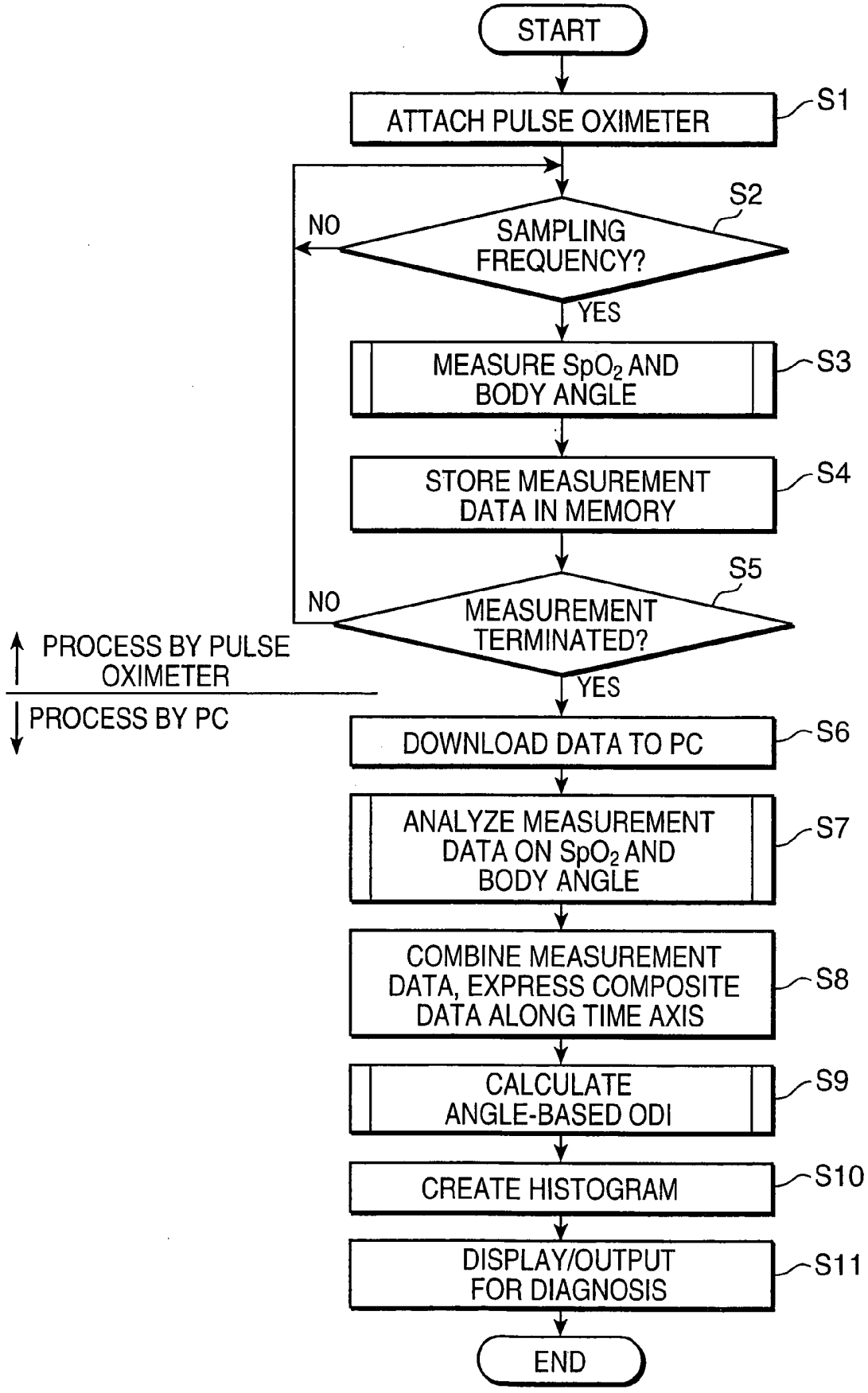

START
ATTACH PULSE OXIMETER
S1
S2
NO
SAMPLING FREQUENCY?
YES
MEASURE SpO_2 AND BODY ANGLE
S3
STORE MEASUREMENT DATA IN MEMORY
S4
S5
NO
MEASUREMENT TERMINATED?
YES
PROCESS BY PULSE OXIMETER
PROCESS BY PC
DOWNLOAD DATA TO PC
S6
ANALYZE MEASUREMENT DATA ON SpO_2 AND BODY ANGLE
S7
COMBINE MEASUREMENT DATA, EXPRESS COMPOSITE DATA ALONG TIME AXIS
S8
CALCULATE ANGLE-BASED ODI
S9
CREATE HISTOGRAM
S10
DISPLAY/OUTPUT FOR DIAGNOSIS
S11
END

FIG.23

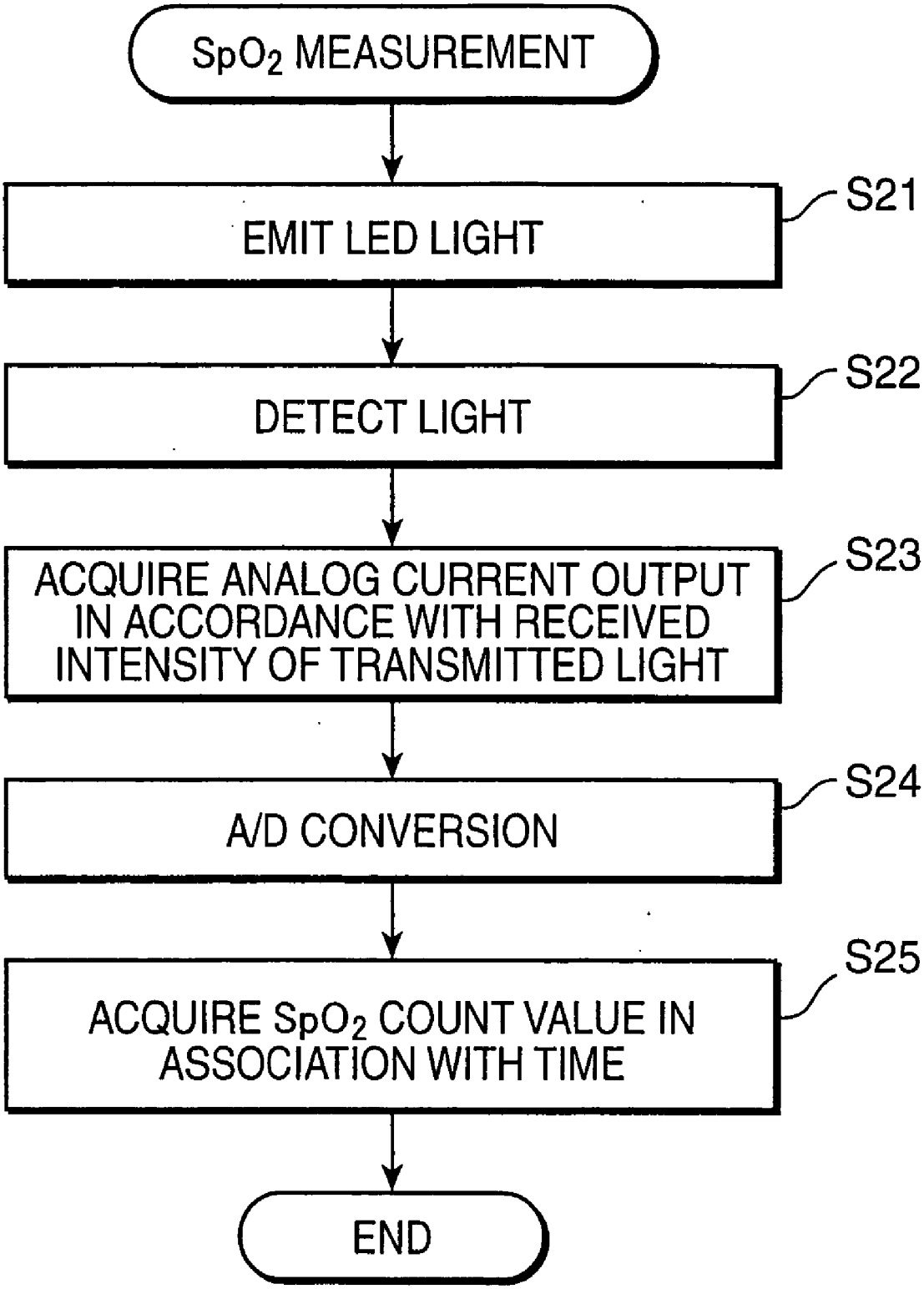

SpO2 MEASUREMENT
EMIT LED LIGHT
S21
DETECT LIGHT
S22
ACQUIRE ANALOG CURRENT OUTPUT IN ACCORDANCE WITH RECEIVED INTENSITY OF TRANSMITTED LIGHT
S23
A/D CONVERSION
S24
ACQUIRE SpO2 COUNT VALUE IN ASSOCIATION WITH TIME
S25
END

FIG.24

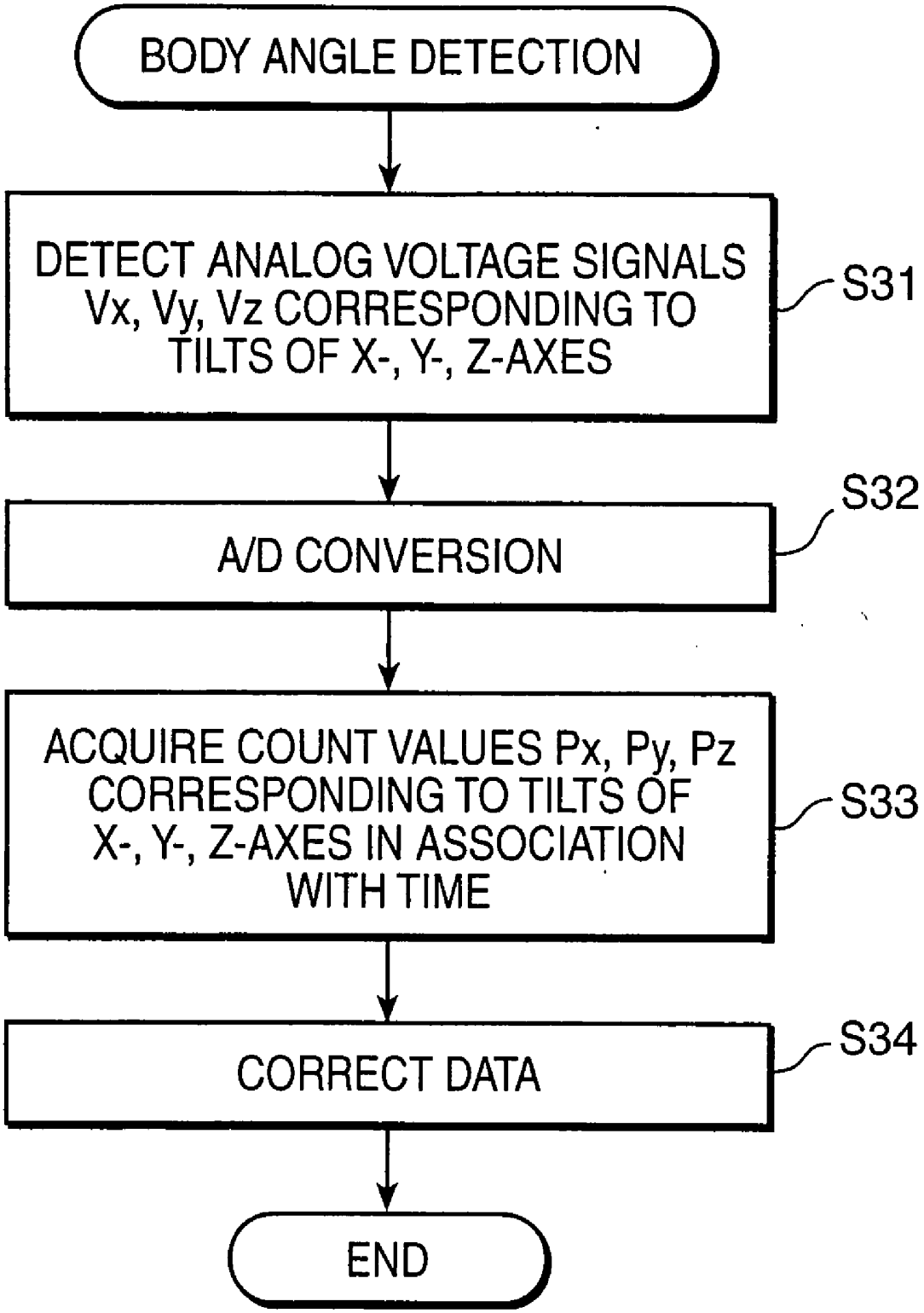

BODY ANGLE DETECTION
DETECT ANALOG VOLTAGE SIGNALS Vx, Vy, Vz CORRESPONDING TO TILTS OF X-, Y-, Z-AXES
S31
A/D CONVERSION
S32
ACQUIRE COUNT VALUES Px, Py, Pz CORRESPONDING TO TILTS OF X-, Y-, Z-AXES IN ASSOCIATION WITH TIME
S33
CORRECT DATA
S34
END

FIG.25

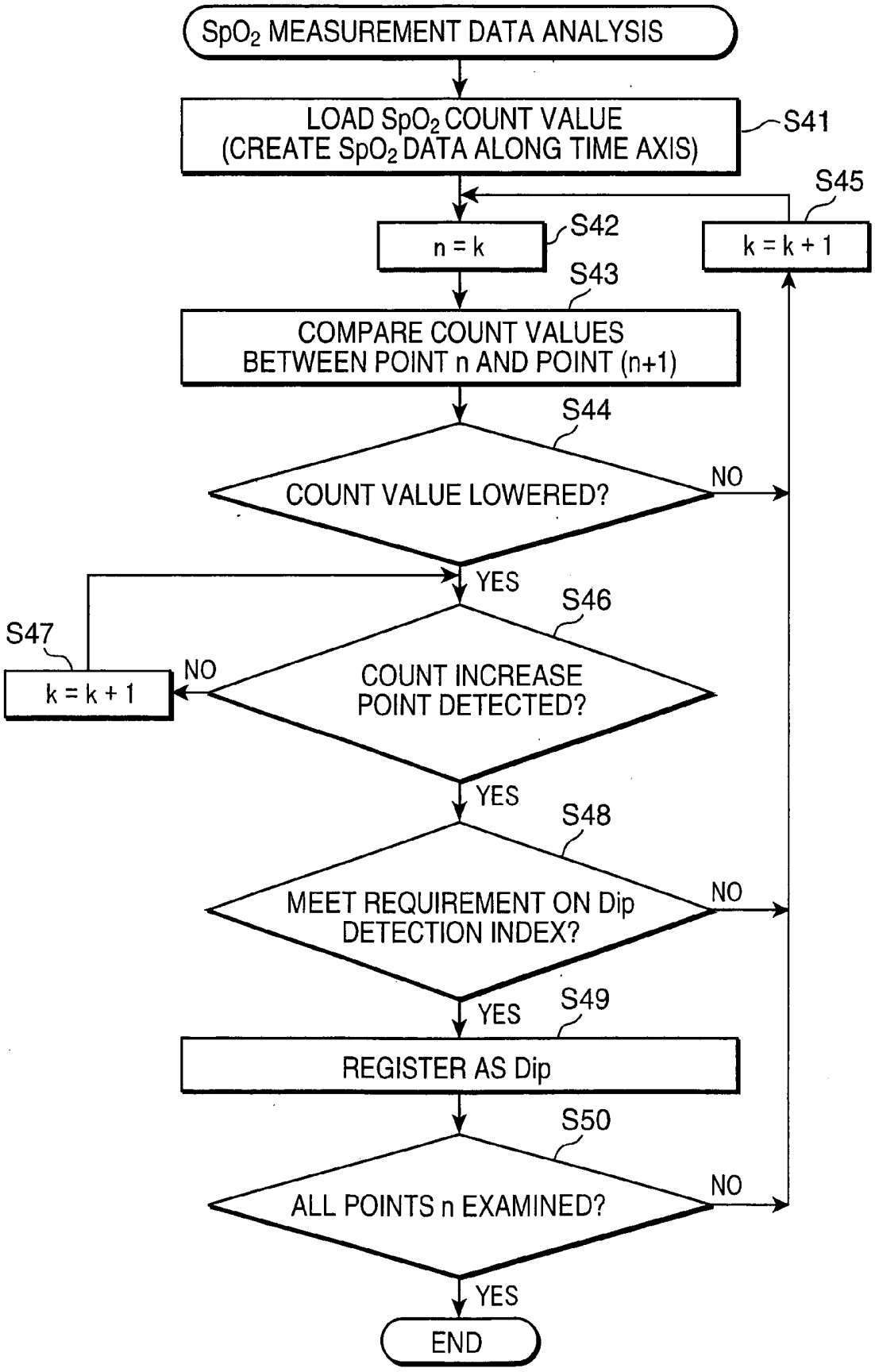

SpO2 MEASUREMENT DATA ANALYSIS
LOAD SpO2 COUNT VALUE (CREATE SpO2 DATA ALONG TIME AXIS)
S41
n = k
S42
k = k + 1
S45
S43
COMPARE COUNT VALUES BETWEEN POINT n AND POINT (n+1)
S44
COUNT VALUE LOWERED?
NO
YES
S46
S47
k = k + 1
NO
COUNT INCREASE POINT DETECTED?
YES
S48
MEET REQUIREMENT ON Dip DETECTION INDEX?
NO
YES
S49
REGISTER AS Dip
S50
ALL POINTS n EXAMINED?
NO
YES
END

