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(54) **AUTONOMIC-NERVOUS STATE JUDGING DEVICE, AUTONOMIC-NERVOUS STATE JUDGING METHOD, AND COMPUTER PROGRAM PRODUCT**

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(57) **ABSTRACT**

An autonomic-nervous state judging device measures an autonomic-nervous index of a subject in sleep at predetermined time intervals. The autonomic-nervous state judging device sets a plurality of cycle frames of a predetermined length each including one sleep cycle, and a judging frame in a cycle frame at a predetermined position. The autonomic-nervous state judging device specifies state of autonomic nervous system in the judging frame based on the autonomic-nervous index, and detects timing of a change in the state of the autonomic nervous system.

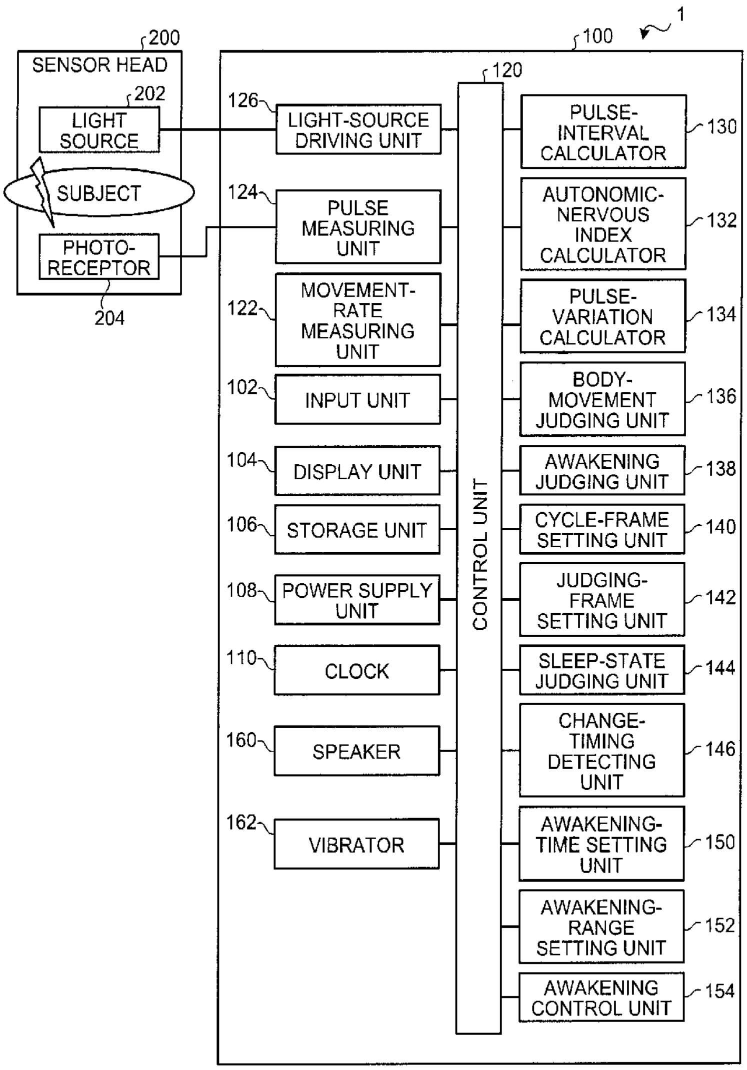


FIG.1

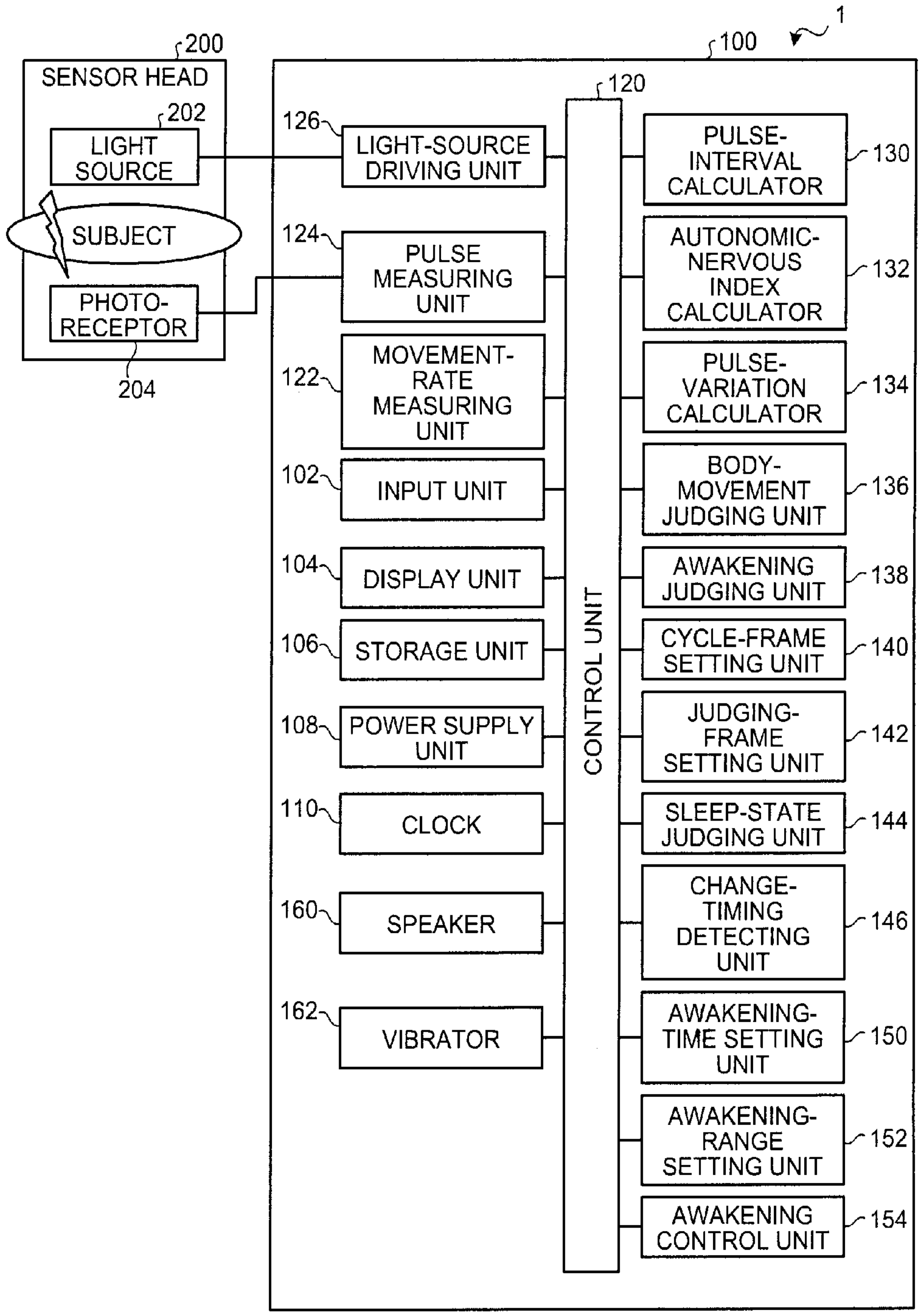

1
200
SENSOR HEAD
202
LIGHT SOURCE
SUBJECT
PHOTO-RECEPTOR
204
100
120
126
LIGHT-SOURCE DRIVING UNIT
124
PULSE MEASURING UNIT
122
MOVEMENT-RATE MEASURING UNIT
102
INPUT UNIT
104
DISPLAY UNIT
106
STORAGE UNIT
108
POWER SUPPLY UNIT
110
CLOCK
160
SPEAKER
162
VIBRATOR
CONTROL UNIT
PULSE-INTERVAL CALCULATOR
130
AUTONOMIC-NERVOUS INDEX CALCULATOR
132
PULSE-VARIATION CALCULATOR
134
BODY-MOVEMENT JUDGING UNIT
136
AWAKENING JUDGING UNIT
138
CYCLE-FRAME SETTING UNIT
140
JUDGING-FRAME SETTING UNIT
142
SLEEP-STATE JUDGING UNIT
144
CHANGE-TIMING DETECTING UNIT
146
AWAKENING-TIME SETTING UNIT
150
AWAKENING-RANGE SETTING UNIT
152
AWAKENING CONTROL UNIT
154