FIG.26

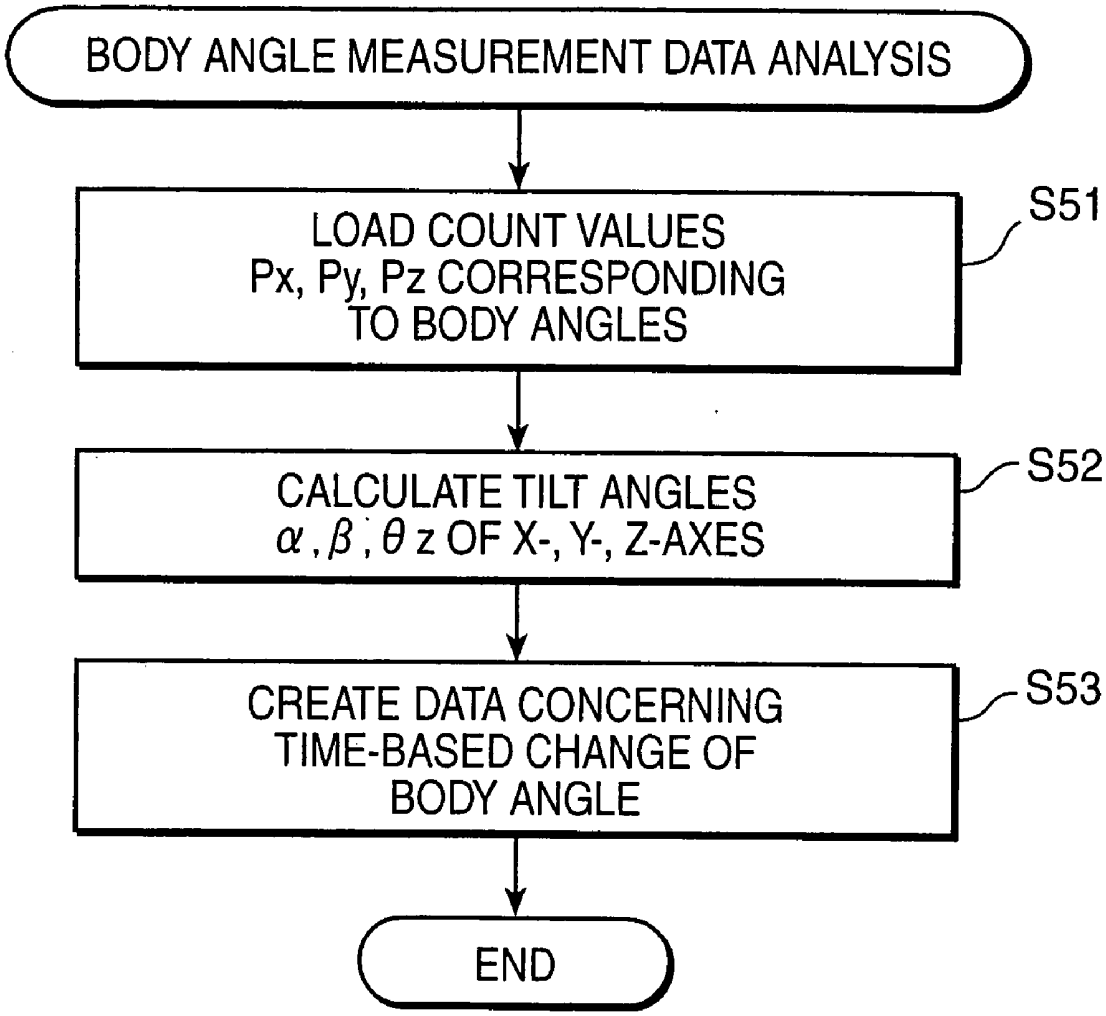

BODY ANGLE MEASUREMENT DATA ANALYSIS
LOAD COUNT VALUES Px, Py, Pz CORRESPONDING TO BODY ANGLES
S51
CALCULATE TILT ANGLES α, β, θz OF X-, Y-, Z-AXES
S52
CREATE DATA CONCERNING TIME-BASED CHANGE OF BODY ANGLE
S53
END

FIG.27

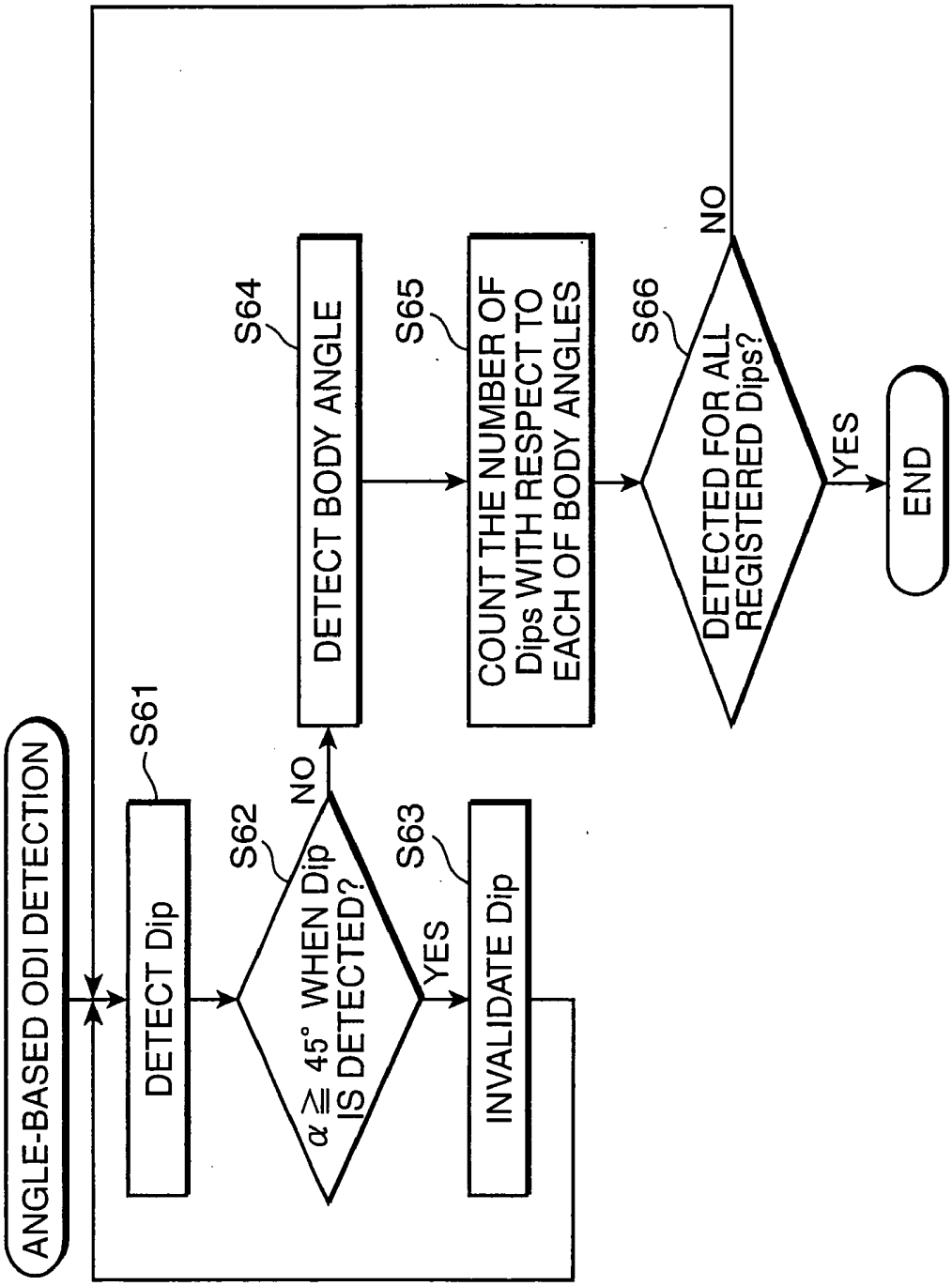

ANGLE-BASED ODI DETECTION
S61
DETECT Dip
S62
α ≧ 45° WHEN Dip IS DETECTED?
NO
YES
S63
INVALIDATE Dip
S64
DETECT BODY ANGLE
S65
COUNT THE NUMBER OF Dips WITH RESPECT TO EACH OF BODY ANGLES
S66
DETECTED FOR ALL REGISTERED Dips?
NO
YES
END

FIG.28

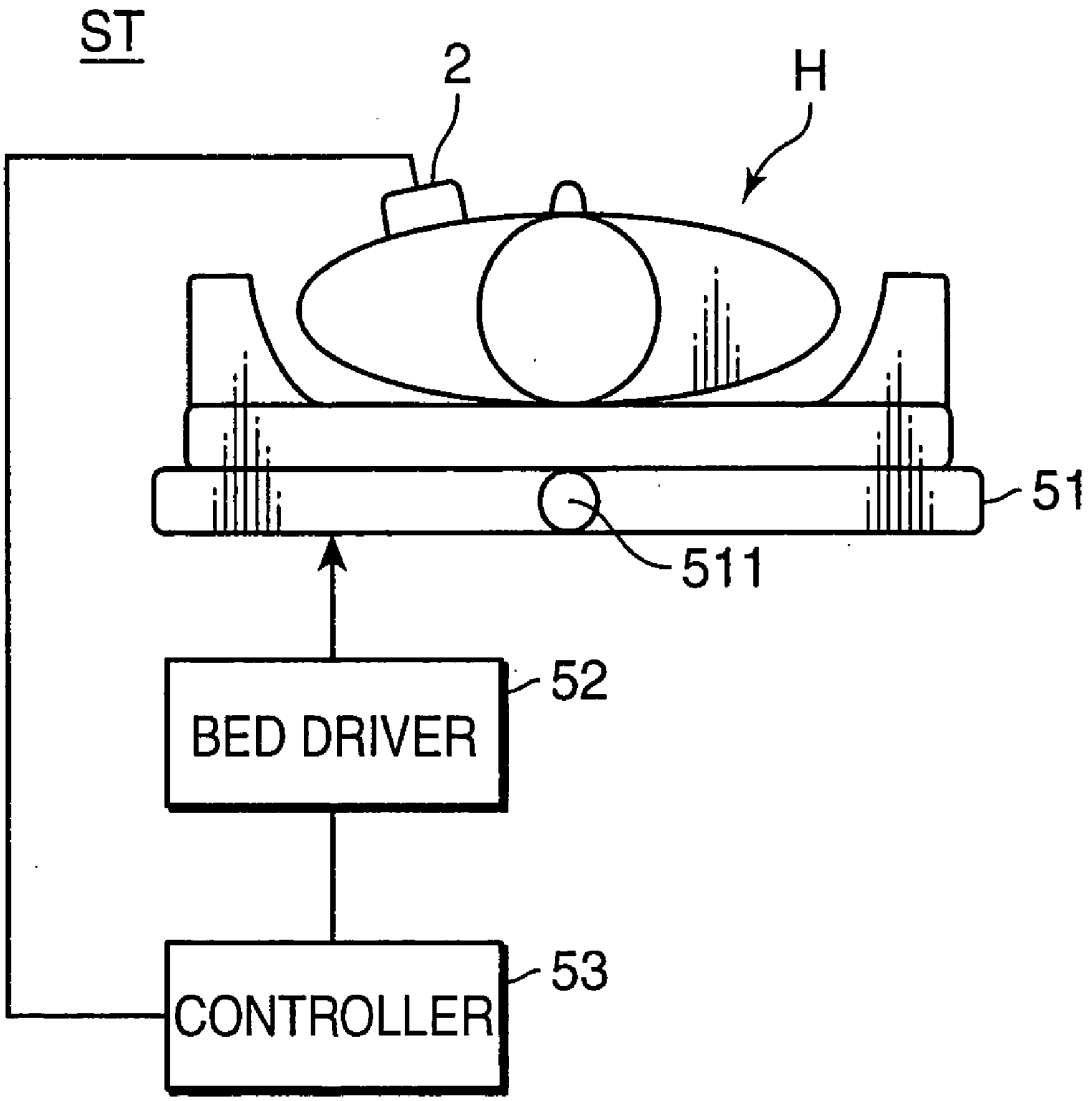
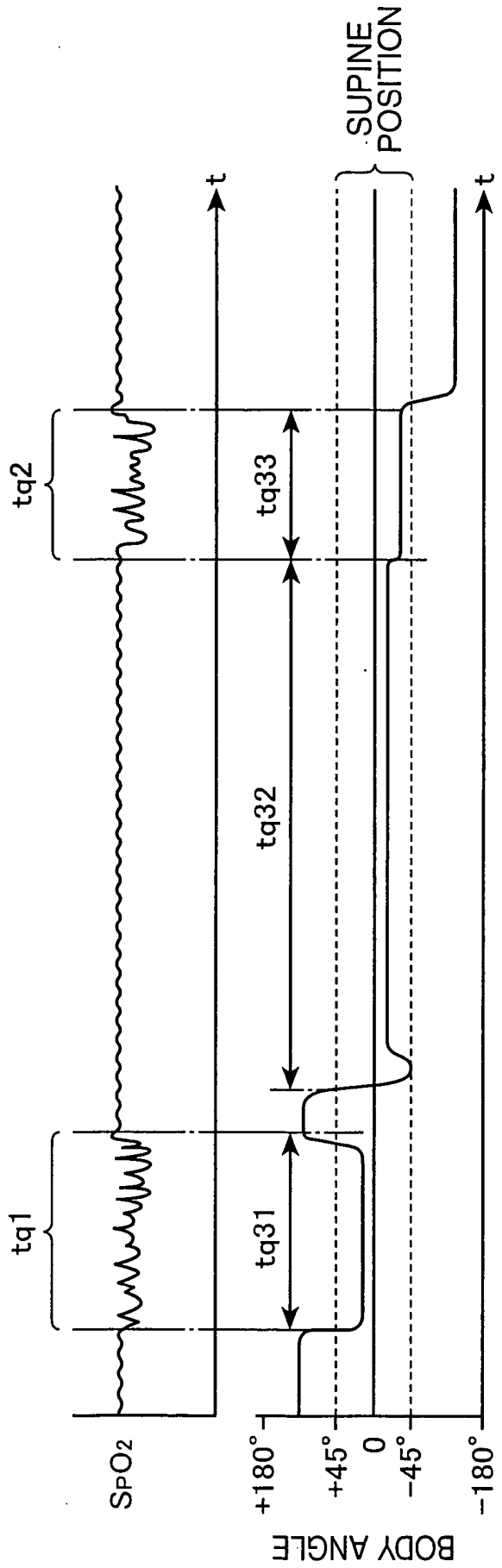


FIG.29


SUPINE POSITION
t
t
tq2
tq33
tq32
tq1
tq31
SpO2
+180°
+45°
0
-45°
-180°
BODY ANGLE