FIG.2

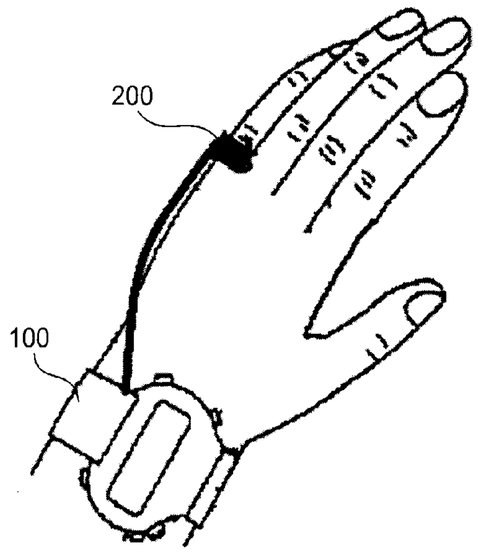

200
100

FIG.3

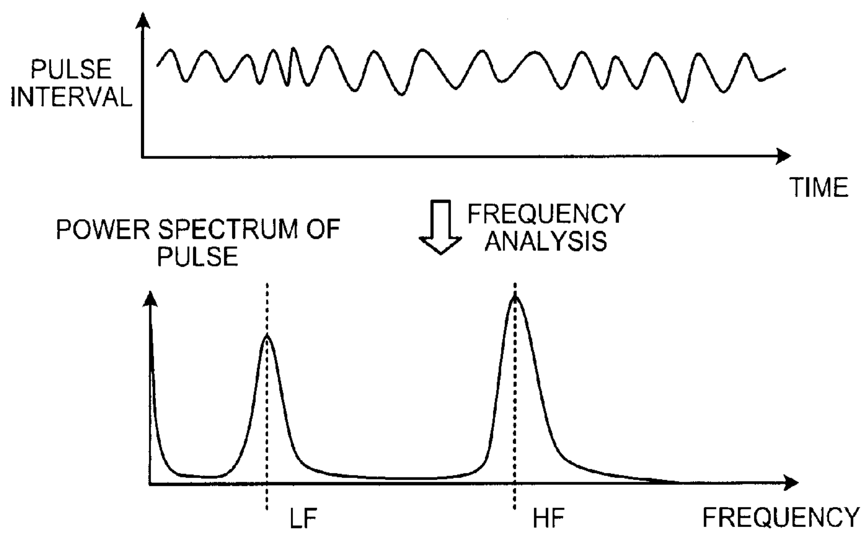

PULSE INTERVAL
TIME
POWER SPECTRUM OF PULSE
FREQUENCY ANALYSIS
LF
HF
FREQUENCY

FIG.4

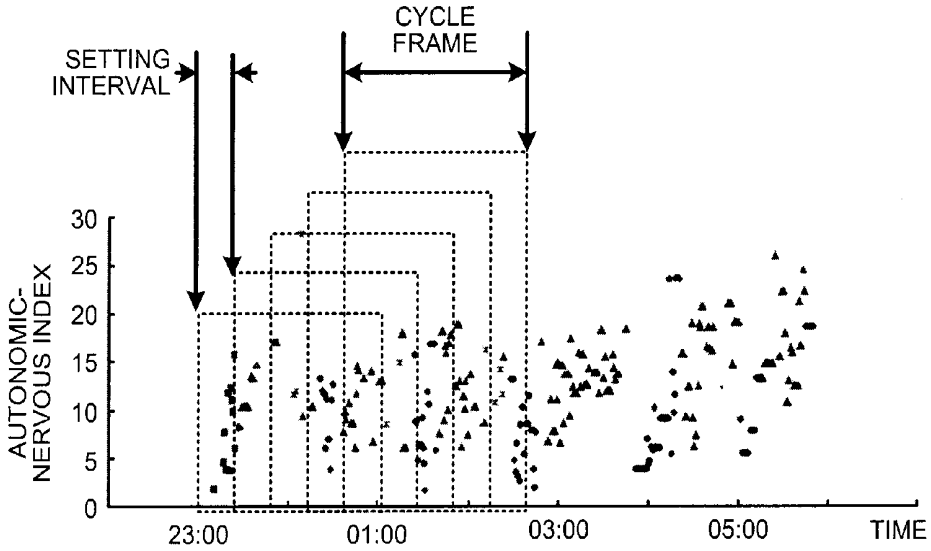

CYCLE
FRAME
SETTING
INTERVAL
30
25
20
15
10
5
0
AUTONOMIC-
NERVOUS INDEX
23:00
01:00
03:00
05:00
TIME

FIG.5

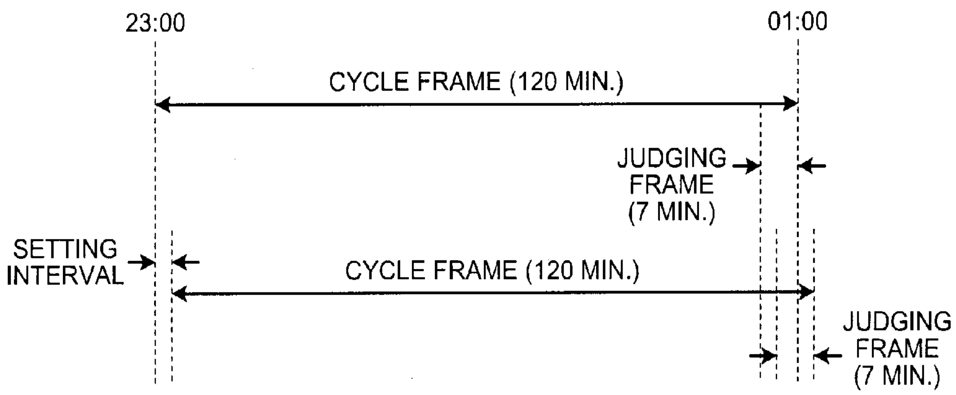

23:00
01:00
CYCLE FRAME (120 MIN.)
JUDGING
FRAME
(7 MIN.)
SETTING
INTERVAL
CYCLE FRAME (120 MIN.)
JUDGING
FRAME
(7 MIN.)

FIG.6

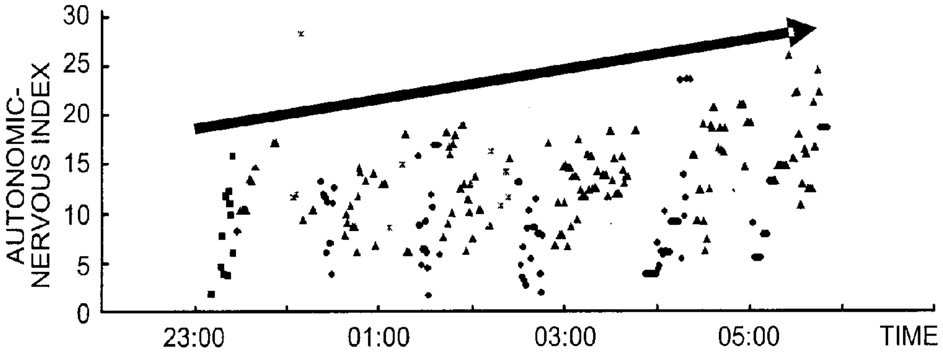

30
25
20
15
10
5
0
AUTONOMIC-NERVOUS INDEX
23:00
01:00
03:00
05:00
TIME

FIG.7

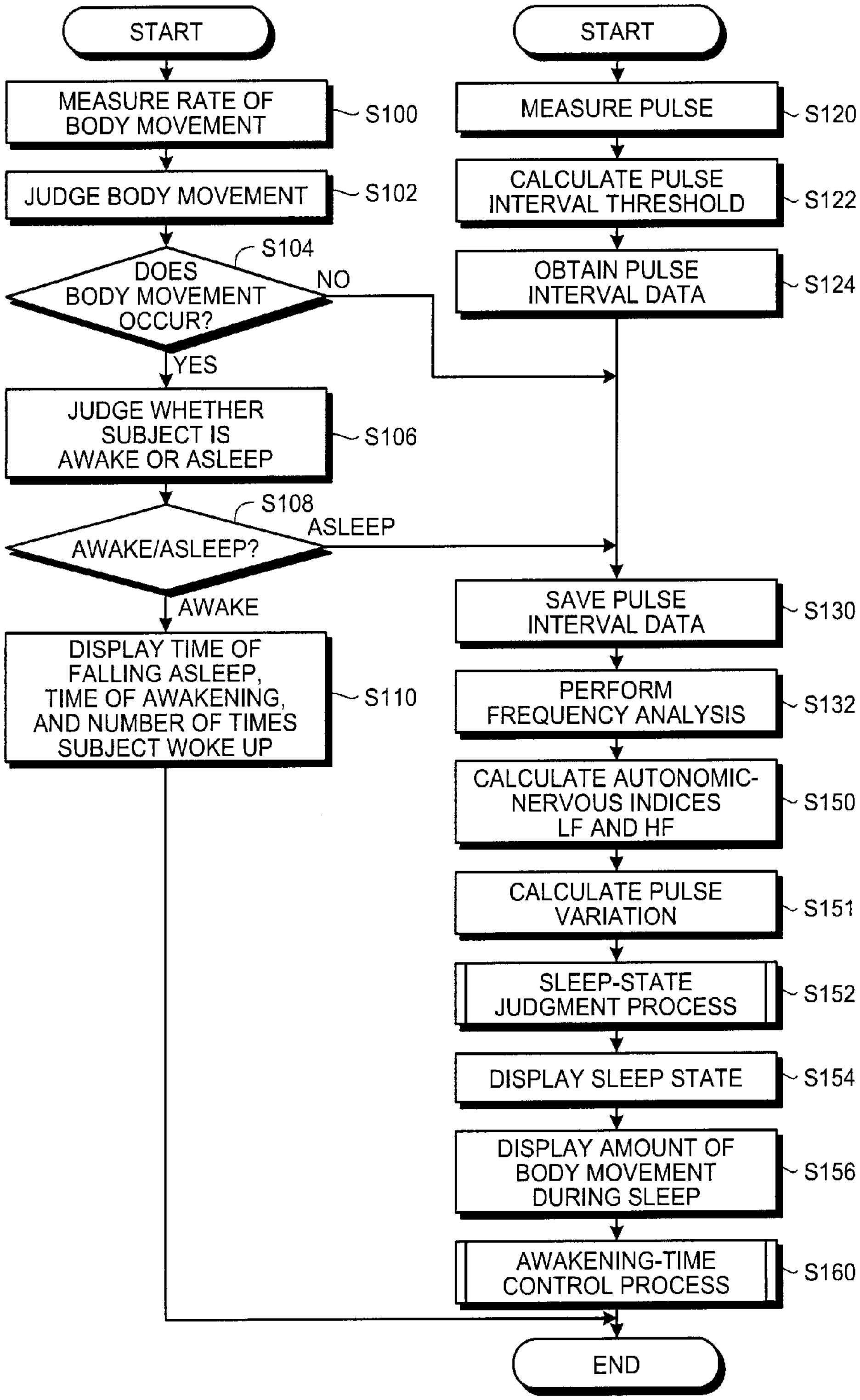

START
MEASURE RATE OF BODY MOVEMENT
S100
JUDGE BODY MOVEMENT
S102
S104
DOES BODY MOVEMENT OCCUR?
NO
YES
JUDGE WHETHER SUBJECT IS AWAKE OR ASLEEP
S106
S108
AWAKE/ASLEEP?
ASLEEP
AWAKE
DISPLAY TIME OF FALLING ASLEEP, TIME OF AWAKENING, AND NUMBER OF TIMES SUBJECT WOKE UP
S110
START
MEASURE PULSE
S120
CALCULATE PULSE INTERVAL THRESHOLD
S122
OBTAIN PULSE INTERVAL DATA
S124
SAVE PULSE INTERVAL DATA
S130
PERFORM FREQUENCY ANALYSIS
S132
CALCULATE AUTONOMIC-NERVOUS INDICES LF AND HF
S150
CALCULATE PULSE VARIATION
S151
SLEEP-STATE JUDGMENT PROCESS
S152
DISPLAY SLEEP STATE
S154
DISPLAY AMOUNT OF BODY MOVEMENT DURING SLEEP
S156
AWAKENING-TIME CONTROL PROCESS
S160
END

FIG.8

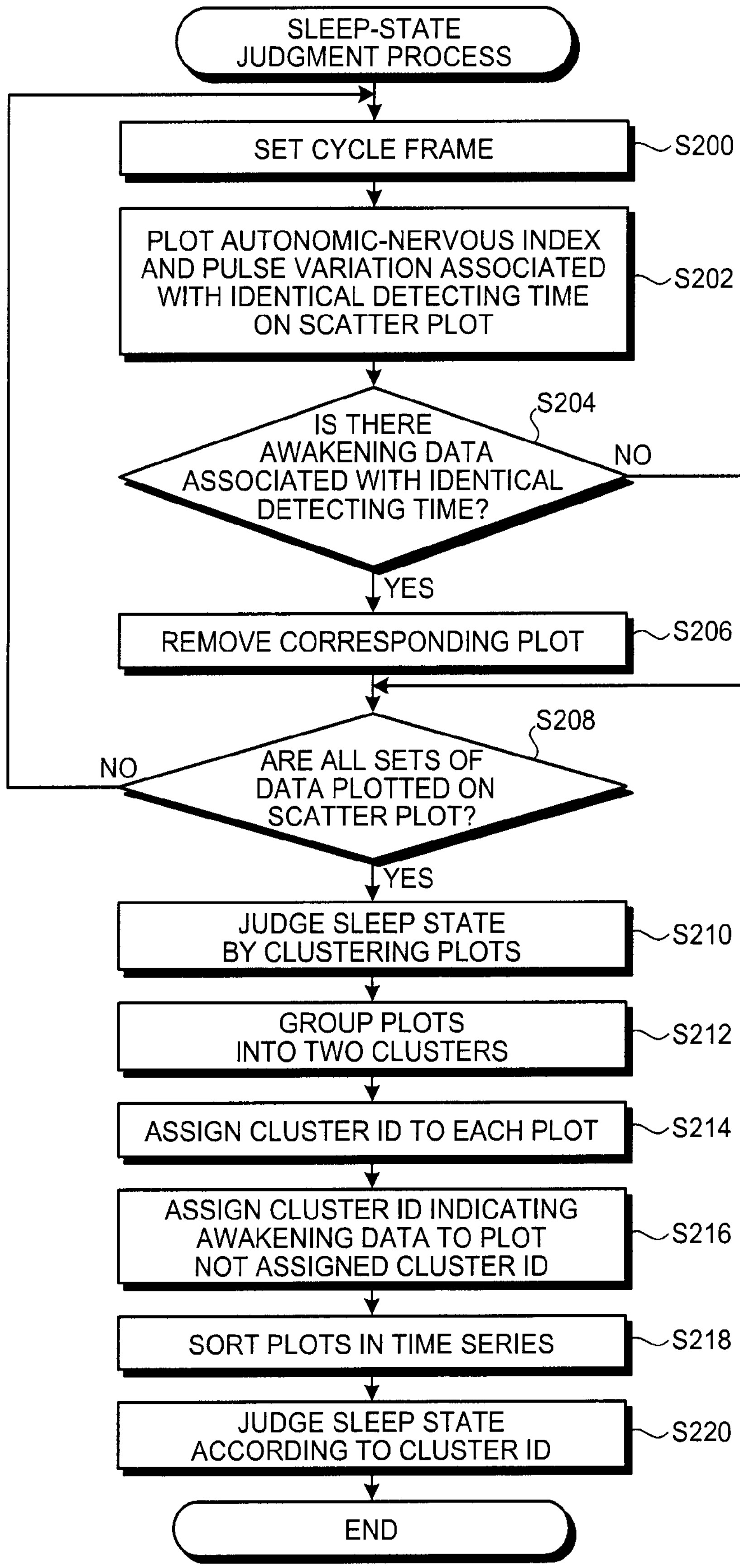

SLEEP-STATE JUDGMENT PROCESS
SET CYCLE FRAME
S200
PLOT AUTONOMIC-NERVOUS INDEX AND PULSE VARIATION ASSOCIATED WITH IDENTICAL DETECTING TIME ON SCATTER PLOT
S202
IS THERE AWAKENING DATA ASSOCIATED WITH IDENTICAL DETECTING TIME?
S204
NO
YES
REMOVE CORRESPONDING PLOT
S206
ARE ALL SETS OF DATA PLOTTED ON SCATTER PLOT?
S208
NO
YES
JUDGE SLEEP STATE BY CLUSTERING PLOTS
S210
GROUP PLOTS INTO TWO CLUSTERS
S212
ASSIGN CLUSTER ID TO EACH PLOT
S214
ASSIGN CLUSTER ID INDICATING AWAKENING DATA TO PLOT NOT ASSIGNED CLUSTER ID
S216
SORT PLOTS IN TIME SERIES
S218
JUDGE SLEEP STATE ACCORDING TO CLUSTER ID
S220
END