PRIOR ART
FIG.30

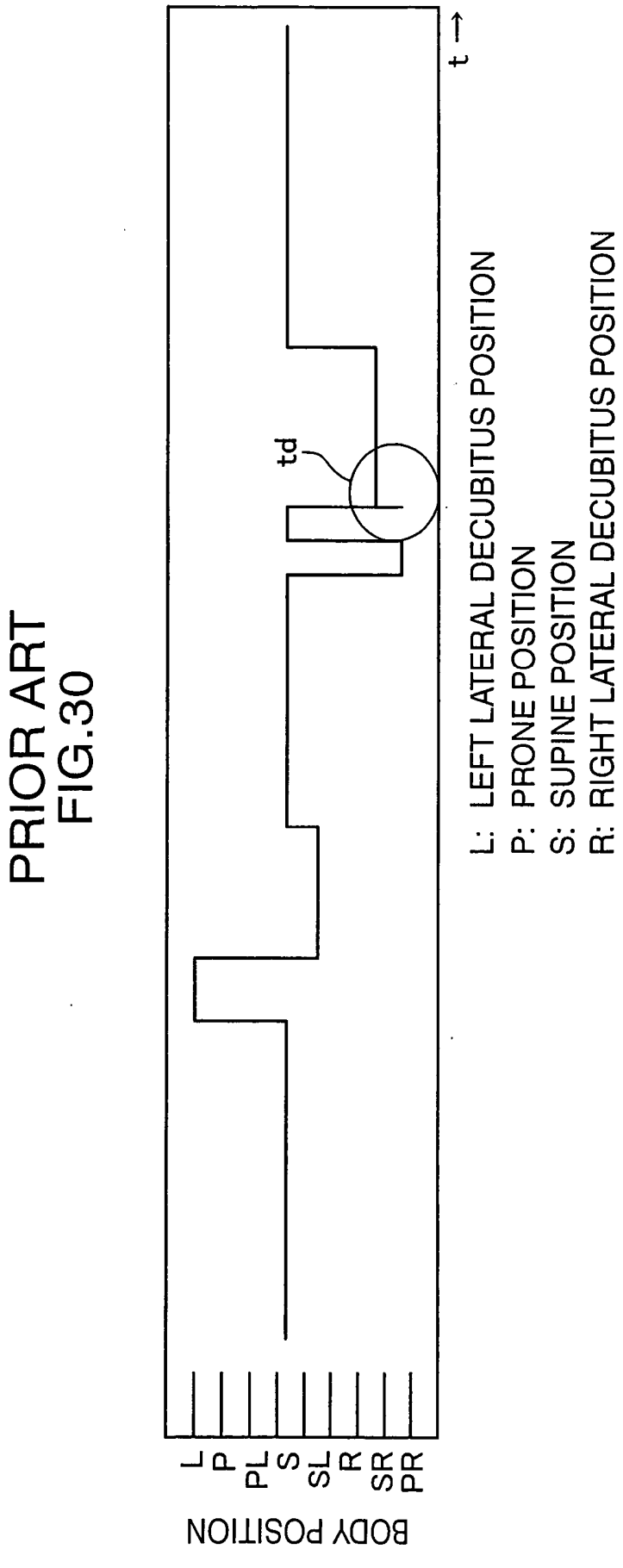
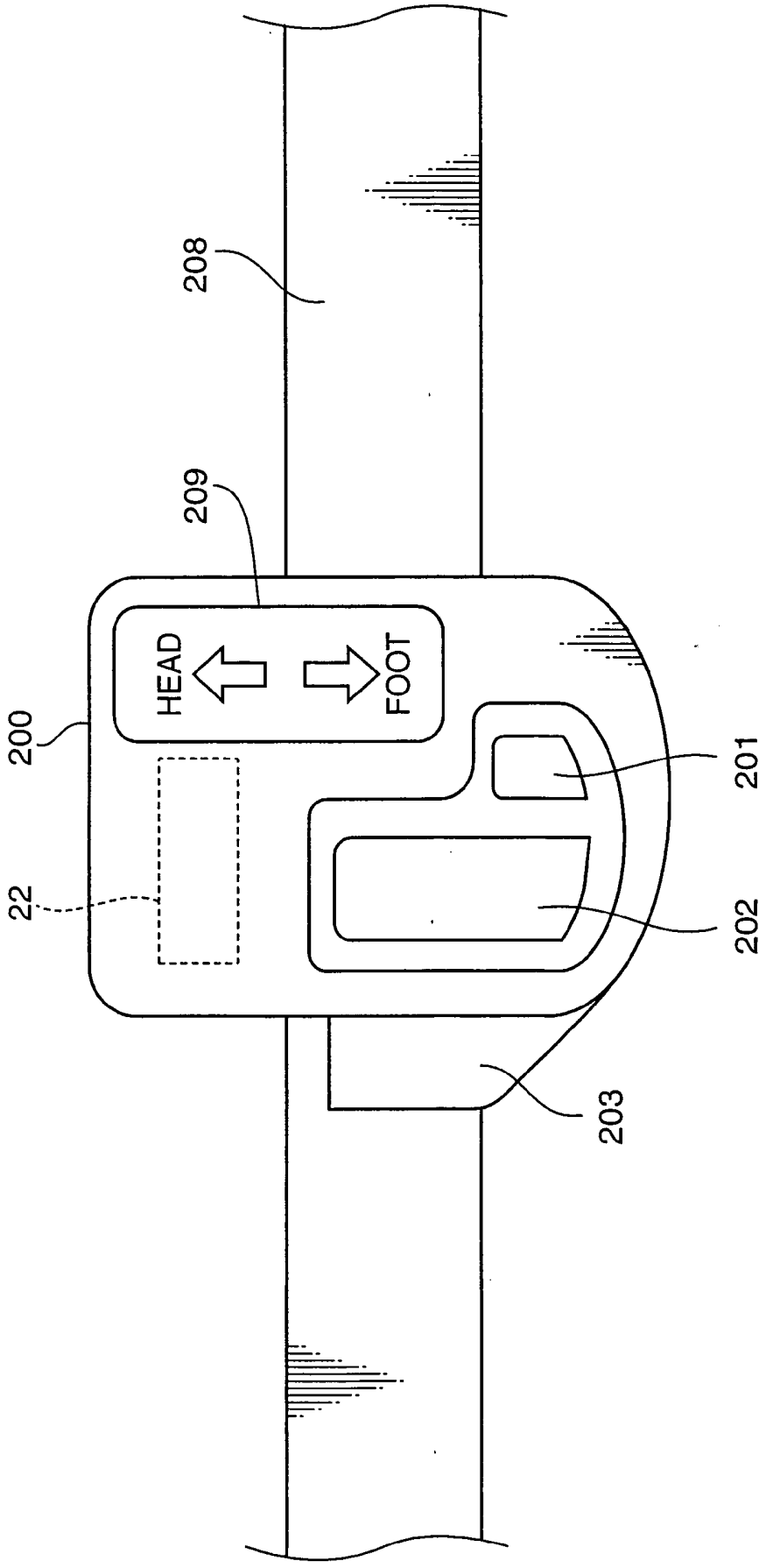


FIG.31



SLEEP EVALUATION METHOD, SLEEP EVALUATION SYSTEM, OPERATION PROGRAM FOR SLEEP EVALUATION SYSTEM, PULSE OXIMETER, AND SLEEP SUPPORT SYSTEM

[0001] This application is based on Japanese Patent Application No. 2005-23674 filed on Jan. 31, 2005, the contents of which are hereby incorporated by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to a method and a system for evaluating sleep of subjects in diagnosing sleep apnea syndrome (hereinafter, called as "SAS"), and more particularly to a sleep evaluation method and a sleep evaluation system capable of accurately obtaining a correlation between apnea and body position of a subject in sleep.

[0004] 2. Description of the Related Art

[0005] SAS, which may cause various diseases resulting from apnea or low respiration in sleep, have recently raised social issues, considering a possibility that SAS may not only cause high blood pressures, cerebrovascular disorders, or ischemic heart diseases, but also may lower labor productivity or induce severe work-related accidents due to daytime sleepiness. There is proposed an approach of measuring a variation in oxygen saturation in an arterial blood (hereinafter, called as "SpO_2" or "blood oxygen saturation") of a subject in sleep, as a process for screening SAS in light of a fact that oxygen is not supplied to the arterial blood in apnea, and the blood oxygen saturation is resultantly lowered.

[0006] Conventionally, there is known a pulse oximeter for measuring the blood oxygen saturation. In the pulse oximeter, a variation in blood oxygen saturation with time is detected by detachably attaching a probe provided with a light emitter and a light detector to a subject's finger, causing the light emitter to project light toward the subject's finger, detecting a variation in light amount passed through the finger in terms of a pulse signal, and processing the measurement result obtained every second interval by a moving-average method. The degree of severity of SAS is determined by integrating the number of peaks where the blood oxygen saturation is lowered, which is supposed to be caused by apnea. An example of indexes for judging the degree of severity of SAS is an oxygen desaturation index (ODI), which represents the number of peaks where blood oxygen saturation is lowered per hour. ODI can be measured with use of the pulse oximeter. Use of the pulse oximeter is simple, because a subject is merely required to attach the probe to his or her finger. Accordingly, it can be said that ODI is a useful index with which a subject i.e. a SAS patient is allowed to easily measure the degree of severity of SAS at home in a condition close to his or her ordinary sleep. Medical institutes typically use apnea hypopnea index (AHI), which represents the number of apneustic respirations or low respirations per hour. AHI is obtained by using polysomnography (PSG) for detecting various evaluation parameters, in addition to the blood oxygen saturation, such as electroencephalogram, airflow by mouth/nasal breathing, snoring sounds, movements of chest/abdomen, and body position.

[0007] It is known that there is a certain causal relation or correlation between apnea and body position of a SAS patient in sleep. Specifically, since the soft palate or posterior part of tongue of a SAS patient is likely to block the pharyngeal cavity while the patient lies in a supine (face-up) position, apnea may likely to be caused due to blockage of the respiratory passage. On the other hand, since blockage of the respiratory passage is unlikely to occur while the patient lies in a lateral decubitus position or in a prone (face-down) position, the patient may relatively unlikely to suffer from apnea when the patient lies in such a position. Since there is a significant correlation between apnea and body position of a SAS patient, the PSG features the body position as one of the evaluation parameters.

[0008] The body position, which is regarded as one of the evaluation parameters by the conventional PSG, is roughly classified into four directions, namely, a supine position, a right lateral decubitus position, a left lateral decubitus position, and a prone position; or nine positions, namely, a mid position between the supine position and the right lateral decubitus position, a mid position between the right lateral decubitus position and the prone position, a mid position between the prone position and the left lateral decubitus position, a mid position between the left lateral decubitus position and the supine position, and a seated position in addition to the above four positions. Accordingly, the conventional PSG has failed to provide sufficient information relating to subtle movements of a subject, which obstructs a user including the subject from accurately recognizing the correlation between apnea and body position. Also, the correlation between apnea and body position differs among individuals. However, the conventional PSG has failed to provide information relating to individual differences, which obstructs a medical staff from accurately determining an optimal approach for treating individual subjects e.g. suggesting a recommended body position in which the subject should lie in sleep.

[0009] **FIG. 29** is a graph showing a relation between change of SpO_2 with time, and actual change of the body position. The graph shows that SpO_2 is lowered twice i:e. at a time duration tq**1** and a time duration tq**2**. In this case, according to the conventional PSG, merely the roughly classified body positions as mentioned above are acquired as the body position parameter. Accordingly, the conventional PSG judges that the body positions at the time durations tq**1** and tq**2** when SpO_2 is lowered are "supine position", as well as the time between the time durations tq**1** and tq**2** when SpO_2 shows a normal value, which disables the medical staff to properly evaluate the correlation between apnea and body position. Obviously, apnea shows dependence on body position that SpO_2 is lowered when the body position is in a position corresponding to a time duration tq**31**, and in a position corresponding to a time duration tq**33**, and that SpO_2 is not lowered when the body position is in a position corresponding to a time duration tq**32**. However, the conventional PSG has failed to provide an evaluation which precisely reflects the dependence.

[0010] Also, as shown in **FIG. 30**, for instance, using a PSG capable of evaluating the body position in eight different positions enables to evaluate the correlation between apnea and body position to some details. However, it is likely that data may be fluctuated in a time duration indicated by a circle td if the body position is a threshold position of judging a change of the body position.

SUMMARY OF THE INVENTION

[0011] It is an object of the present invention to provide a sleep evaluation method, a sleep evaluation system, an operation program for the sleep evaluation system, a pulse oximeter, and a sleep support system that enable to accurately obtain a correlation between body position and apnea of a subject in terms of data.

[0012] According to an aspect of the invention, measurement is made about a necessary evaluation parameter of a subject, the parameter being variable due to sleep apnea of the subject. A body position of the subject is detected in terms of angle information. The parameter measurement and the body angle detection are executed at a predetermined sampling frequency. These data are stored in a storage.

[0013] These and other objects, features and advantages of the present invention will become more apparent upon reading of the following detailed description along with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] **FIG. 1** is a block diagram schematically showing an entire arrangement of a sleep evaluation system in accordance with an embodiment of the invention.

[0015] **FIG. 2** is an illustration showing an example of a sleep evaluation system having a certain hardware construction.

[0016] **FIG. 3** is an illustration for describing a manner as to how a pulse oximeter serving as an evaluation parameter detector is attached to a subject.

[0017] **FIG. 4** is a circuit diagram schematically showing a circuit configuration of the pulse oximeter.

[0018] **FIGS. 5A through 5C** are illustrations showing a three-axis acceleration sensor using a piezoresistor, as an example of a three-axis acceleration sensor, wherein **FIG. 5A** is a perspective view of the three-axis acceleration sensor, **FIG. 5B** is a top plan view thereof, and **FIG. 5C** is a cross-sectional view taken along the line a-a in **FIG. 5B**.

[0019] **FIG. 6A** is an illustration schematically showing a beam model deformed in X-axis direction and Y-axis direction.

[0020] **FIG. 6B** is a circuit diagram schematically showing a bridge circuit for detecting a voltage variation representing the deformation of the beam model shown in **FIG. 6A**.

[0021] **FIG. 7A** is an illustration schematically showing a beam model deformed in Z-axis direction.

[0022] **FIG. 7B** is a circuit diagram schematically showing a bridge circuit for detecting a voltage variation representing the deformation of the beam model shown in **FIG. 7A**.

[0023] **FIG. 8** is an illustration for explaining a principle as to how tilt angles of X-axis, Y-axis, and Z-axis are defined in expressing the position of the acceleration sensor.

[0024] **FIG. 9** is a perspective view showing a correlation between the X-axis, Y-axis, and Z-axis of the acceleration sensor shown in **FIG. 8**, and a lying position of a subject.

[0025] **FIG. 10** is an illustration showing a state that the three-axis acceleration sensor is incorporated in a main body of the pulse oximeter.

[0026] **FIG. 11** is a block diagram showing an arrangement of electrical functions of the pulse oximeter.

[0027] **FIG. 12** is a block diagram showing an arrangement of electrical functions of a personal computer main body, specifically, an analyzer and a processor.

[0028] **FIG. 13** is a graph showing an example of an SpO_2 curve.

[0029] **FIG. 14** is an illustration schematically showing indexes for detecting a Dip in an SpO_2 curve.

[0030] **FIG. 15** is a time chart briefly describing an example of data relating to a change of body angle with time.

[0031] **FIG. 16** is a time chart showing an example of composite data generated by combining an SpO_2 curve and a change of body angle with time.

[0032] **FIG. 17** is a graph showing a histogram of angle-based ODI with respect to a subject A to know a body angle range of the subject A where apnea is observed.

[0033] **FIG. 18** is a graph showing a histogram of angle-based ODI with respect to a subject B to know a body angle range of the subject B where apnea is observed.

[0034] **FIG. 19** is an illustration showing a positional arrangement of a simplified PSG and various sensors for measuring AHI data with respect to a subject H.

[0035] **FIG. 20** is a graph showing a histogram of angle-based AHI with respect to a subject C to know a body angle range of the subject C where apnea or low respiration is observed.

[0036] **FIGS. 21A through 21C** are illustrations showing examples of display of data relating to body position.

[0037] **FIG. 22** is a flowchart showing a flow of overall operations of the sleep evaluation system in **FIG. 2**.

[0038] **FIG. 23** is a flowchart showing details on SpO_2 measurement in Step S3 in the flowchart of **FIG. 22**.

[0039] **FIG. 24** is a flowchart showing details on body angle detection in Step S3 in the flowchart of **FIG. 22**.

[0040] **FIG. 25** is a flowchart showing details on SpO_2 measurement data analysis in Step S7 in the flowchart of **FIG. 22**.

[0041] **FIG. 26** is a flowchart showing details on body angle measurement data analysis in Step S7 in the flowchart of **FIG. 22**.

[0042] **FIG. 27** is a flowchart showing details on angle-based ODI detection, i.e. step S9 in the flowchart of **FIG. 22**.

[0043] **FIG. 28** is a block diagram showing a simplified arrangement of a sleep support system as a modification of the embodiment of the invention.

[0044] **FIG. 29** is a graph showing a relation between change of SpO_2 with time, and change of body position with time.

[0045] **FIG. 30** is an illustration showing how the body position is detected in a conventional arrangement.

[0046] **FIG. 31** is a top plan view of a pulse oximeter provided with a direction guide.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS OF THE INVENTION

[0047] A preferred embodiment of the invention will be described referring to the drawings. First of all, a hardware construction of the embodiment is described. Referring to **FIG. 1** schematically showing an entire arrangement of a sleep evaluation system **1** in accordance with the embodiment, the sleep evaluation system **1** is a system for evaluating a correlation between apnea based on a variation in an evaluation parameter having relevancy to apnea, and body tilt angle of a subject in sleep by measuring a body tilt angle of the subject, and the evaluation parameter simultaneously or concurrently at a predetermined sampling frequency, and by expressing the acquired measurement data along a time axis. The sleep evaluation system **1** includes an evaluation parameter detector **11**, a body position detector **12**, a storage **13**, a system controller **14**, and an analyzer **15** serving as a processor. Hereinafter, the body tilt angle of the subject is simply called as "body angle".

[0048] The evaluation parameter detector **11** measures a predetermined evaluation parameter of a subject, which is varied due to sleep apnea of the subject. Various parameters which are expressed internally and externally with respect to the subject in association with apnea are adoptable as the evaluation parameter to be measured. In the embodiment, blood oxygen saturation, electroencephalogram, airflow by mouth/nasal breathing, snoring sounds, and movements of chest/abdomen, which are regarded as typical evaluation parameters to be measured in a general PSG, are adoptable. Among these evaluation parameters, it is desirable to use blood oxygen saturation as the evaluation parameter because the blood oxygen saturation can be easily measured with use of a commercially available pulse oximeter or a like device.

[0049] The body position detector **12** detects a body position of the subject in terms of angle information. Various angle sensors which are detachably attached to the body trunk portion of the subject or any other appropriate site of the subject and are capable of detecting a body angle of the subject can be used as the body position detector **12**. It is preferable to use an angle sensor having a resolution capable of detecting the body angle in the unit of about 5 degrees or less, and particularly preferable to use an angle sensor having a resolution capable of detecting the body angle in the unit of about 1 degree or less. A preferred example of the body position detector **12** is a three-axis acceleration sensor, which will be described later in detail.

[0050] The storage **13** stores measurement data obtained by the evaluation parameter detector **11** and the body position detector **12**. Examples of the storage **13** include a random access memory (RAM), and an erasable and programmable read only memory (EPROM).

[0051] The system controller **14** includes a microprocessor, and controls the evaluation parameter detector **11** and the body position detector **12** to measure the evaluation parameter and the body angle of the subject respectively at a predetermined sampling frequency so that the measurement data obtained by the evaluation parameter detector **11** and the body position detector **12** are stored in the storage **13**.

[0052] The analyzer **15** analyzes a relation between a variation in the evaluation parameter e.g. a blood oxygen saturation, and the detected body angle of the subject based on the measurement data stored in the storage **13** to obtain a correlation between apnea and body angle of the subject. For instance, the analyzer **15** analyzes ODI, which is an index for judging the degree of severity of SAS, and is acquired with respect to each of the body angles for individual subjects. In the case where measurement data concerning airflow of the respiratory system such as airflow by mouth/nasal breathing and snoring sounds, and movements of the body trunk portion such as movements of chest/abdomen are obtainable as the evaluation parameter in addition to the blood oxygen saturation, it is possible to analyze a correlation between apnea or low respiration, and body angle of the subject. In the latter case, it is desirable to conduct an analysis so that AHI, which is another index for judging the degree of severity of SAS, is obtained with respect to each of the body angles for individual subjects.