FIG.9

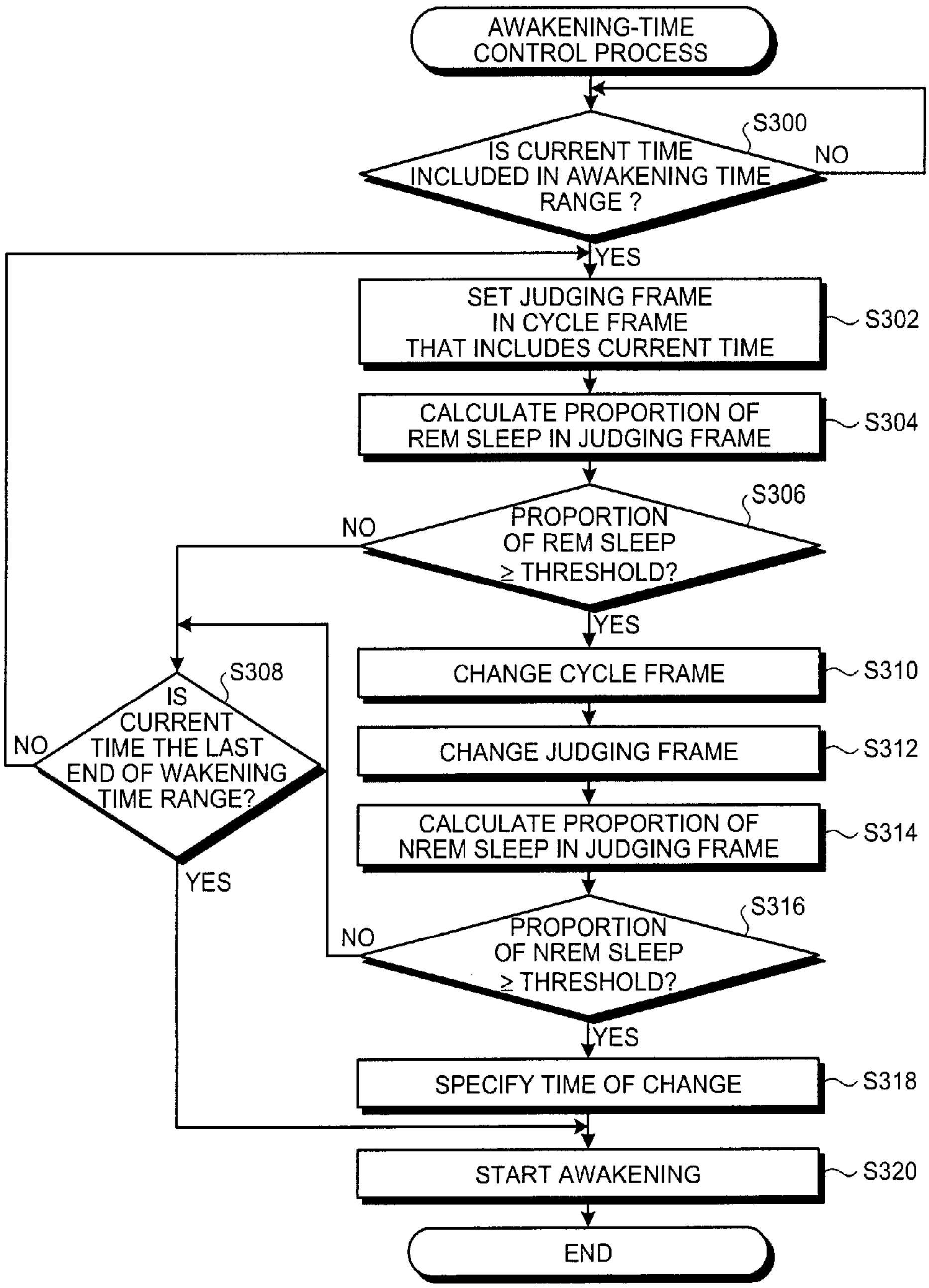

AWAKENING-TIME CONTROL PROCESS
IS CURRENT TIME INCLUDED IN AWAKENING TIME RANGE ?
S300
NO
YES
SET JUDGING FRAME IN CYCLE FRAME THAT INCLUDES CURRENT TIME
S302
CALCULATE PROPORTION OF REM SLEEP IN JUDGING FRAME
S304
PROPORTION OF REM SLEEP ≥ THRESHOLD?
S306
NO
YES
IS CURRENT TIME THE LAST END OF WAKENING TIME RANGE?
S308
NO
YES
CHANGE CYCLE FRAME
S310
CHANGE JUDGING FRAME
S312
CALCULATE PROPORTION OF NREM SLEEP IN JUDGING FRAME
S314
PROPORTION OF NREM SLEEP ≥ THRESHOLD?
S316
NO
YES
SPECIFY TIME OF CHANGE
S318
START AWAKENING
S320
END

FIG.10

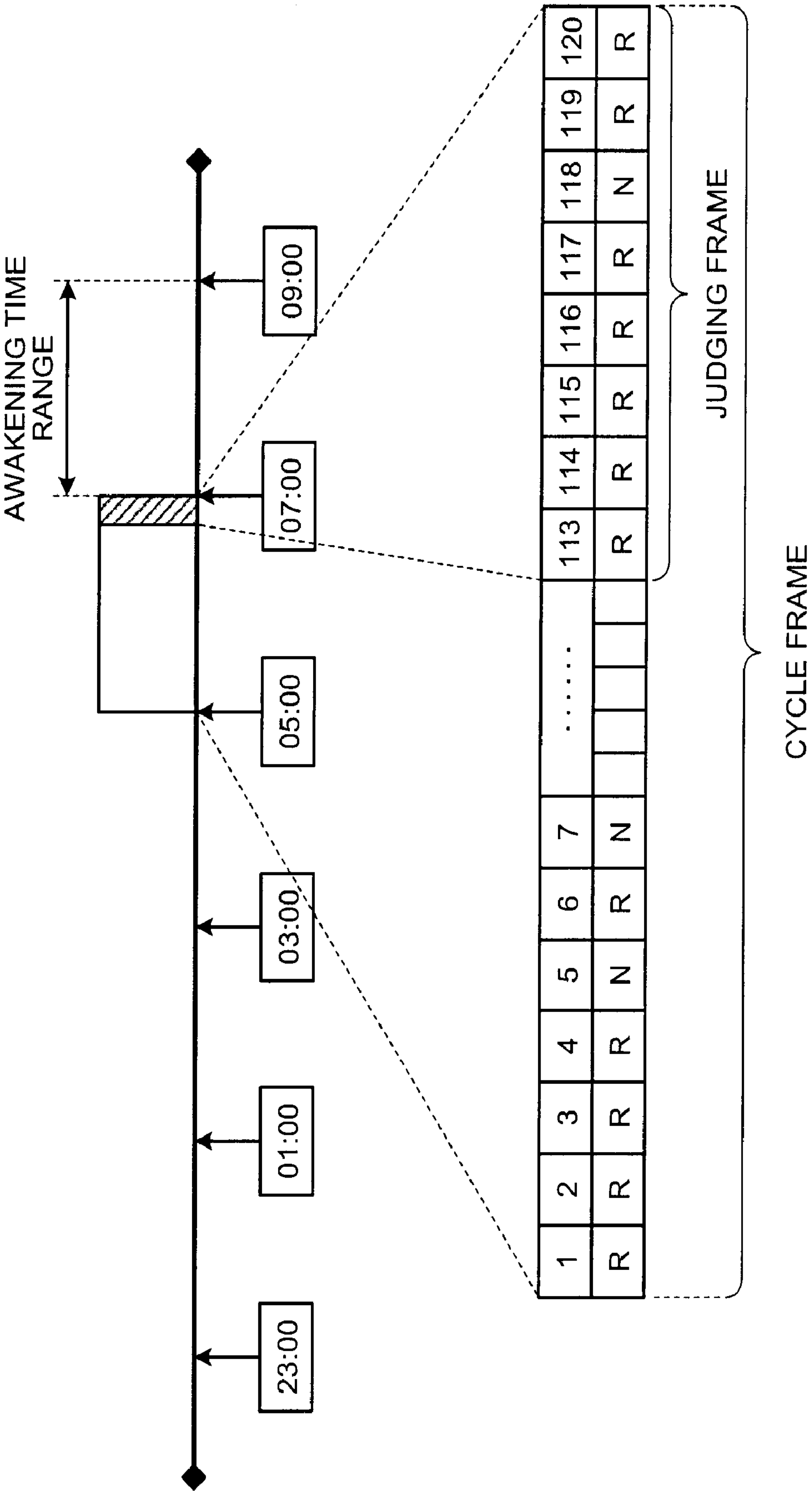

AWAKENING TIME RANGE
09:00
07:00
05:00
03:00
01:00
23:00
JUDGING FRAME
CYCLE FRAME
1
2
3
4
5
6
7
......
113
114
115
116
117
118
119
120
R
N