[0053] The hardware construction of the sleep evaluation system **1** may be arbitrarily designed. The following are some of the examples of the hardware construction of the sleep evaluation system **1**.

[0054] (a) Solely the sensing devices i.e. the evaluation parameter detector **11** and the body position detector **12** are detachably attached to the subject. A personal computer (hereinafter, called as "PC") is constituted of the storage **13**, the system controller **14**, and the analyzer **15**. The PC and the sensing devices are connected by a communication line.

[0055] (b) A pulse oximeter, which serves as the evaluation parameter detector **11** and is adapted to measure the blood oxygen saturation, is equipped with the body position detector **12**, the storage **13**, and the system controller **14**. The pulse oximeter equipped with these devices is connected to a PC i.e. the analyzer **15** serving as the processor by a USB cable or a like device.

[0056] (c) A one-piece system is constructed by additionally providing a function of the analyzer **15** serving as the processor to the pulse oximeter having the arrangement (b).

[0057] **FIG. 2** is an illustration showing an example of a sleep evaluation system S having the hardware construction (b). The sleep evaluation system S includes a pulse oximeter **2** for concurrently or simultaneously measuring a blood oxygen saturation and a body angle of a subject for storing the measurement data, a PC **3** for reading out the measurement data concerning the blood oxygen saturation and the body angle from the pulse oximeter **2** to analyze a correlation between apnea and body angle of the subject, and a USB cable **207** for connecting the pulse oximeter **2** and the PC **3** for communication according to needs.

[0058] The pulse oximeter **2** has a main body **200** and a probe **21**. The oximeter main body **200** and the probe **21** are electrically connected by a probe cable **205** equipped with a connector **204**. The oximeter main body **200** is externally provided with a power switch **201**, an oximeter display **202** with a liquid crystal display, a connecting portion **203** for connecting the oximeter main body **200** to the probe cable **205**, and a connecting portion **206** for connecting the oximeter main body **200** to the USB cable **207**. The oximeter main body **200** internally has a memory serving as the storage **13**, a microprocessor i.e. a central processing unit (CPU) serving

as the system controller **14**, a power battery, and a three-axis acceleration sensor **22** serving as the body position detector **12**. The memory, the microprocessor, and the power battery are not shown in **FIG. 2**.

[**0059**] The probe **21** has a paper-clip like shape capable of securely holding a finger F of a subject to measure the blood oxygen saturation of the subject. Specifically, the probe **21** has a pair of holding pieces which are openably jointed to each other so that the probe **21** can securely hold the finger F with a biasing force of a spring or a like member. As will be described later, a light emitter **211** is provided on one of the holding pieces, and a light detector **212** is provided on the other thereof (see **FIG. 4**).

[**0060**] The oximeter main body **200** and the probe **21** are detachably attached to a subject H in the manner as shown in **FIG. 3**, for instance, in measurement. Specifically, a body belt **208** serving as a fastening device is wound around the body trunk portion of the subject H so that the oximeter main body **200** is fixed to the body trunk portion of the subject H with use of the body belt **208**. Also, the probe **21** is fixedly attached to the finger F of the subject H for measurement. Thereafter, the oximeter main body **200** and the probe **21** are connected to each other by way of the probe cable **205**. At the time of measurement i.e. during sleep of the subject H, the USB cable **207** is not connected to the oximeter main body **200**. The USB cable **207** is connected to the PC **3** after the measurement is completed to read out the measurement data from the pulse oximeter **2**.

[**0061**] As shown in **FIG. 31**, it is desirable to provide a direction guide **209** on an outer surface of a casing of the oximeter main body **200** to display a direction in which the pulse oximeter **2** should normally be attached to the subject H so that outputs from the three-axis acceleration sensor **22** with respect to respective axes thereof are accurately obtained as designed in view of a fact that the three-axis acceleration sensor **22** is built in the pulse oximeter **2**. Specifically, if the pulse oximeter **2** is inadvertently attached to the subject's body in a direction different from the direction corresponding to the designed axial output of the three-axis acceleration sensor **22**, for instance, if the pulse oximeter **2** is attached upside down, plus and minus of X-axis and Y-axis outputs are inverted with respect to the body position of the subject H. In this case, for instance, if the subject rolls over in a rightward direction, such a body position change is misjudged as rolling over in a leftward direction. In view of this, as shown in **FIG. 31**, the direction guide **209** is provided on the surface of the casing of the oximeter main body **200**, wherein "HEAD" and "FOOT" are indicated with arrows to clearly notify a user including the subject H and a medical staff of the direction in which the pulse oximeter **22** should normally be attached to the subject H. This enables to prevent erroneous measurement as described above.

[**0062**] The PC **3** includes a PC main body **30** i.e. a hard disk device, serving as the analyzer **15**, an operating unit **36** having a keyboard and the like, and a display unit **37** having a cathode ray tube (CRT) display or a liquid crystal display.

[**0063**] **FIG. 4** is an illustration schematically showing a circuit configuration of the probe **21** and the oximeter main body **200** connected thereto. The probe **21** includes the light emitter **211** and the light detector **212**. The light emitter **211** has semiconductor light emitting devices for emitting light of two different wavelengths k**1**, k**2**, respectively. For instance, one of the semiconductor light emitting devices is a red LED **211**R for emitting red LED light of the wavelength k**1** in a red wavelength range, and the other one thereof is an infrared LED **211**IR for emitting infrared LED light of the wavelength k**2** in an infrared wavelength range. The light detector **212** has a photoelectric conversion device for generating an electric current in accordance with an intensity of light emitted from the light emitter **211**. An example of the photoelectric conversion device is a silicon photo diode having photosensitivity to at least the wavelengths k**1** and k**2**.

[**0064**] As shown in **FIG. 4**, the light emitter **211** and the light detector **212** are juxtaposed with respect to the finger F for measurement i.e. living tissue from which the blood oxygen saturation is to be measured. For instance, on the tip of the finger F where a pulse beat of the arterial blood is easily detected optically, the light emitter **211** is arranged adjacent the nail portion of the finger tip, and the light detector **212** is arranged adjacent the ball portion of the finger tip. In an actual measurement, fixedly holding the finger F by the probe **21** enables to dispose the light emitter **211** and the light detector **212** at the aforementioned positions. Alternatively, a medicated tape such as a surgical tape or a first-aid adhesive tape may be used to securely position the light emitter **211** and the light detector **212** with respect to the finger F. By the above attachment, the light of the wavelengths λ**1**, λ**2** which has passed through the finger F is detected by the light detector **212**.

[**0065**] The light emitter **211** and the light detector **212** are respectively connected to a light emitting circuit **211**C and a light detecting circuit **212**C. The light emitting circuit **211**C and the light detecting circuit **212**C are fabricated in the oximeter main body **200**. The light emitter **211** and the light detector **212** are electrically connected to the light emitting circuit **211**C and the light detecting circuit **212**C, respectively, by way of the probe cable **205**.

[**0066**] An operation of the light emitting circuit **211**C is controlled by a microprocessor **20**C so that a specified emission control signal is issued to the red LED **211**R and to the infrared LED **211**IR of the light emitter **211**. When the emission control signal is issued to the red LED **211**R and to the infrared LED **211**IR, for instance, the red LED **211**R and the infrared LED **211**IR are alternately driven, and red light and infrared light are alternately emitted. Also, the light detecting circuit **212**C is controlled in synchronism with the emission of the light emitter **211** by the microprocessor **20**C to generate an electric current signal i.e. a pulse signal, which is obtained by photoelectrical conversion of the received light in accordance with the received light intensity.

[**0067**] Oxygen is transported by oxidation/reduction of hemoglobin in the blood. The hemoglobin has such optical characteristics that absorption of red light is decreased, and absorption of infrared light is increased when the hemoglobin is oxidized, and, conversely, absorption of red light is increased and absorption of infrared light is decreased when the hemoglobin is reduced. It is possible to obtain the blood oxygen saturation i.e. an arterial blood oxygen saturation by measuring a variation in transmitted light amounts of the red light and the infrared light, which is detected by the light detecting circuit **212**C, by utilizing the optical characteristics.

[0068] (Description on Three-axis Acceleration Sensor for Detecting Body Angle)

[0069] In this section, the three-axis acceleration sensor **22** built in the oximeter main body **200** is described. **FIGS. 5A through 5C** are illustrations showing a three-axis acceleration sensor using a piezoresistor, as an example of the three-axis acceleration sensor. **FIG. 5A** is a perspective view of the three-axis acceleration sensor, **FIG. 5B** is a top plan view thereof, and **FIG. 5C** is a cross-sectional view taken along the line a-a in **FIG. 5B**. The three-axis acceleration sensor **22** is constructed utilizing a piesoresistive effect. The piezoresistive effect is such that when a mechanical external force is exerted to an object composed of a semiconductor material having a piezo effect, crystal lattice distortion occurs in the object, and the number of carriers or carrier moving degree in the object is varied, which causes a change in resistance of the object.

[0070] The three-axis acceleration sensor **22** includes a sensor body **220** and twelve piezoresistive devices **224**. The sensor body **220** has a four-sided frame-like support **221** formed by dry-etching a base material such as silicon, a weight portion **222** disposed in the middle of the support **221**, and thin beam portions **223** each for connecting a corresponding side portion of the support **221** to the weight portion **222**. The twelve piezoresistive devices **224** are attached to the beam portions **223**, as shown in **FIG. 5A**, for instance. When the weight portion **222** is vibrated by application of acceleration, the beam portions **223** are deformed, and a stress is applied to the piezoresistive devices **224**.

[0071] Specifically, when an external force is exerted to the three-axis acceleration sensor **22**, a tilting force is exerted on the oximeter main body **200**. As a result, the weight portion **222** is deformed about X-axis, Y-axis, or Z-axis (see **FIG. 5A**) depending on the tilting direction of the oximeter main body **200**, thereby deforming the beam portions **223**. Then, a stress is applied to the piezoresistive devices **224** depending on the degree of the deformation of the beam portions **223**, and, as a result, the resistances of the piezoresistive devices **224** are varied depending on the application of the stress. Thus, a tilt angle of the oximeter main body **200** i.e. the body angle of the subject is detected by detecting variations in resistance of the piezoresistive devices **224**, which are signals proportional to acceleration.

[0072] The acceleration-proportional signals regarding the piezoresistive devices **224** can be detected by constituting a Wheatstone bridge circuit of four piezoresistive devices **224** each for the X-axis, Y-axis, and Z-axis, namely, using the twelve piezoresistive devices **224** in total, and by detecting respective variations in resistance resulting from application of stress to the piezoelectric devices **224** as a voltage change.

[0073] **FIG. 6A** is an illustration schematically showing deformation of the beam portions **223** i.e. beam portions **223***a*, **223***b* in X-axis direction and Y-axis direction, i.e., rotational deformation of the beam portions **223** about the X-axis and the Y-axis. **FIG. 6B** is a circuit diagram schematically showing a bridge circuit for detecting a voltage change corresponding to the deformation. In **FIGS. 6A, 6B**, and **FIGS. 7A and 7B**, which will be described later, symbols R1, R2, R3, and R4 represent four piezoresistive devices **224** in association with one of the X-, Y-, and Z-axes, respectively.

[0074] As shown by a deformed beam model in **FIG. 6A**, when acceleration is applied to the acceleration sensor **22** in the X-axis direction and in the Y-axis direction, a tensile stress is applied to the outer piezoresistive device R1 on the beam portion **223***a*, with the result that the resistance of the piezoresistive device R1 is increased, and a compressive stress is applied to the inner piezoresistive device R2 on the beam portion **223***a*, with the result that the resistance of the piezoresistive device R2 is decreased. On the other hand, a tensile stress is applied to the inner piezoresistive device R3 on the beam portion **223***b*, with the result that the resistance of the piezoresistive device R3 is increased, and a compressive stress is applied to the outer piezoresistive device R4 on the beam portion **223***b*, with the result that the resistance of the piezoresistive device R4 is decreased. In other words, counteractive resistance variations occur between the piezoresistive devices R1 and R2, and between the piezoresistive devices R3 and R4. Accordingly, in the case where a bridge circuit as shown in **FIG. 6B** is fabricated, and a constant voltage Vin is applied to the bridge circuit with respect to the X-axis or the Y-axis, an output voltage Vout can be obtained by implementing the equation (1).

$$Vout=\{R4/(R1+R4)-R3/(R2+R3)\}Vin \quad (1)$$

[0075] **FIG. 7A** is an illustration schematically showing deformation of the beam portions **223** or beam portions **223***c*, 223d in Z-axis direction, i.e., vertical deformation of the beam portions **223** in the Z-axis. **FIG. 7B** is a circuit diagram schematically showing a bridge circuit for detecting a voltage change corresponding to the deformation. The weight portion **222** deforms vertically in response to receiving acceleration in the Z-axis direction. For instance, as shown by a deformed beam model in **FIG. 7A**, in the case where the weight portion **222** is deformed upwardly, a compressive stress is applied to the outer piezoresistive device R1 on the beam portion **223***c*, with the result that the resistance of the piezoresistive device R1 is decreased, and a tensile stress is applied to the inner piezoresistive device R2 on the beam portion **223***c*, with the result that the resistance of the piezoresistive device R2 is increased. On the other hand, a tensile stress is applied to the inner piezoresistive device R3 on the beam portion **223***d*, with the result that the resistance of the piezoresistive device R3 is increased, and a compressive stress is applied to the outer piezoresistive device R4 on the beam portion **223***d*, with the result that the resistance of the piezoresistive device R4 is decreased. In other words, counteractive resistance variations occur between the piezoresistive devices R1 and R2, and between the piezoresistive devices R3 and R4. Accordingly, in the case where a bridge circuit as shown in **FIG. 7B** is fabricated, and a constant voltage Vin is applied to the bridge circuit with respect to the Z-axis, an output voltage Vout can be obtained by implementing the equation (2).

$$Vout=\{R3/(R1+R3)-R4/(R2+R4)\}Vin \quad (2)$$

[0076] The above describes a basic operation principle as to how the acceleration applied to the oximeter main body **200** is detected by the three-axis acceleration sensor **22**.

[0077] Next, a principle is described as to how a tilt angle of the oximeter main body **200** is detected with use of the three-axis acceleration sensor **22**. The acceleration sensor **22** is an inertial sensor for measuring a velocity component in input axis direction or sensing axis direction i.e. the X-axis direction, the Y-axis direction, and the Z-axis direction shown in **FIG. 5A**, wherein the velocity component is obtained by subtracting a gravitational acceleration g from a

moment acceleration m. Specifically, the velocity component i.e. acceleration A detected by the acceleration sensor **22** is expressed by the equation (3).

$$A=m-g \tag{3}$$

Here, let it be assumed that the acceleration sensor **22** is stationary on the ground i.e. m=0, and the gravitational acceleration g along a vertical axis is 1 g. Then, in the case where the direction of the sensing axis coincides with the upwardly extending direction of the vertical axis, the gravitational acceleration g is +1 g, and in the case where the sensing axis is tilted by angle θ with respect to the vertical axis, the gravitational acceleration g equals +1 g multiplied by cos θ.

[**0078**] Utilizing the above idea, angles of the X-axis, the Y-axis, and the Z-axis of the acceleration sensor **22** with respect to the vertical axis can be obtained based on gravitational accelerations with respect to the three axes, i.e., the X-, Y-, and Z-axes of the acceleration sensor **22**. **FIG. 8** is an illustration for defining angles of the X-axis, Y-axis, and Z-axis with respect to the vertical axis in expressing the position of the acceleration sensor **22**. Generally, it is proper to express the position of the sensor in terms of angle of the respective axes with respect to the vertical axis. However, in the case where the sensor is in a normal position where the Z-axis coincides with the vertical axis **225***z*, it is practical to use an angle a defined by the X-axis Ax and a reference line **225***x* on an imaginary horizontal plane **225**, and an angle β defined by the Y-axis Ay and a reference line **225***y* on the horizontal plane **225**, in place of using an angle θx defined by the X-axis Ax and the vertical axis **225***z*, and an angle θy defined by the Y-axis Ay and the vertical axis **225***z*, as shown in **FIG. 8**, to express a tilt of the sensor relative to the normal position. The upward direction on the horizontal plane **225** in **FIG. 8** is positive. In view of this, the angles α, β are used to define the tilt of the X-axis Ax and the tilt of the Y-axis Ay with respect to the horizontal plane **225**, and the angle θz is used to define the tilt of the Z-axis Az with respect to the vertical axis **225***z* to express the tilt of the acceleration sensor **22**. Using this definition, when the acceleration sensor **22** is not tilted, i.e. the Z-axis Az coincides with the vertical axis **225***z*, the angles α, β, and θz are all zero, namely, 0 g is outputted from the acceleration sensor **22** with respect to the X-axis, Y-axis, and Z-axis.

[**0079**] Specifically, output values Vx, Vy, and Vz with respect to the X-axis, Y-axis, and Z-axis are obtained by implementing the equations (4), (5), and (6) with use of the angles α, β, and θz, respectively.

$$Vx=X_0+X_s\cdot\sin\alpha \tag{4}$$

$$Vy=Y_0+Y_s\cdot\sin\beta \tag{5}$$

$$Vz=Z_0+Z_s\cdot\cos\theta z \tag{6}$$

where X_0, Y_0, and Z_0 are correction amounts to be added in the respective equations (4), (5), and (6) to cancel initial displacement of the acceleration sensor **22** with respect to the vertical axis. These correction amounts are added to correct an error resulting from positional displacement of the Z-axis of the acceleration sensor **22** with respect to the vertical axis of the oximeter main body **200**. Also, X_s, Y_s, and Z_s represent sensitivities of the acceleration sensor **22** with respect to the X-, Y-, and Z-axes, i.e., count values of outputs from the acceleration sensor **22** with respect to the X-, Y-, and Z-axes per 1 g, which are constants, respectively.