FIG.11

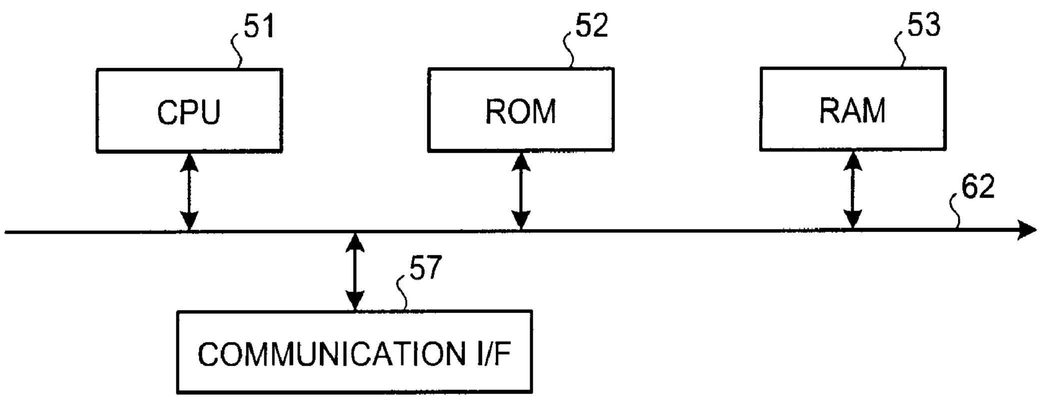


FIG.12

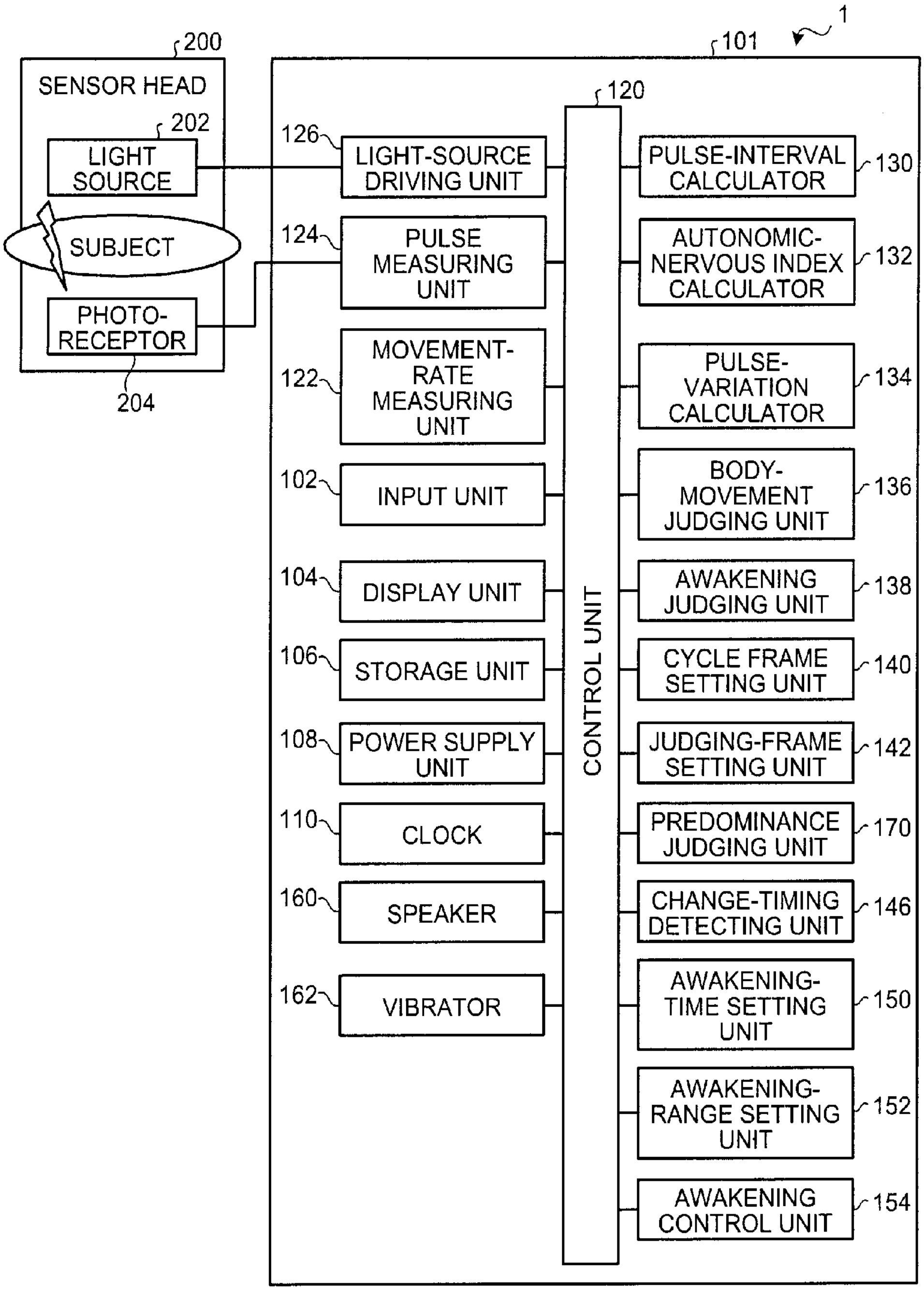
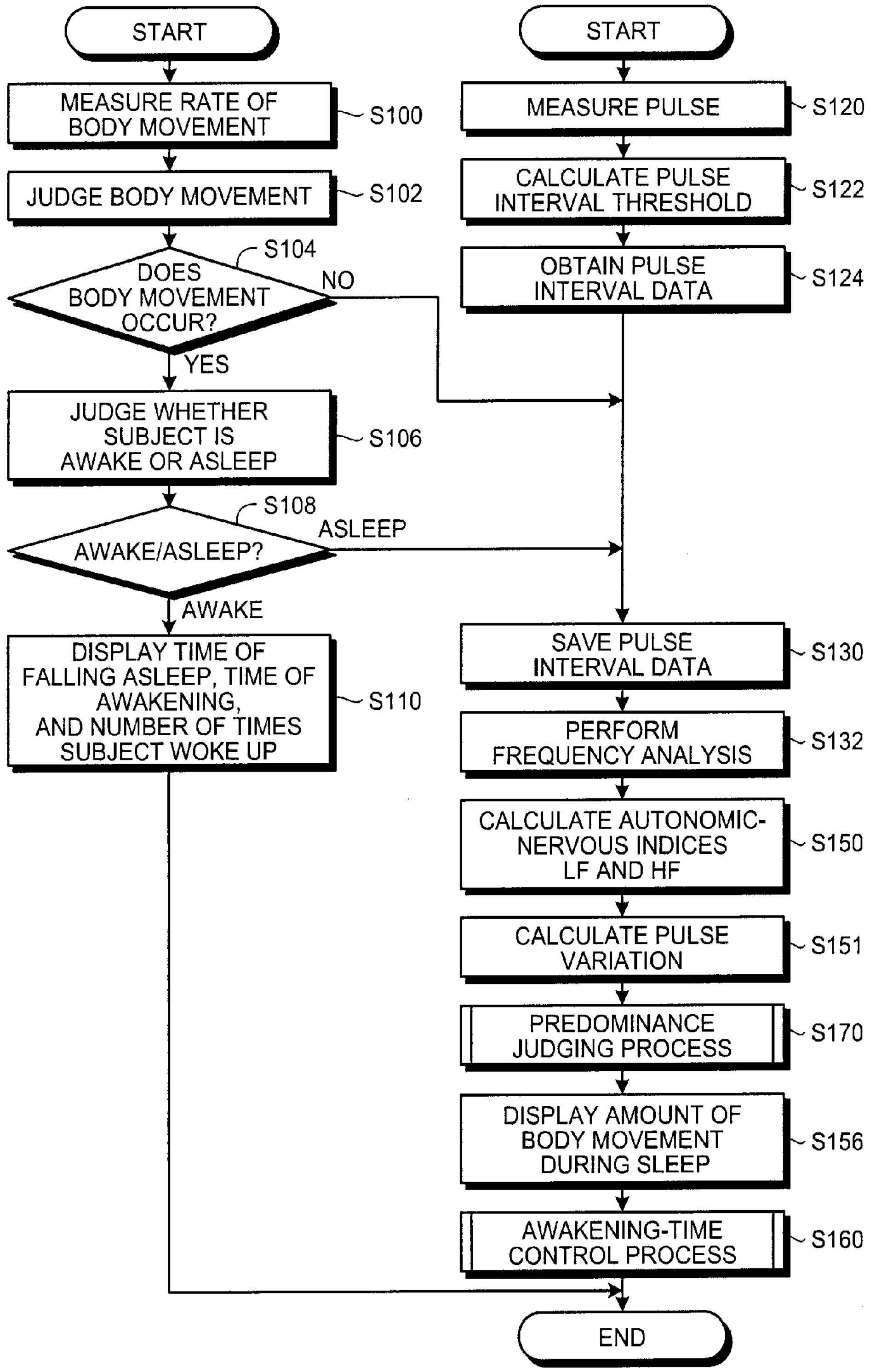

1
200
SENSOR HEAD
202
LIGHT SOURCE
SUBJECT
PHOTO-RECEPTOR
204
101
120
126
LIGHT-SOURCE DRIVING UNIT
124
PULSE MEASURING UNIT
122
MOVEMENT-RATE MEASURING UNIT
102
INPUT UNIT
104
DISPLAY UNIT
106
STORAGE UNIT
108
POWER SUPPLY UNIT
110
CLOCK
160
SPEAKER
162
VIBRATOR
CONTROL UNIT
PULSE-INTERVAL CALCULATOR
130
AUTONOMIC-NERVOUS INDEX CALCULATOR
132
PULSE-VARIATION CALCULATOR
134
BODY-MOVEMENT JUDGING UNIT
136
AWAKENING JUDGING UNIT
138
CYCLE FRAME SETTING UNIT
140
JUDGING-FRAME SETTING UNIT
142
PREDOMINANCE JUDGING UNIT
170
CHANGE-TIMING DETECTING UNIT
146
AWAKENING-TIME SETTING UNIT
150
AWAKENING-RANGE SETTING UNIT
152
AWAKENING CONTROL UNIT
154

FIG.13



START
MEASURE RATE OF BODY MOVEMENT
S100
JUDGE BODY MOVEMENT
S102
S104
DOES BODY MOVEMENT OCCUR?
NO
YES
JUDGE WHETHER SUBJECT IS AWAKE OR ASLEEP
S106
S108
AWAKE/ASLEEP?
ASLEEP
AWAKE
DISPLAY TIME OF FALLING ASLEEP, TIME OF AWAKENING, AND NUMBER OF TIMES SUBJECT WOKE UP
S110
START
MEASURE PULSE
S120
CALCULATE PULSE INTERVAL THRESHOLD
S122
OBTAIN PULSE INTERVAL DATA
S124
SAVE PULSE INTERVAL DATA
S130
PERFORM FREQUENCY ANALYSIS
S132
CALCULATE AUTONOMIC-NERVOUS INDICES LF AND HF
S150
CALCULATE PULSE VARIATION
S151
PREDOMINANCE JUDGING PROCESS
S170
DISPLAY AMOUNT OF BODY MOVEMENT DURING SLEEP
S156
AWAKENING-TIME CONTROL PROCESS
S160
END