[**0080**] A relation is defined as expressed by the equation (7) regarding tilt angles of the three axes with respect to the vertical axis. Obtaining two of the tilt angles in the equation (7) enables to obtain the remaining one of the tilt angles.

$$\sin^2\alpha+\sin^2\beta+\cos^2\theta z=1 \tag{7}$$

[**0081**] The three-axis acceleration sensor **22** may be built in the oximeter main body **200** so that the respective axes of the acceleration sensor **22** coincide with X-, Y-, and Z-axes shown in **FIG. 9** for instance in association with a lying position of the subject. Specifically, in the case where the oximeter main body **200** is attached to the body trunk portion of the subject H in a supine position in the manner as shown in **FIG. 3**, the acceleration sensor **22** is built in the oximeter main body **200**, with the X-axis corresponding to a second axis of the acceleration sensor **22** extending in a longitudinal direction of the subject's body, the Y-axis corresponding to a first axis of the acceleration sensor **22** extending in a sideways direction of the subject's body, and the Z-axis corresponding to a third axis of the acceleration sensor **22** extending in a depthwise direction of the subject's body.

[**0082**] In the above state, when the subject H makes a movement around the Y-axis, the acceleration sensor **22** detects whether the subject H is in a seated position, in other words, whether the subject H is in a standing position or in a lying position, based on a tilt angle of the X-axis i.e. an output value from the acceleration sensor **22** with respect to the X-axis. Also, in the case where the subject H rolls over around the X-axis, the acceleration sensor **22** detects a body angle of the subject H i.e. the position of the subject H based on a tilt angle of the Y-axis i.e. an output value from the acceleration sensor **22** with respect to the Y-axis. Further, the acceleration sensor **22** detects whether the subject H is in a supine position or a prone position based on the symbol (plus or minus) of the tilt angle of the Z-axis i.e. an output value from the acceleration sensor **22** with respect to the Z-axis.

[**0083**] **FIG. 10** is an illustration schematically showing a state that the three-axis acceleration sensor **22** is built in the oximeter main body **200**. There is no point to be considered if the vertical axis of the oximeter main body **200** i.e. the Z-axis in **FIG. 9** in which the oximeter main body **200** is attached to the subject H according to the predetermined manner completely coincides with the Z-axis Az of the acceleration sensor **22**. Normally, however, it is not always the case that the vertical axis of the oximeter main body **200** and the Z-axis Az of the acceleration sensor **22** completely coincide with each other, and there remains a tilt of the Z-axis Az with respect to the vertical axis due to the attachment error. Accordingly, the X-axis Ax and the Y-axis Ay of the acceleration sensor **22** are also tilted with respect to the horizontal plane. Specifically, as shown in **FIG. 10**, the Z-axis is tilted by an angle θz_0 with respect to the vertical axis **225***z* due to the attachment error, and the X-axis and the Y-axis are tilted by angles α_0 and β_0 with respect to the reference lines **225***x* and **225***y* on the horizontal plane **225**, respectively. Accordingly, it is required to correct such initial tilts.

[**0084**] Correction amounts to cancel the initial tilts can be obtained by making output values from the acceleration sensor **22** with respect to the X-, Y-, and Z-axes coincident with 0 g when the oximeter main body **200** is placed still on

the horizontal plane. Specifically, initial output values Vx_0, Vy_0, and Vz_0 from the acceleration sensor **22** with respect to the X-, Y-, and Z-axes when the oximeter main body **200** is placed still on the horizontal plane are expressed by the equations (8), (9), and (10), which are derived from the equations (4), (5), and (6), respectively.

$$Vx_0=X_0+X_s\cdot\sin\alpha_0 \quad (8)$$

$$Vy_0=Y_0+Y_s\cdot\sin\beta_0 \quad (9)$$

$$Vz_0=Z_0+Z_s\cdot\cos\theta z_0 \quad (10)$$

[**0085**] The output 0 g indicates a state that the Z-axis of the acceleration sensor **22** is not tilted with respect to the vertical axis of the oximeter main body **200**. In other words, this state corresponds to $\alpha_0=0$, $\beta_0=0$, and $\theta z_0=0$. Substituting these equations in the equations (8), (9), and (10) and implementing the equations (11), (12), and (13) enables to obtain the correction amounts X_0, Y_0, and Z_0 to cancel the initial tilts.

$$X_0=Vx_0 \quad (11)$$

$$Y_0=Vy_0 \quad (12)$$

$$Z_0=Vz_0-Z_8 \quad (13)$$

The correction amounts X_0, Y_0, and Z_0 are analog-to-digitally converted into digital values, and the digital values are stored in the memory provided in the pulse oximeter **2**, as correction amount count values.

[**0086**] Next, description is made as to how the body position of the subject H is detected based on the output values from the acceleration sensor **22** with respect to the X-, Y-, and Z-axes. First, the output value from the acceleration sensor **22** with respect to the X-axis is used to detect whether the subject H is in a seated position. Assuming that Px is a count value of the output from the acceleration sensor **22** with respect to the X-axis after A/D conversion, the count value Px is obtained by implementing the equation (14) based on the equation (4).

$$Px=Px_0+Pxs\cdot\sin\alpha \quad (14)$$

where Px_0 is a count value of the correction amount X_0 after A/D conversion; and Px_s is a count value (constant) of the output from the acceleration sensor **22** with respect to the X-axis per 1 g after AID conversion.

[**0087**] The tilt angle α of the X-axis can be obtained by implementing the equation (15). When $\alpha\geqq 45°$, it is judged that the subject H is in a seated position, and when $\alpha<45°$, it is judged that the subject H is in a lying position.

$$\alpha=\sin^{-1}\left[\frac{P_x-P_{x0}}{P_{xS}}\right] \quad (15)$$

[**0088**] Subsequently, the output value from the acceleration sensor **22** with respect to the Y-axis is used to detect the body angle of the subject H. Assuming that Py is a count value of the output from the acceleration sensor **22** with respect to the Y-axis after A/D conversion, the count value Py is obtained by implementing the equation (16) based on the equation (5).

$$Py=Py_0+Pys\cdot\sin\beta \quad (16)$$

where Py_0 is a count value of the correction amount Y_0 after A/D conversion, and Pys is a count value (constant) of the output from the acceleration sensor **22** with respect to the Y-axis per 1 g after A/D conversion.

[**0089**] The tilt angle β of the Y-axis can be obtained by implementing the equation (17). In the equation (17), the angle β is 180° or less.

$$\beta=\sin^{-1}\left[\frac{P_y-P_{y0}}{P_{yS}}\right] \quad (17)$$

[**0090**] In implementing the equation (17), two cases satisfy the equation: $Py-Py_0=0$, namely, a case where $\beta=0°$, which corresponds to a supine position, and a case where $\beta=180°$, which corresponds to a prone position. The count value of the output from the acceleration sensor **22** with respect to the Z-axis is used to judge whether the computation results represents a supine position or a prone position. Specifically, when $\beta=0°$, $\theta z=0°$. Accordingly, the count value of the output from the acceleration sensor **22** with respect to the Z-axis is positive i.e. a count value per +1 g. On the other hand, when $\beta=180°$, $\theta z=180°$. Accordingly, the count value of the output from the acceleration sensor **22** with respect to the Z-axis is negative i.e. a count value per −1 g. This enables to make a judgment as to whether the computation results represents a supine position or a prone position.

[**0091**] The tilt angle of the Z-axis can be also obtained by the following approach. Assuming that Pz is a count value of the output from the acceleration sensor **22** with respect to the Z-axis after A/D conversion, the count value Pz is obtained by implementing the equation (18).

$$Pz=Pz_0+Pzs\cdot\cos\theta z \quad (18)$$

where Pz_0 is a count value of the correction amount Z_0 after A/D conversion, and Pzs is a count value (constant) of the output from the acceleration sensor **22** with respect to the Z-axis per 1 g after A/D conversion.

[**0092**] The tilt angle θz of the Z-axis can be obtained by implementing the equation (19).

$$\theta z=\cos^{-1}\left[\frac{P_z-P_{z0}}{P_{zS}}\right] \quad (19)$$

[**0093**] (Description on Electrical Configuration)

[**0094**] **FIG. 11** is a block diagram of an arrangement showing electrical functions of the pulse oximeter **2**. The pulse oximeter **2** includes a first A/D converter **231**, a second A/D converter **232**, an oximeter calculator **24**, a memory **25** serving as the memory, an oximeter controller **26**, and an oximeter interface (I/F) **27** in addition to the oximeter display **202**, the probe **21** serving as a blood oxygen saturation measuring device, and the three-axis acceleration sensor **22** serving as the body tilt detector.

[**0095**] As mentioned above, the probe **21** has the light emitter **211** and the light detector **212** to acquire measurement data concerning the blood oxygen saturation of the subject. Also, the three-axis acceleration sensor **22** acquires measurement data concerning the body angle of the subject.

[0096] An analog current signal outputted from the light detector **212** at a predetermined sampling frequency in accordance with the transmitted amounts of red light and infrared light is converted into a voltage signal by a current/voltage converting circuit (not shown), and the voltage signal is converted into a digital signal by the first A/D converter **231**. Similarly, respective output values i.e. analog current signals from the three-axis acceleration sensor **22** with respect to the X-, Y-, and Z-axes are converted into voltage signals corresponding to the aforementioned output values Vx, Vy, and Vz, and then these voltage signals are converted into digital signals by the second A/D converter **232**.

[0097] The oximeter calculator **24** is a functioning part for obtaining count values corresponding to blood oxygen saturation (SpO_2) and body angle based on the digital measurement signals outputted from the first A/D converter **231** and from the second A/D converter **232**, respectively. The oximeter calculator **24** includes an SpO_2 count detector **241**, a body tilt count detector **242**, and a data corrector **243**.

[0098] The SpO_2 count detector **241** detects a count value corresponding to SpO_2 every predetermined cycle e.g. every one second in response to receiving the digital measurement signal from the first A/D converter **231** at a fixed interval. The body tilt count detector **243** detects count values corresponding to respective tilts of the X-, Y-, and Z-axes i.e. the aforementioned Px, Py, and Pz every predetermined cycle in response to receiving the digital measurement signal from the second A/D converter **232** at a fixed interval.

[0099] The data corrector **243** is a functioning part for correcting the count values corresponding to the respective tilts of the X-, Y-, and Z-axes detected by the body tilt count detector **243** by an amount corresponding to axial displacement resulting from the attachment error of the three-axis acceleration sensor **22** to the pulse oximeter **2**. Specifically, the data corrector **243** corrects the count values corresponding to the tilts of the X-, Y-, and Z-axes detected by the body tilt count detector **243**, using the correction amount count values X_0, Y_0, and Z_0 with respect to the X-, Y-, and Z-axes, which are obtained by implementing the equations (11), (12), and (13), respectively.

[0100] The memory **25** includes e.g. a RAM or a like device, and has a measurement data storage **251** and a correction amount storage **252**. The measurement data storage **251** temporarily stores the measurement data acquired by the probe **21** and by the three-axis acceleration sensor **22** i.e. the count values corresponding to the respective measurement data in association with the time when the respective data have been acquired. The correction amount storage **252** stores correction amount count values obtained by analog-to-digitally converting the analog correction amounts X_0, Y_0, and Z_0 with respect to the X-, Y-, and Z-axes, which are used in correcting the count values corresponding to the tilts of the X-, Y, and Z-axes by the data corrector **243**.

[0101] The oximeter controller **26** controls sensing operations by the probe **21** i.e. the light emitter **211** and the light detector **212**, and by the three-axis acceleration sensor **22**, an operation of calculating the count values by the oximeter calculator **24**, and an operation of writing the count values into the memory **25**. Specifically, the oximeter controller **26** causes the probe **21** and the three-axis acceleration sensor **22** to acquire the measurement data concerning SpO_2 and body angle of the subject at the predetermined sampling frequency, causes the oximeter calculator **24** to calculate the respective count values corresponding to the measurement data, and causes the memory **25** to store the obtained count values therein.

[0102] The oximeter I/F **27** is an interface for connecting the PC **3** and the pulse oximeter **2** for data communication. Specifically, the oximeter I/F **27** functions as an interface for downloading the count values corresponding to the measurement data stored in the memory **25** of the pulse oximeter **2** to the PC **3**.

[0103] **FIG. 12** is a block diagram of an arrangement primarily showing electrical functions of a PC main body **30** i.e. an analyzer or a processor of the PC **3**. The PC main body **30** includes an SpO_2 calculator **31**, a tilt angle calculator **32**, a main calculator **33**, a PC display controller **34**, a PC interface (I/F) **351**, an RAM **352**, and an ROM **353**.

[0104] The SpO_2 calculator **31** is a functioning part for obtaining the number of times when the SpO_2 is lowered due to apnea of the subject, and includes a time series data generator **311**, a Dip detector **312**, and a Dip threshold setter **313**.

[0105] The time series data generator **311** creates data concerning an SpO_2 curve by expressing the count values corresponding to the SpO_2, which have been acquired from the measurement data storage **251** of the memory **25** of the pulse oximeter **2** in association with the data acquired time, along a time axis. **FIG. 13** is a graph showing an example of the SpO_2 curve. Expressing the SpO_2 count values acquired at the predetermined sampling frequency along the time axis enables to obtain one SpO_2 curve with respect to the subject. In the case where sleep apnea occurred in the subject, the SpO_2 is lowered. In other words, the SpO_2 curve shows a plurality of peaks where the SpO_2 is temporarily lowered. Hereinafter, a peak where the SpO_2 is lowered is called as "Dip". For instance, in **FIG. 13**, the times t**1**, t**2**, and t**3** correspond to Dips.

[0106] The Dip detector **312** detects a Dip having relevancy to apnea of the subject based on the data concerning the SpO_2 curve created by the time series data generator **311**. The Dip threshold setter **313** sets a Dip detection threshold in detecting a "significant Dip" by the Dip detector **312**.

[0107] Detecting a Dip corresponds to detecting an event of apnea or low respiration in the measurement data acquired concerning the subject. **FIG. 14** is an illustration schematically showing indexes for detecting a Dip. Examples of the index for Dip detection include a gradient of downslope of the SpO_2 curve, a lowering degree of SpO_2, a time duration when lowering of the SpO_2 is continued, and a time required for the subject to recover to his or her normal sleep state, i.e. a recovery rate. In this embodiment, Dip detection by the Dip detector **312** and by the Dip threshold setter **313** can be defined, as shown in **FIG. 14** to judge whether a detected Dip of the SpO_2 curve is a significant Dip when the following requirements are satisfied, for instance.

[0108] time duration when lowering of SpO_2 is continued: 8 to 120 sec.,

[0109] gradient of downslope of SpO_2 curve: >1%/10 sec.,

[0110] lowering degree of SpO_2: >2% to >5%, and

[0111] time required for recovery: <20 sec.

[0112] The Dip in this detection is not obtained based on a lowering degree relative to a. certain reference value, but is obtained based on a lowering degree relative to a certain point of the SpO_2 curve which is varied with time, i.e., a certain point of time during a sleeping time of the subject. For instance, in the case where there are defined three thresholds Dip**1**, Dip**2**, and Dip**3**, e.g., thresholds 2%, 3%, and 4% regarding the lowering degree of Dip, as shown in **FIG. 13**, Dips that show lowering relative to the start points of time when the respective Dips occurred by the respective thresholds are used as a detection index, in place of Dips that show lowering relative to the initial SpO_2 at the measurement start time by the respective thresholds. This technique enables to accurately detect lowering of the SpO_2.

[0113] In the SpO_2 curve illustrated in **FIG. 13**, if the Dip threshold setter **313** sets the lowering degree of 2% as a threshold for Dip detection, the Dip detector **312** judges that a Dip is found if the lowering degree exceeds the threshold and the other indexes satisfy the aforementioned requirements, and then, the Dip detector **312** counts the event as one Dip. Binary signals on the timeline indicated by "Dip1 COUNT" in **FIG. 13** represent the number of Dips which are counted on the basis of lowering degree of 2%. Likewise, binary signals on the timeline indicated by "Dip2 COUNT" represent the number of Dips counted on the basis of lowering degree of 3%, and binary signals on the timeline indicated by "Dip3 COUNT" represent the number of Dips counted on the basis of lowering degree of 4%, respectively. Data concerning the SpO_2 curve, and data concerning the number of Dips obtained in the SpO_2 calculator **31** are sent to the main calculator **33**.

[0114] The tilt angle calculator **32** is a functioning part for calculating data concerning change of the body angle of the subject with time during the sleeping time of the subject, and includes an X-axis tilt angle detector **321**, a Y-axis tilt angle detector **322**, a Z-axis tilt angle detector **323**, and a tilt angle data generator **324**.

[0115] The X-axis tilt angle detector **321** obtains data concerning change of the tilt angle a of the X-axis with time based on the equation (15), using the count value Px corresponding to the tilt of the X-axis of the three-axis acceleration sensor **22**, which is outputted from the measurement data storage **251** of the memory **25** of the pulse oximeter **2**. Likewise, the Y-axis tilt angle detector **322** obtains data concerning change of the tilt angle β of the Y-axis with time based on the equation (17), using the count value Py corresponding to the tilt of the Y-axis of the three-axis acceleration sensor **22**, and the Z-axis tilt angle detector **323** obtains data concerning change of the tilt angle θz of the Z-axis with time based on the equation (19), using the count value Pz corresponding to the tilt of the Z-axis of the three-axis acceleration sensor **22**.

[0116] The tilt angle data generator **324** calculates a time period when the subject is in a seated position, e.g., a time period when the tilt angle $\alpha \geqq 45°$, based on the time-based change of the tilt angle a of the X-axis detected by the X-axis tilt angle detector **321**. Also the tilt angle data generator **324** obtains data concerning a time-based change of the body angle of the subject based on the time-based change of the tilt angle β of the Y-axis detected by the Y-axis tilt angle detector **322**, namely, a change of the body position of the subject, and based on the time-based change of the tilt angle θz of the Z-axis detected by the Z-axis tilt angle detector **323**, namely, a judgment as to whether the subject is in a supine position or a prone position.

[0117] **FIG. 15** is a time chart schematically showing an example of data concerning time-based change of the body angle of the subject generated by the tilt angle data generator **324**. As shown in **FIG. 15**, the tilt angle data generator **324** generates data concerning the body position of the subject in terms of angle information represented by "BODY ANGLE", in place of the roughly classified body directions as in the conventional art. Also, since this arrangement enables to obtain a seated time tz when the subject is in a seated position based on the tilt angle a of the X-axis, the seated time tz in the time chart can be extracted as discriminated data. It is often the case that the tilt angle β of the Y-axis is continuously changed during a seated time including a walking time, unlike a sleeping time. In the example of **FIG. 15**, the body angle is continuously changed in the seated time tz. The data concerning time-based change of the body angle obtained in the tilt angle calculator **32** is sent to the main calculator **33**.

[0118] The main calculator **33** is a functioning part for obtaining a relation between apnea or low respiration, and body angle of the subject, and includes a data synthesizer **331**, a data discriminator **332**, an angle-based ODI calculator **331**, an angle-based AHI calculator **334**, a recommended angle calculator **335**, and a histogram calculator **336**.

[0119] The data synthesizer **331** creates composite data by expressing the data concerning the SpO_2 curve and the number of Dips outputted from the SpO_2 calculator **31**, and the data concerning the time-based change of body angle outputted from the tilt angle calculator **32** along a common time axis. By the data synthesis, basic data for obtaining a correlation between apnea and body angle of the subject can be obtained.

[0120] **FIG. 16** is a time chart showing an example of the composite data created by the data synthesizer **331** in a graph. As shown in the time chart, a drastic SpO_2 lowering i.e. a Dip is not found until the point of time t**11** when the subject is supposed to be in a position close to a lateral decubitus position, and the time after the point of time t**14**. However, several Dips are found during a time period from t**11** to t**14** when the subject is supposed to be in a position close to a supine position. Also, observing a relation between change of body angle, and occurrence of Dip concerning the SpO_2 during the time period from t**11** to t**14**, Dip occurs during a time period from t**11** to t**12**, and Dip does not occur after the point of time t**12** at which the body angle is slightly changed. Further, at the point of time t**13** when the body angle is slightly changed, namely, is returned to a body angle close to the body angle in the time period from t**11** to t**12**, Dip occurs. In this way, a correlation between apnea and body angle of the subject during the time period from t**11** to t**14** can be accurately obtained by acquiring data concerning the body position of the subject in terms of angle information, whereas, in the conventional arrangement, the body position corresponding to the time period from t**11** to t**14** is simply judged as a supine position.

[0121] The data discriminator **332** discriminates and extracts data corresponding to the time period when analysis

on ODI or AHI is to be executed with respect to all the composite data created by the data synthesizer **331**. The data discrimination can be performed based on a command signal issued from the operating unit **36**. Alternatively, the data discriminator **332** may invalidate data which is attached with an identification code indicating that the data is acquired in the seated time tz (see **FIG. 15**) by the tilt angle data generator **324**, from among all the composite data.

[**0122**] The angle-based ODI calculator **333** screens the composite data created by the data synthesizer **331** with respect to each of the body angles as shown in **FIG. 16**, for instance, and counts the number of Dips with respect to each of the body angles. The angle-based ODI is an index, which represents the number of Dips counted on the basis of body angle, unlike the conventional ODI, which is counted on the basis of time.

[**0123**] It is possible to create a histogram relating to the Dip number in terms of body angle with respect to a specific subject based on a computation result of the angle-based ODI calculator **333**. **FIG. 17** is an example of a histogram obtained with respect to a subject A. In case of the subject A, the number of Dip is large when the body angle lies in the range from 40° to −50°. In other words, it is judged that apnea is likely to occur when the body angle is in the aforementioned range. In view of this, it is possible to treat the subject A by suggesting use of a pillow that enables to secure the body angle at 40° or larger so that occurrence of apnea may be suppressed.

[**0124**] **FIG. 18** is an illustration showing an example of a histogram obtained with respect to another subject B. In case of the subject B, the number of Dip is large when the body angle lies in the range from **20**° to −40°. Particularly, Dip occurs frequently in a wide range when the body angle is minus. In view of this, it is possible to treat the subject B by suggesting use of a pillow that enables to secure the body angle at 20° or larger. In this way, since the angle-based ODI can be obtained by the angle-based ODI calculator **333**, this arrangement enables to provide individual subjects with accurate diagnosis depending on body position.

[**0125**] The angle-based AHI calculator **334** screens AHI data concerning airflow by mouth/nasal breathing, snoring sounds, movements of chest/abdomen, and movements of leg muscles, which is necessary for calculating AHI and is expressed along a time axis, in addition to the composite data concerning SpO_2 and body angle that is created by the data synthesizer **331** with respect to each of the body angles by referring thereto, and counts the number of Dips resulting from apnea or low respiration with respect to each of the body angles. The angle-based AHI is an index, which represents the number of Dips counted on the basis of body angle, unlike the conventional AHI, which is counted on the basis of time. In this arrangement, as shown in **FIG. 12**, it is possible to input measurement data which has been acquired by a measuring device other than the pulse oximeter **2** to the main controller **33**, as the AHI data, by way of an external data input device **39**.

[**0126**] Alternatively, it is possible to provide the pulse oximeter **2** with a function of integrally acquiring measurement data necessary for calculating AHI other than the SpO_2 for storage, and to download the measurement data along with the SpO_2 count values. The pulse oximeter provided with this function is called as "simplified PSG" hereinafter.

[**0127**] **FIG. 19** is an illustration showing a positional arrangement of the simplified PSG **2**P, and various sensors for detecting AHI data with respect to a subject H. **FIG. 19** shows a positional arrangement concerning sensors of a well-known polysomnograph (PSG). An airflow sensor **41** for detecting airflow by mouth/nasal breathing, a snoring sound sensor **42** for detecting snoring sounds, a chest sensor **43** for detecting movements of a chest, an abdomen sensor **44** for detecting movements of an abdomen, and leg sensors **45** for detecting movements of leg muscles are attached to the subject H, in addition to the probe **21** for detecting SpO_2. The simplified PSG **2**P is attached to the body trunk portion of the subject H.

[**0128**] The simplified PSG **2**P is internally provided with a memory for storing measurement data from the respective sensors, and a body tilt detector corresponding to the three-axis acceleration sensor **22**. Acquiring predetermined measurement data with respect to the subject H with use of the simplified PSG **2**P, and allowing the acquired measurement data to be downloaded to the PC main body **30** enables to cause the angle-based AHI calculator **334** to screen the measurement data with respect to each of the body angles and to count the number of Dips resulting from apnea or low respiration with respect to each of the body angles.

[**0129**] It is possible to create a histogram relating to the Dip number in terms of body angle with respect to a specific subject based on a computation result of the angle-based AHI calculator **334**. **FIG. 20** is an example of a histogram obtained with respect to a subject C. In case of the subject C, the frequency of occurrence of Dip is large when the body angle lies in the range from 40° to -50°. In other words, it is judged that apnea is likely to occur when the body angle is in the aforementioned range. In view of this, it is possible to treat the subject C by suggesting use of a pillow that enables to secure the body angle at 40° or larger so that occurrence of apnea or low respiration may be suppressed.

[**0130**] The recommended angle calculator **335** calculates a body angle with less or no likelihood of occurrence of Dip in the subject i.e. a body angle having a frequency of occurrence of Dip less than a predetermined number of times based on a computation result of the angle-based ODI calculator **333** or the angle-based AHI calculator **334**, and defines the body angle as the recommended body angle with less or no likelihood of apnea. Providing the recommended angle calculator **335** enables to provide the data that readily notifies the subject of the body angle effective in suppressing apnea.

[**0131**] The histogram calculator **336** creates a histogram showing a relation between the body angle and the number of Dips based on the computation result of the angle-based ODI calculator **333** or the angle-based AHI calculator **334**. Obtaining the histograms (see **FIGS. 17, 18**, and **20**) enables to allow the subject to grasp the correlation between body angle, and apnea or low respiration.

[**0132**] The PC display controller **34** is a functioning part for displaying the various data calculated in the main calculator **33** on the display unit **37** in the form of a certain image or for outputting the various data to an output unit **38**. For instance, the PC display controller **34** generates the composite data image as shown in **FIG. 16** created by the data synthesizer **331**, and displays the image on the display unit **37**. The PC display controller **34** includes an ODI

display data generator **341**, an AHI display data generator **342**, and a body position related display data generator **343**.

[**0133**] The ODI display data generator **341** generates predetermined data concerning ODI for display/output in response to receiving display designation from the operating unit **36** by using the data obtained by the angle-based ODI calculator **333** and by the histogram calculator **336**. For instance, the ODI display data generator **341** generates the histogram image as shown in **FIGS. 17 and 18** for displaying on the display unit **37** or outputting to the output unit **38**. Likewise, the AHI display data generator **342** generates predetermined data concerning AHI for display/output in response to receiving display designation from the operating unit **36** by using the data obtained by the angle-based AHI calculator **334** and by the histogram calculator **336**. For instance, the AHI display data generator **342** generates the histogram image as shown in **FIG. 20** for displaying on the display unit **37** or outputting to the output unit **38**. It is desirable to configure the ODI display data generator **341** and the AHI display data generator **342** in such a manner that data for displaying/outputting ODI or AHI in a designated angle range be creatable in response to receiving designation on the body angle range from the operating unit **36**

[**0134**] The body position related display data generator **343** converts the body angle data acquired in the tilt angle calculator **32** into a body direction for display. For instance, in the case where data concerning time-based change of body angle, as shown in **FIG. 21A** is acquired, the body angle data is displayed on the display unit **37**, and also display data capable of displaying the body angle data as a body direction is generated in response to designation on an arbitrary point on the graph with use of a cursor. This is performed considering a case that it is convenient to display the body position in terms of body direction rather than angle information that is expressed numerically.

[**0135**] In the above arrangement, as shown in **FIG. 21B**, for instance, the body position may be classified into four body directions, i.e., a supine position, a prone position, a left lateral decubitus position, and a right lateral decubitus position, and correlations between the respective body directions and body angles may be defined as shown in **FIG. 21C**. Further alternatively, the four body directions may each be classified into two sub directions, and eight body directions in total may be displayed.

[**0136**] The PC I/F **351** is an interface for connecting the PC main body **30** and the pulse oximeter **2** for data communication. The RAM **352** temporarily stores therein the measurement data downloaded from the memory **25** of the pulse oximeter **2**, and various data obtained in the relevant sections of the PC main body **30**. The ROM **353** stores therein an operation program for operating the PC main body **30** or the sleep evaluation system S, and the like.

[**0137**] (Description on Operation Flow)

[**0138**] An operation of the sleep evaluation system S having the arrangement is described based on the flowcharts shown in **FIGS. 22 through 26**, and also referring to the block diagrams of **FIGS. 11 and 12** according to needs. **FIG. 22** is a flowchart showing a flow of overall operations of the sleep evaluation system S. In this embodiment, described is a flow, in which the pulse oximeter **2** is attached to the subject H, as shown in **FIG. 3**, the SpO_2 and the body angle are concurrently detected, and the angle-based ODI is obtained with respect to the subject H.

[**0139**] First, the pulse oximeter **2** is attached to the subject's body (Step Si). Specifically, the oximeter main body **200** is attached to the body trunk portion of the subject H with use of the body belt **208** serving as the fastening device, and a finger of the subject H is securely held by the probe **21** (see **FIGS. 2 and 3**). After completion of these operations, measurement is started. A timer may be set so that a time is started to be measured upon lapse of a certain time, considering a time required for the subject H to fall asleep.

[**0140**] When the measurement is started, it is judged whether the current time is coincident with the time of the predetermined sampling frequency (Step S**2**). If it is judged that the current time is coincident with the time of the sampling frequency (YES in Step S**2**), measurement data concerning SpO_2 of the subject H is acquired from the probe **21**, and measurement data concerning body angle of the subject H is acquired from the three-axis acceleration sensor **22** (Step S**3**). Then, after A/D conversion or a predetermined computation is executed, the measurement data is stored in the memory **25** (see **FIG. 11**) of the pulse oximeter **2** (Step S**4**).

[**0141**] Then, it is judged whether the measurement is to be terminated (Step S**5**). In the case where it is judged that the system S is on halfway of the measurement (NO in Step S**5**), the routine returns to Step S**2** to cyclically repeat the operations from Step S**2** to Step S**4**. The measurement is carried on even if the subject wakes up in the middle of sleep such as going to the bathroom. On the other hand, if the predetermined measurement period is ended, or the subject H intentionally terminates the measurement because he or she completely wakes up in the measurement period (YES in Step S**5**), the measurement operation with use of the pulse oximeter **2** is terminated.

[**0142**] Thereafter, as shown in **FIG. 2**, the pulse oximeter **2** and the PC **3** are connected by way of the USB cable **207** so that the measurement data stored in the pulse oximeter **2** is downloaded from the pulse oximeter **2** to the PC **3** (Step S**6**). Specifically, the measurement data concerning SpO_2 and body angle, which is stored in the memory **25** of the pulse oximeter **2**, is temporarily saved in the RAM **352** of the PC main body **30** via the oximeter I/F **27** and the PC I/F **351** (see **FIG. 12**).

[**0143**] Then, the measurement data downloaded to the PC **3** is analyzed by the SpO_2 calculator **31** and the tilt angle calculator **32** (Step S**7**). Specifically, the SpO_2 calculator **31** computes the number of times when the SpO_2 is lowered resulting from apnea of the subject H. Also, the tilt angle calculator **32** computes data concerning time-based change of the body angle of the subject H during his or her sleep.

[**0144**] Subsequently, the data synthesizer **331** of the main calculator **33** creates composite data concerning the SpO_2 curve and the time-based change of the body angle by expressing the data along a common time axis (Step S**8**). Then, the number of Dips with respect to each of the body angles is counted by the angle-based ODI calculator **333** to obtain angle-based ODI (Step S**9**).

[**0145**] Thereafter, a histogram showing a relation between body angle and the Dip number is created by the histogram calculator **336** so that a correlation is obtained between

apnea and body position of the subject H in terms of angle information i.e. a body angle (Step S10). Then, the display controller **34** causes the display unit **37** to display or causes the output unit **38** to output the histogram as an image suitable to represent the histogram in response to receiving designation from the operating unit **36** (Step S11). Then, the routine ends. This is the flow on the entire operation of the system S. Next, flows of Step S3, Step S7, and Step S9 are described in detail one by one.

[0146] **FIG. 23** is a flowchart showing details on the SpO_2 measurement in Step S3 of the flowchart in **FIG. 22**. When it is judged that the current time is coincident with the time of the predetermined sampling frequency, the red LED **211**R or the infrared **211**IR (see **FIG. 4**) provided in the probe **21** are turned on to emit red light or infrared light toward the finger F of the subject H (Step S21). The light detector **212** detects transmitted light through the finger F in synchronization with the light emission (Step S22), and an analog current output in accordance with the received light intensity is acquired by the light detecting circuit **212**C (Step S23).

[0147] The acquired analog current output is converted into a digital measurement signal by the first A/D converter **231** (see **FIG. 11**) (Step S24). Then, the SpO_2 count detector **241** detects a count value of SpO_2 corresponding to the digital measurement signal at the predetermined sampling frequency (Step S25). The SpO_2 count value is stored in the measurement data storage **251** of the memory **25** in association with the time when the count value has been acquired. The above routine is cyclically repeated at the predetermined sampling frequency.

[0148] **FIG. 24** is a flowchart showing details on the body angle detection in Step S3 of the flowchart in **FIG. 22**. When it is judged that the current time is coincident with the time of the sampling frequency, sensor outputs i.e. analog current signals regarding the X-, Y-, and Z-axes of the three-axis acceleration sensor **22** (see **FIG. 11**) are obtained. The analog current signals are current-to-voltage converted into voltage signals, which, in turn, are detected as analog voltage signals Vx, Vy, and Vz with respect to the X-, Y-, and Z-axes (Step S31).

[0149] The analog voltage signals, Vx, Vy, and Vz are analog-to-digitally converted into digital signals by the second A/D converter **232** (Step S32). Then, the body tilt count detector **243** detects count values Px, Py, and Pz corresponding to the respective tilts of the X-, Y-, and Z-axes, which correspond to the digital measurement signals obtained at the sampling frequency (Step S33).

[0150] Subsequently, the data corrector **243** corrects the count values Px, Py, and Pz with use of the correction amount count values X_0, Y_0, and Z_0, which are stored in the correction amount storage **252**, to correct axial displacement resulting from attachment error of the three-axis acceleration sensor **22** to the pulse oximeter **2** (Step S34). The count values Px, Py, and Pz corresponding to the respective tilts of the X-, Y, and Z-axes after the data correction are stored in the measurement data storage **251** of the memory **25** in association with the time when the respective count values have been acquired. The above routine is cyclically repeated at the sampling frequency.

[0151] **FIG. 25** is a flowchart showing details on the SpO_2 measurement data analysis in Step S7 of the flowchart in **FIG. 22**. First, the time series data generator **311** (see **FIG. 12**) of the SpO_2 calculator **31** creates data on a SpO_2 curve by expressing the SpO_2 count values which have been downloaded from the pulse oximeter **2** to the PC **3** along a time axis (Step S41). The data on the SpO_2 curve is data showing time-based change of SpO_2, as shown in **FIG. 13**, but actually is data that has been loaded to the RAM **352** or a like device.