FIG.14

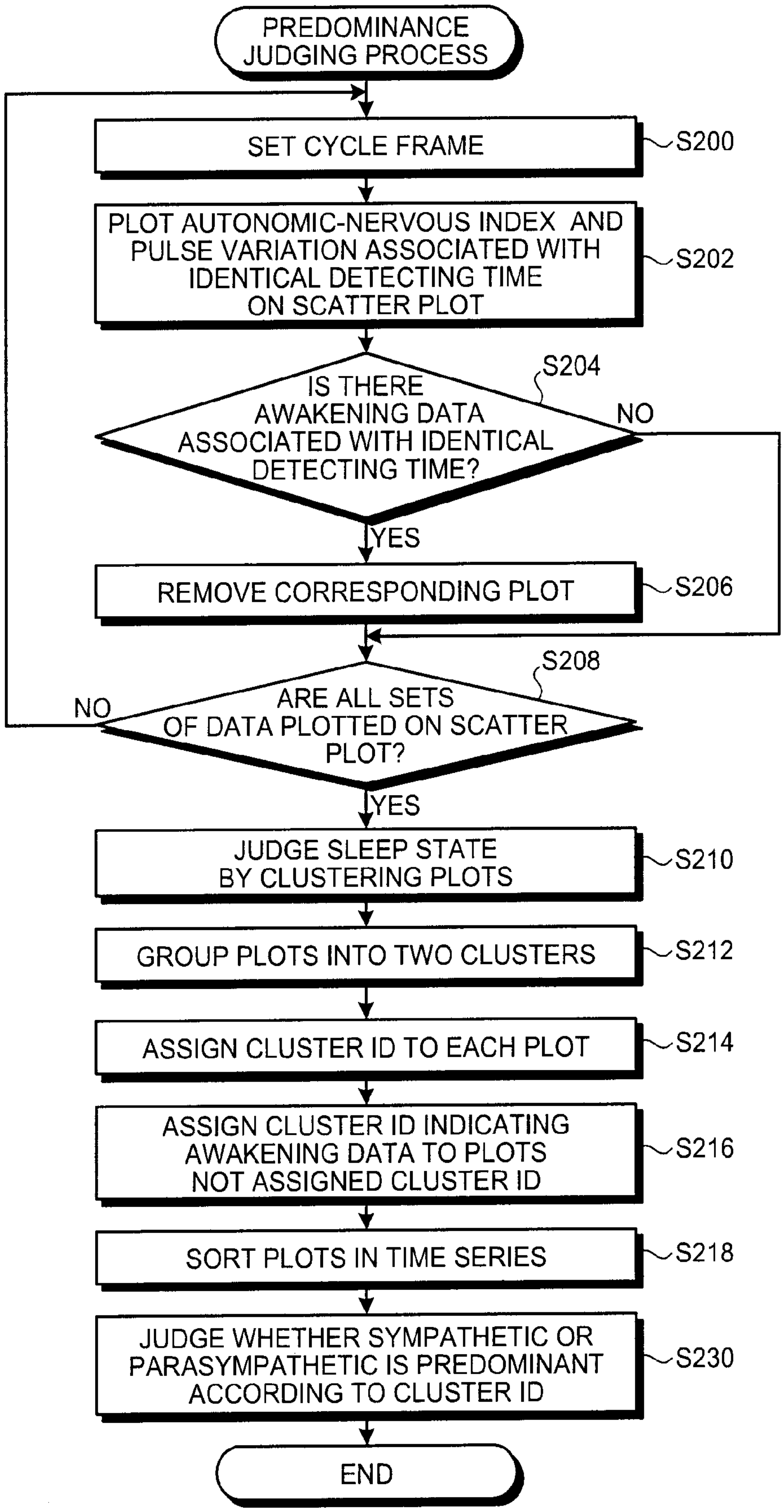
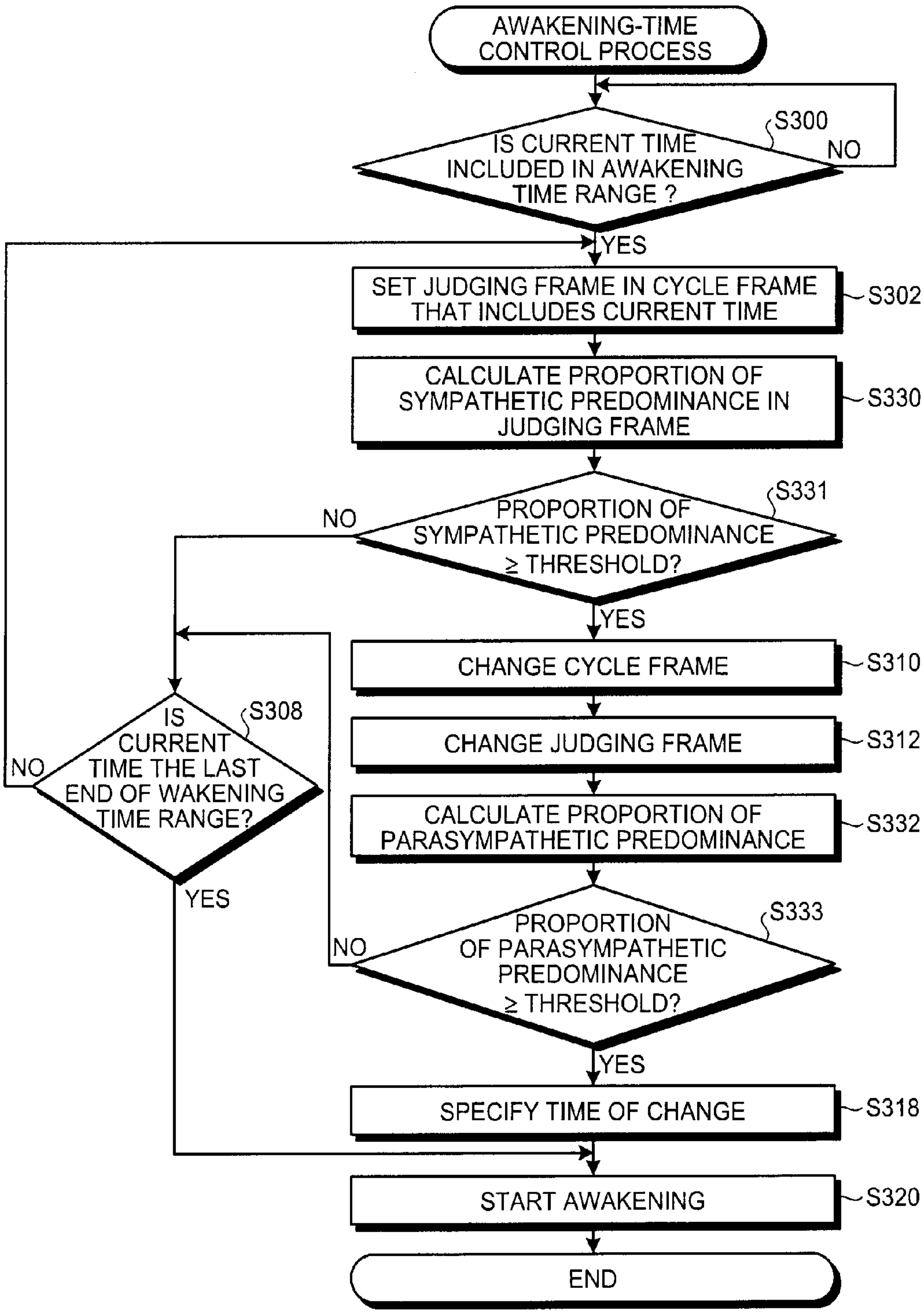

PREDOMINANCE JUDGING PROCESS
SET CYCLE FRAME
S200
PLOT AUTONOMIC-NERVOUS INDEX AND PULSE VARIATION ASSOCIATED WITH IDENTICAL DETECTING TIME ON SCATTER PLOT
S202
IS THERE AWAKENING DATA ASSOCIATED WITH IDENTICAL DETECTING TIME?
S204
NO
YES
REMOVE CORRESPONDING PLOT
S206
ARE ALL SETS OF DATA PLOTTED ON SCATTER PLOT?
S208
NO
YES
JUDGE SLEEP STATE BY CLUSTERING PLOTS
S210
GROUP PLOTS INTO TWO CLUSTERS
S212
ASSIGN CLUSTER ID TO EACH PLOT
S214
ASSIGN CLUSTER ID INDICATING AWAKENING DATA TO PLOTS NOT ASSIGNED CLUSTER ID
S216
SORT PLOTS IN TIME SERIES
S218
JUDGE WHETHER SYMPATHETIC OR PARASYMPATHETIC IS PREDOMINANT ACCORDING TO CLUSTER ID
S230
END

FIG.15


AWAKENING-TIME CONTROL PROCESS
IS CURRENT TIME INCLUDED IN AWAKENING TIME RANGE ?
S300
NO
YES
SET JUDGING FRAME IN CYCLE FRAME THAT INCLUDES CURRENT TIME
S302
CALCULATE PROPORTION OF SYMPATHETIC PREDOMINANCE IN JUDGING FRAME
S330
PROPORTION OF SYMPATHETIC PREDOMINANCE ≥ THRESHOLD?
S331
NO
YES
CHANGE CYCLE FRAME
S310
CHANGE JUDGING FRAME
S312
CALCULATE PROPORTION OF PARASYMPATHETIC PREDOMINANCE
S332
PROPORTION OF PARASYMPATHETIC PREDOMINANCE ≥ THRESHOLD?
S333
NO
YES
IS CURRENT TIME THE LAST END OF WAKENING TIME RANGE?
S308
NO
YES
SPECIFY TIME OF CHANGE
S318
START AWAKENING
S320
END

AUTONOMIC-NERVOUS STATE JUDGING DEVICE, AUTONOMIC-NERVOUS STATE JUDGING METHOD, AND COMPUTER PROGRAM PRODUCT

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based upon and claims the benefit of priority from the prior Japanese Patent Application No. 2006-250059 filed on Sep. 14, 2006 and the prior Japanese Patent Application No. 2007-210601 filed on Aug. 13, 2007; the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to an autonomic-nervous state judging device, an autonomic-nervous state judging method, and a computer program product.