[0152] A "significant Dip" is detected by executing the following operation regarding an SpO_2 count value at an arbitrary judging point n, wherein the judging point n is sequentially defined along the time axis e.g. at a time interval corresponding to the sampling frequency with respect to the SpO_2 curve obtained in Step S41 by the Dip detector **312**. Specifically, at an initial stage of measurement, n=k (Step S42), and a comparison is made between SpO_2 count values between the judging point n and an adjacent point (n+1) (Step S43).

[0153] Then, a judgment is made whether the SpO_2 count value at the point (n+1) is lower than the SpO_2 count value at the point n (Step S44). If the SpO_2 count value at the point (n+1) is not lower than the SPO_2 count value at the point n (NO in Step S44), it means that there is no Dip. Accordingly, k is incremented by one: k=k+1 (Step S45), and the routine returns to Step S42 to cyclically repeat the above operation of setting a next point (n+1) on the time axis as a measurement reference.

[0154] If, on the other hand, the SpO_2 count value at the point (n+1) is lower than the SPO_2 count value at the point n (YES in Step S44), the point n is advanced on the time axis until a point where the SpO_2 count value is increased is found because there is a possibility that a Dip has occurred. Specifically, it is judged whether the SpO_2 count value is increased at the targeted point n after the start point of time when the candidate Dip is detected in Step S44 (Step S46). If it is judged that the SpO_2 count value is not increased after the start point of time when the candidate Dip is detected (NO in Step S46), k is incremented by one: k=k+1 to advance the point n (Step S47), and the judgment in Step S46 is cyclically repeated.

[0155] If, on the other hand, it is judged that the SpO_2 count value is increased (YES in Step S46), it means that the Dip is directed to an end. Accordingly, a judgment is made whether the candidate Dip satisfies the requirements on the aforementioned predetermined Dip detection index (Step S48). The Dip detection index may include a gradient of downslope of SpO_2 curve, a lowering degree of SpO_2, a time duration when lowering of SpO_2 is continued, or other phenomenon, as described above. In the case where the recovery time or recovery rate, i.e. a time or speed which is necessary for the SpO_2 count value to recover to its level corresponding to the point of time when the Dip is started to be observed is included as the index, a step is additionally provided after Step S46 to judge whether the SpO_2 count value is recovered to its level corresponding to the point of time when the Dip is started to be observed. Alternatively, the data may be smoothed by a moving-average method in judging whether the SpO_2 count value is decreased or increased.

[0156] If it is judged that the candidate Dip satisfies the requirements on the predetermined Dip detection index (YES in Step S48), the Dip detector **312** judges that the

candidate Dip is a significant Dip, and registers the Dip in the RAM **352** or an equivalent device in association with time information relating to the time when the Dip is judged so (Step S**49**). In the registration, the judgment as to whether the Dip satisfies the requirements on the Dip detection index is executed based on the threshold information stored in the Dip threshold setter **313**. For instance, if the lowering degree of SPO_2 is adopted as the index, the Dip detector **312** judges whether the candidate Dip satisfies the requirements on the lowering degree of SpO_2, using one or more than one of the thresholds Dip**1**, Dip**2**, and Dip**3** shown in **FIG. 13**.

[**0157**] If, on the other hand, it is judged that the candidate Dip does not satisfy the requirements on the Dip detection index (NO in Step S**48**), k is incremented by one: k=k+1 to advance the point n (Step S**45**). Then, the routine returns to Step S**42**, and the operations from Step S**42** to Step S**48** are cyclically repeated to search for a next Dip. Also, in the case where it is judged that there remains a judging point n (NO in Step S**50**) after the registration of Dip in Step S**49**, similarly to the operation after the negative judgment in Step S**48**, the routine returns to Step S**42** to cyclically repeat the operations to search for a next Dip. This is the operations on the SpO_2 measurement data analysis routine.

[**0158**] **FIG. 26** is a flowchart showing details on the body angle measurement data analysis in Step S**7** of the flowchart in **FIG. 22**. First, data concerning the count values Px, Py, and Pz corresponding to the respective tilts of the X-, Y-, and Z-axes that has been downloaded from the oximeter **2** to the PC **3** are loaded to the RAM **352** or an equivalent device (Step S**51**). The data is data showing time-based change of the count values Px, Py, and Pz corresponding to the tilts of the X-, Y-, and Z-axes.

[**0159**] Referring to **FIG. 26**, the X-axis tilt angle detector **321**, the Y-axis tilt angle detector **322**, and the Z-axis tilt angle detector **323** of the tilt angle calculator **32** respectively calculate tilt angles α, β, and θz of the X-, Y-, and Z-axes (Step S**52**). Then, the tilt angle data generator **324** detects a time period when the subject H is in a seated position based on the time-based change of the tilt angle α of the X-axis, and obtains data concerning time-based change of the body angle of the subject H based on the tilt angle β of the Y-axis and the tilt angle θz of the Z-axis (Step S**53**). The data is as shown in **FIG. 15**, for instance. This is the operations on the body angle measurement data analysis routine.

[**0160**] **FIG. 27** is a flowchart showing details on the angle-based ODI detection in Step S**9** of the flowchart in **FIG. 22**. In this operation, the number of Dips with respect to each of the body angles is counted in association with the data concerning time-based change of the body angle obtained by implementing the operations of the flowchart in **FIG. 26**. The Dips are detected and registered in accordance with the operations of the flowchart in **FIG. 25**.

[**0161**] Referring to **FIG. 27**, first, the Dip that has been registered and stored at an earliest time in the RAM **352** is retrieved, for instance (Step S**61**). Then, data discrimination is conducted by the data discriminator **332** of the main calculator **33**, in other words, it is judged whether the tilt angle α of the X-axis when the Dip is detected is 45° or larger (Step S**62**). If $\alpha \geqq 45°$ (YES in Step S**62**), the judgment result means that the Dip is invalid because it indicates that the subject H is in a seated position. Accordingly, the Dip is invalidated (Step S**63**), and the routine returns to Step S**61** to detect a second earliest Dip that has been registered and stored in the RAM **352**.

[**0162**] If, on the other hand, $\alpha < 45°$ (NO in Step S**62**), the angle-based ODI calculator **333** detects a body angle of the subject H when the Dip is detected based on the tilt angle β of the Y-axis and the tilt angle θz of the Z-axis (Step S**64**). Then, the number of Dips is counted with respect to each of the predetermined body angles, e.g., by 5° interval (Step S**65**). Then, it is judged whether there remains any Dip that has been registered in the RAM **352** (Step S**66**). If it is judged that there remains a Dip (NO in Step S**66**), the routine returns to Step S**61** to detect a next Dip. The above operations are cyclically repeated with respect to all the registered Dips. Angle-based AHI may be detected by implementing operations similar to the operations of the flowchart in **FIG. 27**.

[**0163**] (Description on Modifications)

[**0164**] In the embodiment, described is the sleep evaluation system S of evaluating a correlation between apnea and body angle of a subject to diagnose SAS dedicatedly. The embodiment may be modified to provide a sleep support system of providing a subject i.e. a SAS patient with a comfortable sleep environment with no or less likelihood of apnea.

[**0165**] **FIG. 28** is a simplified block diagram showing an arrangement of the sleep support system ST. The sleep support system ST includes a pulse oximeter **2**, serving as a measuring device, which is capable of concurrently measuring a body angle and a blood oxygen saturation of a subject H at a predetermined sampling frequency, a bed **51** designed in such a manner that the angle of the bed **51** is pivotally adjustable about an axis **511** of rotation while supporting the subject H in a certain lying position, a bed driver **52** for drivingly adjusting the angle of the bed **51**, and a controller **53** for determining the angle of the bed **51** adjusted by the bed driver **52**.

[**0166**] A measurement operation of the pulse oximeter **2** is controlled by the controller **53** so that measurement data concerning the body angle and the blood oxygen saturation of the subject H can be obtained at a predetermined sampling frequency. The measurement data is sent to the controller **53** in a time-series manner. The measurement data is stored by an amount corresponding to a time period required for diagnosing apnea of the subject H. The controller **53** evaluates a correlation between apnea based on lowering of the blood oxygen saturation, and body angle of the subject H by expressing the acquired measurement data along a time axis to detect a body angle with no or less likelihood of apnea for the subject H.

[**0167**] Upon detecting the recommended body angle with no or less likelihood of apnea, the controller **53** sends, to the bed driver **52**, a control signal to position the bed **51** to such an angle that makes it possible to secure the subject H at the recommended body angle. In response to receiving the control signal, the bed driver **52** drives the bed **51** so that the bed **51** is positioned to the angle to secure the subject H at the recommended body angle. There is likelihood that the subject H may roll out of the bed **51** if the angle of the bed **51** is too large. In view of this, the top surface of the bed **51** has a certain concave portion in the Y-direction (see **FIG. 9**),

as shown in **FIG. 28**. Also, a predetermined upper limit is defined for the angle of the bed **51** so that the bed driver **52** does not tilt the bed **51** over the upper limit. In this arrangement, a comfortable sleep environment is provided for the subject H, with the body position of the subject H secured to such an angle that is unlikely or less likely to cause apnea.

[**0168**] Further, it is possible to provide an operation program of executing a process to be implemented by the sleep evaluation system S, as an embodiment to carry out the invention. The program may be provided as a program product by recording the program on a computer-readable recording medium, which is an attachment to a computer, such as a flexible disk, a CD-ROM, an ROM, an RAM, or a memory card. Also, the program may be provided by recording the program on a recording medium equipped in the PC main body **30** shown in **FIG. 2**. Further alternatively, the program may be provided by downloading via a network.

[**0169**] In general, the routines executed to implement the embodiment of the invention, whether implemented as part of an operating system or a specific application, component, program, object, module or sequence of instructions will be referred to as "programs". The program comprises one or more instructions that are resident at various times in various memory and storage devices in a computer, and that cause the computer to perform the steps necessary to execute steps or elements embodying the various aspects of the invention.

[**0170**] The embodiment of the invention has and will be described in the context of functioning the computer and computer system. However, those skilled in the art will appreciate that various embodiments of the invention are capable of being distributed as a program product in a variety of forms, and that the invention applies equally regardless of the particular type of signal bearing media used to actually carry out the distribution. Examples of signal bearing media include but are not limited to recordable type media such as volatile and non-volatile memory devices, floppy and other removable disks, hard disk drives, optical disks (e.g., CD-ROM's, DVD's, etc.), among others, and transmission type media such as digital and analog communication links, including the Internet.

[**0171**] As described above, a sleep evaluation method is performed by measuring a body angle and a blood oxygen saturation of a subject in sleep concurrently at a predetermined sampling frequency to acquire measurement data concerning the body angle and the blood oxygen saturation; and expressing the measurement data along a time axis to evaluate a correlation between apnea based on lowering of the blood oxygen saturation and the body angle of the subject.

[**0172**] With this method, the body position of the subject in sleep can be measured in terms of body angle, which is a minute parameter, in place of body direction, which is a rough parameter, such as supine position or lateral decubitus position, and the blood oxygen saturation can be concurrently measured with the body angle. Accordingly, a correlation between apnea and body position of the subject in sleep can be accurately obtained.

[**0173**] The correlation between apnea and body position of the subject is obtained by way of a relation between apnea and body angle, which represents how much the body of the subject is tilted with respect to a reference plane in terms of angle, in place of a relation between apnea and body direction, which is a rough parameter as detected in the conventional art. This enables to securely acquire a causal relation between apnea and body position of the subject. Accordingly, the subject i.e. individual SAS patients are provided with a proper treatment having dependence on body position.

[**0174**] A sleep evaluation system comprises: an evaluation parameter detector for measuring an evaluation parameter of a subject, the evaluation parameter being varied due to sleep apnea of the subject; a body position detector for detecting a body position of the subject in terms of angle information; a storage for storing measurement data acquired by the evaluation parameter detector and by the body position detector therein; and a controller for causing the evaluation parameter detector to measure the evaluation parameter, and causing the body position detector to measure a body angle of the subject at a predetermined sampling frequency to store the measurement data in the storage.

[**0175**] With this arrangement, the body position of the subject in sleep can be measured by the body position detector in terms of angle information, the evaluation parameter, which is varied due to sleep apnea of the subject, can be measured by the evaluation parameter detector, and the measurement data concerning the body angle and the evaluation parameter can be stored in the storage. This arrangement enables to securely acquire the correlation between body position and evaluation parameter of the subject in sleep based on the measurement data stored in the storage.

[**0176**] The correlation between body position and evaluation parameter of the subject in sleep can be accurately obtained based on the measurement data having relevancy to apnea, which is stored in the storage. This arrangement enables to provide the individual SAS patients with a proper treatment having dependence on body position.

[**0177**] Preferably, the evaluation parameter detector may include a sensor for detecting a blood oxygen saturation of the subject.

[**0178**] With the above arrangement, the correlation between body position of the subject in sleep and apnea, which is observed as a variation in blood oxygen saturation, e.g., arterial blood oxygen saturation can be accurately obtained. Since the blood oxygen saturation is used as the evaluation parameter having relevancy to apnea, the evaluation parameter can be obtained with use of a commercially available pulse oximeter or a like device non-invasively with less stress to the subject.

[**0179**] Preferably, the sleep evaluation system may be further provided with an analyzer for analyzing a correlation between a variation in the evaluation parameter or in a blood oxygen saturation, and the body angle of the subject based on the measurement data stored in the storage to determine a correlation between apnea and the body angle of the subject.

[**0180**] With this arrangement, a causal relation between apnea and body angle of the subject in sleep can be obtained with use of the analyzer. According to the arrangement, ODI, which is an index for determining the degree of severity of

SAS, can be obtained with respect to each of the body angles for individual subjects with use of the analyzer.

[0181] The analyzer may preferably analyze a correlation at least between measurement data concerning an airflow of a respiratory system and movements of a body trunk portion of the subject, and the body angle of the subject, in addition to the correlation between the variation in the blood oxygen saturation and the body angle of the subject to determine a correlation between the apnea or a low respiration, and the body angle of the subject.

[0182] With this arrangement, a causal relation between apnea or low respiration, and body angle of the subject in sleep can be obtained with use of the analyzer. According to the arrangement, AHI, which is a frequently used index among medical institutes with use of PSG, can be obtained with respect to each of the body angles for individual subjects with use of the analyzer.

[0183] It may be preferable that the body position detector judges at least whether the body position of the subject is a seated position or a lying position, and the storage stores information relating to the judgment result on the body position of the subject therein.

[0184] This construction enables to discriminate a period corresponding to a state that the subject wakes up in the middle of sleep evaluation sometimes accompanied by walking, which normally includes a transient time corresponding to a seated position, thereby enabling to discriminate the measurement data acquired while the subject is in the seated position from the measurement data acquired while the subject is in the lying position. Since the measurement data acquired while the subject is in the seated position, which cannot be handled as valid measurement data can be discriminated from the measurement data acquired while the subject is in the lying position, reliability on measurement data can be enhanced.

[0185] It may be preferable that the body position detector includes a three-axis acceleration sensor having a first axis, a second axis, and a third axis, an output from the three-axis acceleration sensor with respect to the first axis is used to measure the body angle of the subject, an output from the three-axis acceleration sensor with respect to the second axis is used to judge whether the body position of the subject is the seated position or the lying position, and an output from the three-axis acceleration sensor with respect to the third axis is used to judge whether the lying position of the subject is a supine position or a prone position.

[0186] With this arrangement, the body angle of the subject can be measured in different body positions, i.e., a supine position and a prone position with use of the single sensing device, and a judgment can be made as to whether the subject is in the seated position. According to this arrangement, attaching the single sensing device, i.e., the three-axis acceleration sensor to the subject enables to measure the body angle of the subject in different body positions, i.e., the supine position and the prone position, and enables to judge whether the subject is in the seated position. This arrangement enables to reduce a stress to the subject during the measurement. Also, the configuration of the system can be simplified by incorporating the three-axis acceleration sensor in the pulse oximeter or a like device.

[0187] Preferably, the analyzer may analyze a correlation between a variation in the evaluation parameter or in a blood oxygen saturation, and the body angle of the subject, using measurement data indicating that the body position of the subject is the lying position.

[0188] With this arrangement, sleep of the subject can be evaluated, with the invalid data acquired while the subject is in the seated position eliminated, with use of the analyzer. Accordingly, the correlation between apnea and body angle of the subject can be more accurately obtained.

[0189] A sleep evaluation system comprises: a pulse oximeter including a blood oxygen saturation measuring device for acquiring measurement data concerning a blood oxygen saturation of a subject, a body position detector for acquiring measurement data concerning a body angle of the subject, a storage for storing the measurement data acquired by the blood oxygen saturation measuring device and by the body position detector therein, and a controller for causing the blood oxygen saturation measuring device to acquire the measurement data concerning the blood oxygen saturation of the subject, and causing the body position detector to acquire the measurement data concerning the body angle of the subject at a predetermined sampling frequency to store the measurement data acquired by the blood oxygen saturation measuring device and by the body position detector in the storage; a fastening device for securely holding the body position detector of the pulse oximeter on a body trunk portion of the subject; and a processor for acquiring the measurement data stored in the storage of the pulse oximeter to analyze a correlation between a variation in the blood oxygen saturation and the body angle of the subject for display.

[0190] With this arrangement, the pulse oximeter is provided with the blood oxygen saturation measuring device for acquiring the measurement data concerning the blood oxygen saturation, and the body tilt detector for acquiring the measurement data concerning the body angle. The measurement data is acquired with the pulse oximeter attached to the body trunk portion of the subject, and the acquired measurement data is stored in the storage of the pulse oximeter. The measurement data stored in the storage is read out after the subject wakes up, and the readout measurement data is analyzed by the processor such as a personal computer. Thus, a causal relation between apnea and body angle of the subject in sleep can be obtained.

[0191] The system can be configured by the pulse oximeter, the personal computer, and the like, the measurement data concerning the body angle and the blood oxygen saturation of the subject can be acquired with use of the pulse oximeter alone, and the measurement data can be stored in the storage. This arrangement enables to simplify the configuration of the system and reduce a stress to the subject during the measurement.

[0192] Preferably, the processor may include a display controller for displaying a correlation between a peak where the blood oxygen saturation is lowered and the body angle of the subject by expressing the measurement data along a time axis.

[0193] With this arrangement, the correlation between apnea and body angle of the subject can be securely obtained based on the relation between the peak where the blood oxygen saturation is lowered and the body angle of the subject. The correlation between apnea and body angle of

the subject can be securely obtained by observing an image or the like generated and displayed by the display controller.

[0194] Preferably, the processor may include a histogram calculator for expressing a correlation between a frequency of occurrence of a peak where the blood oxygen saturation is lowered and the body angle of the subject in a histogram.

[0195] With this arrangement, since the correlation between the frequency of occurrence of apnea and the body angle of the subject can be securely obtained, ODI or a like index can be automatically displayed with respect to each of the body angles for individual subjects.

[0196] Preferably, the processor may include a calculator for outputting a body angle of the subject with no or less likelihood of occurrence of the peak where the blood oxygen saturation is lowered as a recommended body angle for the subject with no or less likelihood of apnea.

[0197] With this arrangement, since the body angle capable of preventing apnea of the subject can be readily obtained, an approach for treating individual SAS patients can be readily determined.

[0198] It may be preferable that the body position detector of the pulse oximeter judges at least whether a body position of the subject is a seated position or a lying position, the storage stores information relating to the judgment result on the body position therein, and the processor includes a data discriminator for discriminating measurement data indicating that the body position of the subject is the lying position.

[0199] With this arrangement, since sleep of the subject can be evaluated with use of the processor, with the invalid data acquired while the subject is in the seated position being discriminated and eliminated by the data discriminator, the correlation between apnea and body angle of the subject can be more accurately determined.

[0200] A pulse oximeter comprises: a blood oxygen saturation measuring device for acquiring measurement data concerning a blood oxygen saturation of a subject; a body position detector for acquiring measurement data concerning a body angle of the subject; a storage for storing the measurement data acquired by the blood oxygen saturation measuring device and by the body position detector therein; and a controller for causing the blood oxygen saturation measuring device to acquire the measurement data concerning the blood oxygen saturation of the subject, and causing the body position detector to acquire the measurement data concerning the body angle of the subject at a predetermined sampling frequency to store the measurement data acquired by the blood oxygen saturation measuring device and by the body position detector in the storage.

[0201] With this arrangement, the measurement data concerning the blood oxygen saturation and the measurement data concerning the body angle of the subject in sleep can be acquired with use of the pulse oximeter, and stored in the storage. Accordingly, the sleep evaluation system for obtaining a causal relation between apnea and body angle of the subject in sleep can be configured by causing the processor such as a personal computer to read out the measurement data stored in the storage for analysis after the subject wakes up. The causal relation between apnea and body angle of the subject can be obtained by reading out the measurement data from the storage and analyzing the readout measurement data after the subject wakes up. Thus, the system for evaluating dependence of SAS patients on body position can be configured with use of the pulse oximeter alone.

[0202] Preferably, the pulse oximeter may be further provided with a display unit and a processor. The processor has a function of acquiring the measurement data stored in the storage, and analyzing a correlation between a variation in the blood oxygen saturation, and the body angle of the subject to cause the display unit to display the correlation.

[0203] With this arrangement, since the causal relation between apnea and body angle of the subject in sleep can be obtained with use of the pulse oximeter alone without use of an external processor, the configuration of the system for evaluating dependence of SAS patients on body position can be simplified.

[0204] Preferably, the pulse oximeter may be further provided with a direction guide provided on an outer surface of a casing of the pulse oximeter to notify a direction in which the pulse oximeter is normally attached to the subject.

[0205] With this arrangement, the subject is guided to attach the pulse oximeter in a proper direction as displayed on the guide display. The subject is securely guided to attach the pulse oximeter in a proper direction. Accordingly, in the case where the three-axis acceleration sensor is used as the body position detector, for instance, outputs from the three-axis acceleration sensor with respect to the three axes can be used as designed. If the pulse oximeter is attached in a wrong direction, rolling over of the subject in a rightward direction may be misjudged as rolling over in a leftward direction. Providing the direction guide enables to prevent occurrence of such a misjudgment.

[0206] A program product is adapted for operating a sleep evaluation system provided with an evaluation parameter detector for measuring an evaluation parameter of a subject, the evaluation parameter being varied due to sleep apnea of the subject, a body position detector for detecting a body position of the subject in terms of angle information, a storage for storing measurement data acquired by the evaluation parameter detector and by the body position detector therein, and an analyzer. The program product comprises: a program which allows a computer to execute the steps of making the evaluation parameter detector to measure the evaluation parameter, and making the body position detector to measure a body angle of the subject at a predetermined sampling frequency to acquire measurement data concerning the evaluation parameter and the body angle, making the storage to store the measurement data therein, and making the analyzer to analyze a correlation between a variation in the evaluation parameter and the body angle of the subject based on the measurement data stored in the storage; and a signal bearing media bearing the program.

[0207] With this program product, the correlation between body position and evaluation parameter of the subject in sleep can be evaluated with use of the analyzer based on the measurement data having relevancy to apnea of the subject, which is stored in the storage. This enables to provide individual SAS patients with a proper treatment having dependence on body position.

[0208] Another program product is adapted for operating a sleep evaluation system provided with a pulse oximeter including a blood oxygen saturation measuring device for

acquiring measurement data concerning a blood oxygen saturation of a subject, a body position detector for acquiring measurement data concerning a body angle of the subject, a storage for storing the measurement data acquired by the blood oxygen saturation measuring device and by the body position detector therein, and a processor. The program product comprises: a program which allows a computer to execute the steps of making the blood oxygen saturation measuring device to acquire measurement data concerning the blood oxygen saturation, and making the body position detector to acquire measurement data concerning the body angle at a predetermined sampling frequency, making the storage to store the measurement data therein, and making the processor to acquire the measurement data stored in the storage of the pulse oximeter to analyze a correlation between a variation in the blood oxygen saturation and the body angle of the subject; and a signal bearing media bearing the program.

[0209] With this program product, the correlation between apnea and body position of the subject in sleep can be evaluated with use of the processor based on the measurement data concerning the blood oxygen saturation and the body angle, which is stored in the storage of the pulse oximeter, by using the system comprised of the pulse oximeter and the processor such as a personal computer. This enables to provide individual SAS patients with a proper treatment having dependence on body position.

[0210] A sleep support system comprises: a bed for supporting a subject in a lying position; a bed driver for adjusting an angle of the bed; and a controller for determining the angle of the bed adjusted by the bed driver. The controller is operative to cause a measuring device to measure a body angle and a blood oxygen saturation of the subject in sleep on the bed concurrently at a predetermined sampling frequency to acquire measurement data concerning the body angle and the blood oxygen saturation, to evaluate a correlation between apnea based on lowering of the blood oxygen saturation and the body angle of the subject by expressing the measurement data along a time axis, to determine a body angle of the subject with no or less likelihood of apnea, and to output the body angle of the subject with no or less likelihood of apnea as a designated angle of the bed to be adjusted by the bed driver.

[0211] With this arrangement, the angle of the bed with no or less likelihood of apnea can be determined concurrently with detection of the body angle where apnea of the subject is observed. This arrangement enables to provide the subject with a comfortable sleep environment with no or less likelihood of apnea. Since the angle of the bed is adjusted so that the body of the subject is secured to such a body position that has no or less likelihood of apnea, while detecting the apnea, a comfortable sleep environment is provided for the subject.

[0212] Although the present invention has been fully described by way of example with reference to the accompanying drawings, it is to be understood that various changes and modifications will be apparent to those skilled in the art. Therefore, unless otherwise such changes and modifications depart from the scope of the present invention hereinafter defined, they should be construed as being included therein.

What is claimed is:

1. A sleep evaluation method comprising the steps of:

measuring a body angle and a blood oxygen saturation of a subject in sleep concurrently at a predetermined sampling frequency to acquire measurement data concerning the body angle and the blood oxygen saturation; and

expressing the measurement data along a time axis to evaluate a correlation between apnea based on lowering of the blood oxygen saturation and the body angle of the subject.

2. A sleep evaluation system comprising:

an evaluation parameter detector for measuring an evaluation parameter of a subject, the evaluation parameter being varied due to sleep apnea of the subject;

a body position detector for detecting a body position of the subject in terms of angle information;

a storage for storing measurement data acquired by the evaluation parameter detector and by the body position detector therein; and

a controller for causing the evaluation parameter detector to measure the evaluation parameter, and causing the body position detector to measure a body angle of the subject at a predetermined sampling frequency to store the measurement data in the storage.

3. The sleep evaluation system according to claim 2, wherein

the evaluation parameter detector includes a sensor for detecting a blood oxygen saturation of the subject.

4. The sleep evaluation system according to claim 2, further comprising an analyzer for analyzing a correlation between a variation in the evaluation parameter or in a blood oxygen saturation, and the body angle of the subject based on the measurement data stored in the storage to determine a correlation between apnea and the body angle of the subject.

5. The sleep evaluation system according to claim 4, wherein

the analyzer analyzes a correlation at least between measurement data concerning an airflow of a respiratory system and movements of a body trunk portion of the subject, and the body angle of the subject, in addition to the correlation between the variation in the blood oxygen saturation and the body angle of the subject to determine a correlation between the apnea or a low respiration, and the body angle of the subject.

6. The sleep evaluation system according to claim 2, wherein

the body position detector judges at least whether the body position of the subject is a seated position or a lying position, and

the storage stores information relating to the judgment result on the body position of the subject therein.

7. The sleep evaluation system according to claim 6, wherein

the body position detector includes a three-axis acceleration sensor having a first axis, a second axis, and a third axis,

an output from the three-axis acceleration sensor with respect to the first axis is used to measure the body angle of the subject,

an output from the three-axis acceleration sensor with respect to the second axis is used to judge whether the body position of the subject is the seated position or the lying position, and

an output from the three-axis acceleration sensor with respect to the third axis is used to judge whether the lying position of the subject is a supine position or a prone position.

8. The sleep evaluation system according to claim 6, wherein

the analyzer analyzes a correlation between a variation in the evaluation parameter or in a blood oxygen saturation, and the body angle of the subject, using measurement data indicating that the body position of the subject is the lying position.

9. A sleep evaluation system comprising:

a pulse oximeter including

a blood oxygen saturation measuring device for acquiring measurement data concerning a blood oxygen saturation of a subject,

a body position detector for acquiring measurement data concerning a body angle of the subject,

a storage for storing the measurement data acquired by the blood oxygen saturation measuring device and by the body position detector therein, and

a controller for causing the blood oxygen saturation measuring device to acquire the measurement data concerning the blood oxygen saturation of the subject, and causing the body position detector to acquire the measurement data concerning the body angle of the subject at a predetermined sampling frequency to store the measurement data acquired by the blood oxygen saturation measuring device and by the body position detector in the storage;

a fastening device for securely holding the body position detector of the pulse oximeter on a body trunk portion of the subject; and

a processor for acquiring the measurement data stored in the storage of the pulse oximeter to analyze a correlation between a variation in the blood oxygen saturation and the body angle of the subject for display.

10. The sleep evaluation system according to claim 9, wherein

the processor includes a display controller for displaying a correlation between a peak where the blood oxygen saturation is lowered and the body angle of the subject by expressing the measurement data along a time axis.

11. The sleep evaluation system according to claim 9, wherein

the processor includes a histogram calculator for expressing a correlation between a frequency of occurrence of a peak where the blood oxygen saturation is lowered and the body angle of the subject in a histogram.

12. The sleep evaluation system according to claim 11, wherein

the processor includes a calculator for outputting a body angle of the subject with no or less likelihood of occurrence of the peak where the blood oxygen saturation is lowered as a recommended body angle for the subject with no or less likelihood of apnea.

13. The sleep evaluation system according to claim 9, wherein

the body position detector of the pulse oximeter judges at least whether a body position of the subject is a seated position or a lying position,

the storage stores information relating to the judgment result on the body position therein, and

the processor includes a data discriminator for discriminating measurement data indicating that the body position of the subject is the lying position.

14. A pulse oximeter comprising:

a blood oxygen saturation measuring device for acquiring measurement data concerning a blood oxygen saturation of a subject;

a body position detector for acquiring measurement data concerning a body angle of the subject;

a storage for storing the measurement data acquired by the blood oxygen saturation measuring device and by the body position detector therein; and

a controller for causing the blood oxygen saturation measuring device to acquire the measurement data concerning the blood oxygen saturation of the subject, and causing the body position detector to acquire the measurement data concerning the body angle of the subject at a predetermined sampling frequency to store the measurement data acquired by the blood oxygen saturation measuring device and by the body position detector in the storage.

15. The pulse oximeter according to claim 14, further comprising a display unit and a processor, wherein

the processor has a function of acquiring the measurement data stored in the storage, and analyzing a correlation between a variation in the blood oxygen saturation, and the body angle of the subject to cause the display unit to display the correlation.

16. The pulse oximeter according to claim 14, further comprising a direction guide provided on an outer surface of a casing of the pulse oximeter to notify a direction in which the pulse oximeter is normally attached to the subject.

17. A program product for operating a sleep evaluation system provided with an evaluation parameter detector for measuring an evaluation parameter of a subject, the evaluation parameter being varied due to sleep apnea of the subject, a body position detector for detecting a body position of the subject in terms of angle information, a storage for storing measurement data acquired by the evaluation parameter detector and by the body position detector therein, and an analyzer, the program product comprising:

a program which allows a computer to execute the steps of

making the evaluation parameter detector to measure the evaluation parameter, and making the body posi-

tion detector to measure a body angle of the subject at a predetermined sampling frequency to acquire measurement data concerning the evaluation parameter and the body angle,

making the storage to store the measurement data therein, and

making the analyzer to analyze a correlation between a variation in the evaluation parameter and the body angle of the subject based on the measurement data stored in the storage; and

a signal bearing media bearing the program.

18. A program product for operating a sleep evaluation system provided with a pulse oximeter including a blood oxygen saturation measuring device for acquiring measurement data concerning a blood oxygen saturation of a subject, a body position detector for acquiring measurement data concerning a body angle of the subject, a storage for storing the measurement data acquired by the blood oxygen saturation measuring device and by the body position detector therein, and a processor, the program product comprising:

a program which allows a computer to execute the steps of

making the blood oxygen saturation measuring device to acquire measurement data concerning the blood oxygen saturation, and making the body position detector to acquire measurement data concerning the body angle at a predetermined sampling frequency,

making the storage to store the measurement data therein, and

making the processor to acquire the measurement data stored in the storage of the pulse oximeter to analyze a correlation between a variation in the blood oxygen saturation and the body angle of the subject; and

a signal bearing media bearing the program.

19. A sleep support system comprising:

a bed for supporting a subject in a lying position;

a bed driver for adjusting an angle of the bed; and

a controller for determining the angle of the bed adjusted by the bed driver,

the controller being operative to cause a measuring device to measure a body angle and a blood oxygen saturation of the subject in sleep on the bed concurrently at a predetermined sampling frequency to acquire measurement data concerning the body angle and the blood oxygen saturation, to evaluate a correlation between apnea based on lowering of the blood oxygen saturation and the body angle of the subject by expressing the measurement data along a time axis, to determine a body angle of the subject with no or less likelihood of apnea, and to output the body angle of the subject with no or less likelihood of apnea as a designated angle of the bed to be adjusted by the bed driver.

* * * * *

专利名称(译)	睡眠评估方法，睡眠评估系统，睡眠评估系统的操作程序，脉搏血氧计和睡眠支持系统		
公开(公告)号	US20060173257A1	公开(公告)日	2006-08-03
申请号	US11/341326	申请日	2006-01-27
申请(专利权)人(译)	柯尼卡美能达，INC.		
当前申请(专利权)人(译)	柯尼卡美能达，INC.		
[标]发明人	NAGAI YOSHIROH KITAJIMA KAZUMI		
发明人	NAGAI, YOSHIROH KITAJIMA, KAZUMI		
IPC分类号	A61B5/00 A61G7/00		
CPC分类号	A61B5/087 A61B5/1116 A61B5/1135 A61B5/14551 A61B5/4818 A61B5/6819 A61B5/6828 A61B5/6831 A61B7/00 G01P15/123 G01P15/18 A61B5/6823 A61B5/6826 A61B2562/0219 A61B2562/046 G01P2015/0842		
优先权	2005023674 2005-01-31 JP		
外部链接	Espacenet USPTO		

摘要(译)

测量对象的必要评估参数，该参数由于受试者的睡眠呼吸暂停而变化。根据角度信息检测对象的身体位置。以预定的采样频率执行参数测量和体角检测。这些数据存储在存储器中。睡眠评估系统包括：评估参数检测器，用于测量对象的评估参数;体位置检测器，用于根据角度信息检测对象的身体位置;存储器，用于存储由评估参数检测器和体位检测器获取的测量数据;控制器，用于使评估参数检测器测量评估参数，并使体位检测器以预定的采样频率测量对象的体角，以将测量数据存储在存储器中。