[0004] 2. Description of the Related Art

[0005] To measure stages of sleep, there is a known technology in which brain waves, eyeball movement, electromyographic activity and the like are recorded by using sleep polygraphs. There is another known technology in which pulse fluctuation is analyzed based on pulse intervals to determine the state of autonomic nervous system. For example, JP-A H7-143972 (KOKAI) discloses a technology for judging sleep state based on sympathetic and parasympathetic activities. JP-A 2005-152310 (KOKAI) discloses a technology in which the sleep stage of a subject is detected in real time by using information such as pulse fluctuation of the subject lying on an air mattress.

[0006] It is said that if a person is woken up at the later stage of rapid eye movement (REM) sleep, the person feels fresh. Therefore, it is preferred that a person be awakened at the later stage of REM sleep. Thus, there is a demand for a technology of controlling awakening time according to the state of autonomic nervous system such as sleep state.

[0007] In such awakening control, it is necessary to specify timing of a change in the state of autonomic nervous system. However, the state of autonomic nervous system substantially fluctuates, and it is difficult to accurately specify timing of a change in its state.

SUMMARY OF THE INVENTION

[0008] According to an aspect of the present invention, an autonomic-nervous state judging device includes a measuring unit that measures, at regular intervals, an autonomic-nervous index that indicates state of autonomic nervous system of a subject in a sleep state, a first setting unit that sets a plurality of cycle frames of a first time length, each of which includes one sleep cycle, at intervals shorter than the first time length, a second setting unit that sets a judging frame of a second time length shorter than the first time length at a predetermined position in each of the cycle frames, a specifying unit that specifies state of autonomic nervous system in the judging frame based on the autonomic-nervous index in corresponding one of the cycle frames, and a detecting unit that detects time of a change in the state of autonomic nervous system specified by the specifying unit.

[0009] According to another aspect of the present invention, an autonomic-nervous state judging method includes measuring, at regular intervals, an autonomic-nervous index that indicates state of autonomic nervous system of a subject in a sleep state, setting a plurality of cycle frames of a first time length, each of which includes one sleep cycle, at intervals shorter than the first time length, setting a judging frame of a second time length shorter than the first time length at a predetermined position in each of the cycle frames, specifying unit state of autonomic nervous system in the judging frame based on the autonomic-nervous index in corresponding one of the cycle frames, and detecting time of a change in the state of autonomic nervous system specified at the specifying.

[0010] According to still another aspect of the present invention, a computer program product includes a computer program that implements the above methods on a computer.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is a block diagram of an autonomic-nervous state judging system according to a first embodiment of the present invention;

[0012] FIG. **2** is an example of how an autonomic-nervous state judging device is attached to a subject;

[0013] FIG. **3** is a schematic diagram for explaining a process performed by an autonomic-nervous index calculator shown in FIG. **1**;

[0014] FIG. **4** is a graph for explaining a process performed by a cycle frame setting unit shown in FIG. **1**;

[0015] FIG. **5** is a schematic diagram for explaining a judging frame;

[0016] FIG. **6** is a graph of autonomic-nervous indices obtained during a sleep state of a subject;

[0017] FIG. **7** is a flowchart of a process procedure of awakening a subject according to the first embodiment;

[0018] FIG. **8** is a detailed flowchart of a sleep-state judgment process shown in FIG. **7**;

[0019] FIG. **9** is a detailed flowchart of an awakening-time control process shown in FIG. **7**;

[0020] FIG. **10** is a schematic for explaining a process performed by a change-timing detecting unit shown in FIG. **1**;

[0021] FIG. **11** is a block diagram of a hardware configuration of the autonomic-nervous state judging device;

[0022] FIG. **12** is a block diagram of an autonomic-nervous state judging system according to a second embodiment of the present invention;

[0023] FIG. **13** is a flowchart of a process procedure of awakening a subject according to the second embodiment;

[0024] FIG. **14** is a detailed flowchart of an predominance judgment process shown in FIG. **13**; and

[0025] FIG. **15** is a detailed flowchart of an awakening-time control process shown in FIG. **13**.

DETAILED DESCRIPTION OF THE INVENTION

[0026] Exemplary embodiments of the present invention are explained in detail below with reference to the accompanying drawings.

[0027] FIG. **1** is a block diagram of an autonomic-nervous state judging system **1** according to a first embodiment of the present invention. The autonomic-nervous state judging system **1** detects timing of changes in a sleep state of a subject, and awakens a subject based on the changes.

[0028] The autonomic-nervous state judging system **1** includes an autonomic-nervous state judging device **100** and a sensor head **200**. The autonomic-nervous state judging device **100** includes an input unit **102**, a display unit **104**, a storage unit **106**, a power supply unit **108**, a clock **110**, a control unit **120**, a movement-rate measuring unit **122**, a pulse measuring unit **124**, a light-source driving unit **126**, a pulse-interval calculator **130**, an autonomic-nervous index calculator **132**, a pulse-variation calculator **134**, a body-movement judging unit **136**, an awakening judging unit **138**, a cycle-frame setting unit **140**, a judging-frame setting unit **142**, a sleep-state judging unit **144**, a change-timing detecting unit **146**, an awakening-time setting unit **150**, an awakening-range setting unit **152**, an awakening control unit **154**, a speaker **160**, and a vibrator **162**. The sensor head **200** includes a light source **202** and a photoreceptor **204**.

[0029] FIG. **2** is an example of how the autonomic-nervous state judging device **100** is attached to a subject. The autonomic-nervous state judging device **100** can be worn on a wrist like a wristwatch, and in this case, the sensor head **200** for measuring pulse is worn, for example, on a little finger.

[0030] The input unit **102** is a switch that is used by a user to switch the power ON/OFF and to provide requests or instructions to change display. The display unit **104** includes, for example, a liquid crystal display (LCD), and displays various types of information such as a result of sleep state judgment.

[0031] The storage unit **106** stores therein measurement data such as pulse data, electrocardiographic data, and body movement data. The storage unit **106** further stores therein data that are obtained after various processes such as pulse interval data, and pulse variation data, and a threshold value used to judge the state of sleep. The storage unit **106** can be a flash memory or the like. The power supply unit **108** is a battery that supplies power to the autonomic-nervous state judging device **100**. The clock **110** is a timer, specifically, a real-time clock integrated circuit and the like.

[0032] The control unit **120** controls measuring time, and stores and processes received data. The movement-rate measuring unit **122** measures the rate of body movement to obtain analog movement rate data and converts the analog data to digital data. The movement-rate measuring unit **122** is a sensor that senses body movements in three axial directions of −2 g to 2 g, and is mounted on the autonomic-nervous state judging device **100**. Specifically, the analog data is converted through a 10-bit analog-to-digital (A/D) converter to digital data after adjustment of gain and offset of the analog data through an adjusting circuit. The movement-rate measuring unit **122** outputs the digital data to the control unit **120**.

[0033] The sensor head **200** includes, for example, a blue light emitting diode as the light source **202** and a photo diode as the photoreceptor **204**. The sensor head **200** irradiates the skin surface of a subject with light, and detects changes that occur in reflected light due to changes in blood flow in capillaries.

[0034] The pulse measuring unit **124** measures pulse of a subject to obtain analog data, and converts the analog data to digital data. Specifically, the pulse measuring unit **124** converts electric current output from the photo diode of a pulse sensor, that is, the sensor head **200**, into voltage through a current-to-voltage converter. The pulse measuring unit **124** amplifies the voltage with an amplifier, and, after filtering it with a high-pass filter (cutoff frequency: 0.1 Hz) and a low-pass filter (cutoff frequency: 50 Hz), converts the analog data to digital data through the 10-bit A/D converter. Pulse data after conversion is output to the control unit **120**. The light-source driving unit **126** drives the light source **202**. The pulse-interval calculator **130** calculates pulse interval data from the pulse data obtained by the pulse measuring unit **124**. The pulse-interval data is data on time intervals in one pulse cycle. Specifically, the pulse-interval calculator **130** takes a sample of pulse data from the pulse measured by the pulse measuring unit **124**. The pulse-interval calculator **130** differentiates the sampled pulse data with respect to time to derive direct current (DC) fluctuation component in the pulse data, and eliminates the DC fluctuation component from the pulse data.

[0035] After the removal of the DC fluctuation component, the pulse-interval calculator **130** acquires the maximum value and the minimum value of the pulse data during a period of approximately one second before and after a processing point in the pulse data. A value between the maximum value and the minimum value is set as a pulse interval threshold. For example, with a difference between the maximum value and the minimum value defined as amplitude, a value of 90% of the amplitude from the minimum value is used as the pulse interval threshold. The pulse-interval calculator **130** also detects the time when a sequence of pulses with an interval that matches the pulse interval threshold appears, and obtains pulse interval data.

[0036] The pulse interval data is unequally spaced data, and to be converted to an equally spaced data for performing frequency analysis. The pulse-interval calculator **130** performs interpolation of the unequally spaced data, and performs resampling to generate equally spaced pulse interval data. For example, the pulse-interval calculator **130** generates equally spaced pulse interval data by using three sampling points around a point of interpolation according to a third-order polynomial interpolation technique.

[0037] The autonomic-nervous index calculator **132** calculates two autonomic-nervous indices for judging a sleep state of a subject. The two autonomic-nervous indices are a low-frequency (LF) index in a low-frequency area of about 0.05 Hz to 0.15 Hz and a high-frequency (HF) index in a high-frequency area of about 0.15 Hz to 0.4 Hz.

[0038] FIG. **3** depicts graphs for explaining a process performed by the autonomic-nervous index calculator **132**, in which equally spaced pulse interval data is converted into a frequency spectral distribution through fast Fourier transform (FFT) method. The autonomic-nervous index calculator **132** acquires the autonomic-nervous indices LF and HF from the frequency spectral distribution. Specifically, the autonomic-nervous index calculator **132** acquires the autonomic-nervous indices LF and HF by taking arithmetic average of total of three points, i.e., a peak value of a plurality of power spectra, and points before and after the peak value at even intervals from the peak value.

[0039] From the point of view of reducing load of data processing, the FFT method is used in the embodiment as a frequency analyzing method. However, other methods such as autoregressive (AR) model, maximum entropy method, wavelet method can be used.

[0040] The pulse-variation calculator **134** calculates pulse variation in the pulse data obtained by the pulse measuring unit **124**. The pulse variation is a second-by-second variation in the pulse of a subject within one minute. The body-movement judging unit **136** differentiates the three-axial direction movement rate data obtained by the movement-rate measuring unit **122**, with respect to time, and obtains a differential coefficient thereof. The body-movement judging unit **136** obtains variation in body movement and the amount of body movement. The variation in body movement is represented by a square-root of sum of squares of the differential coefficient of each movement rate in three axial directions. The amount of body movement is represented by an average of variations in body movement during a pulse interval. When the variation in body movement is larger than a predetermined threshold, the body-movement judging unit **136** judges that body movement has occurred. For example, the minimum value of 0.01 G (gravity), used to measure minute body movement, is used as the predetermined threshold.

[0041] The awakening judging unit **138** judges that a subject is awake when frequency of occurrence of body movement is equal to or higher than a predetermined threshold. The awakening judging unit **138** judges that a subject is sleeping when frequency of occurrence of body movement is lower than the predetermined threshold. For example, from frequency of occurrence of body movement in the past awakening state, **20** times/minute is preferably used as the predetermined threshold. Specifically, the awakening judging unit **138** acquires information about occurrence of body movement from the body-movement judging unit **136**, and calculates frequency of occurrence of body movement in a set interval zone.

[0042] The cycle-frame setting unit **140** sets a cycle frame, that is, a time interval or a time frame including one cycle of sleep (hereinafter, "sleep cycle"). Length of the one sleep cycle is about 90 minutes to 120 minutes. Accordingly, the cycle-frame setting unit **140** can set the cycle frame to, for example, 120 minutes or 90 minutes. The length of the cycle frame is cited above by way of example, and the cycle frame can be set to any length as long as it includes the sleep cycle. In the following example, the cycle-frame setting unit **140** sets a time period of past 120 minutes from the current time as a cycle frame.

[0043] As shown in FIG. **4**, if measuring of the autonomic-nervous index starts at 23:00 o'clock, a time period from 23:00 o'clock to 01:00 o'clock is set as a cycle frame. During the time period of the cycle frame autonomic-nervous indices are measured continuously. The cycle frame setting unit **140** sets cycle frames at a setting interval of, for example, one minute. Specifically, at 01:01 o'clock, the cycle frame setting unit **140** sets a time period of 120 minutes from 23:01 o'clock to 01:01 o'clock as a cycle frame. The setting interval can be set to any length as long as it is shorter than the cycle frame. It is preferred that the setting interval be shorter as compared to a judging frame, which is described at a later stage.

[0044] Referring back to FIG. **1**, the judging-frame setting unit **142** sets a judging frame, which is a time frame to judge a change in sleep state of a subject. A time length of the judging frame is set in advance, and the judging frame is, for example, a rearmost portion of the cycle frame.

[0045] In an example of FIG. **5**, a judging frame is set in a cycle frame from 23:00 o'clock to 01:00 o'clock. That is, the judging frame is a time frame of seven minutes ending at 01:00 o'clock. A judging frame set in a cycle frame from 23:01 o'clock to 01:01 o'clock is of a time frame of seven minutes ending at 01:01 o'clock. Thus, a relative position of a judging frame in a cycle frame is set in advance. When a cycle frame is set, an absolute position of a judging frame is specified based on the relative position.

[0046] For example, when a judging frame of seven minutes is to be set at the rearmost portion of a cycle frame, and when the cycle-frame setting unit **140** sets a cycle frame from 23:00 o'clock to 01:00 o'clock, the judging-frame setting unit **142** sets a judging frame from 00:53 o'clock to 01:00 o'clock. The judging frame is only required to be a time frame whose relative position in a cycle frame is set in advance, and need not be a time frame that is at a rearmost portion of the cycle frame.

[0047] When the cycle frame setting unit **140** sets cycle frames at a setting interval of one minute, the judging-frame setting unit **142** sets judging frames in the cycle frames at one minute time interval.

[0048] The sleep-state judging unit **144** judges a sleep state of a subject as state of autonomic nervous system of the subject based on autonomic-nervous indices LF and HF calculated by the autonomic-nervous index calculator **132** and pulse variation calculated by the pulse-variation calculator **134**. As the sleep state, depth of sleep is calculated. The depth of sleep is an index indicating brain activity of a subject. In the first embodiment, the sleep-state judging unit **144** judges a sleep state of a subject based on non-rapid eye movement (NREM) sleep or rapid eye-movement (REM) sleep.

[0049] REM sleep or NREM sleep, as shown in FIG. **6**, is differentiated according to a magnitude correlation between the autonomic-nervous indices and a threshold. In an example shown in FIG. **6**, there is a gradual increase in values of the autonomic-nervous indices corresponding to REM sleep and NREM sleep as time passes. This happens due to circadian rhythm. When a base of the autonomic-nervous indices increases, if all autonomic-nervous indices are used to judge whether a subject is in a state of REM sleep or NREM sleep, there is high possibility of misjudgment.

[0050] In addition, the autonomic-nerve indices are likely to vary according to an individual. Therefore, if values of autonomic-nervous indices during a time period from 23:00 o'clock to 05:00 o'clock are used to judge a sleep state of a subject, it is not possible to determine the sleep state accurately.

[0051] According to the embodiment, the sleep-state judging unit **144** judges sleep state at a plurality of points of time using autonomic-nervous indices only from a judging frame in a cycle frame. Thus, influence of the circadian rhythm is eliminated, and it is possible to judge sleep state accurately.

[0052] The change-timing detecting unit **146** detects timing of a change in sleep state based on sleep state in each of judging frames judged by the sleep-state judging unit **144**.

[0053] The awakening-time setting unit **150** sets awakening time according to an instruction from a subject. The awakening-range setting unit **152** sets an awakening time range. The term "awakening time range" as used herein refers to a range of a time period predetermined based on the awakening time. The awakening time range is, for example, two hours.

[0054] More specifically, the awakening-range setting unit **152** holds a predetermined range of time period, and determines the predetermined range as the awakening time range based on the awakening time set by the awakening-time setting unit **150**.

[0055] In the embodiment, the awakening-range setting unit **152** determines the awakening time range to a predetermined time period earlier than the awakening time set by the awakening-time setting unit **150**. However, the awakening time range is not limited to the above-mentioned range.

[0056] It is possible to set the awakening time range to a predetermined time period later than the awakening time. It is also possible to set the awakening time range to a predetermined time period with the awakening time at the middle of the time period.

[0057] The awakening control unit **154** determines time to start the speaker **160** and the vibrator **162**, and starts the speaker **160** and the vibrator **162** at the time. The speaker **160** outputs alarm sound, and the vibrator **162** generates vibrations to awaken a subject. Thus, the awakening control unit **154** controls an environment around a subject by starting the speaker **160** and the vibrator **162** at the awakening time.

[0058] FIG. **7** is a flowchart of an awakening process performed by the autonomic-nervous state judging system **1**. A subject wears the autonomic-nerve condition judging system **1** before falling asleep, and switches it ON to start up the awakening function through the input unit **102**. The subject specifies a time. Accordingly, the awakening-time setting unit **150** sets the time as awakening time. The movement-rate measuring unit **122** starts measuring the rate of body movement (step S**100**). The pulse measuring unit **124** starts measuring the pulse (step S**120**).

[0059] The movement-rate measuring unit **122** measures the rate of body movement to obtain movement rate data that indicates body movements in three axial directions. The body-movement judging unit **136** obtains body movement data from the movement rate data acquired by the movement-rate measuring unit **122**. When the variation in body movement is larger than a predetermined threshold, the body-movement judging unit **136** judges that body movement has occurred (step S**102**). When body movement has occurred (Yes at step S**104**), the awakening judging unit **138** judges whether the subject is awake or asleep (step S**106**). When the subject is awake (Awake at step S**108**), the awakening judging unit **138** causes the storage unit **106** to store therein time of falling asleep, awakening time and the number of times the subject woke up during sleep. The awakening judging unit **138** also displays the time of falling asleep, the awakening time and the number of times the subject woke up during sleep on the display unit **104** (step S**110**).

[0060] On the other hand, when the pulse measuring unit **124** starts measuring the pulse, the pulse-interval calculator **130** calculates a pulse interval threshold, which is a dynamic threshold for calculating a pulse interval (step S**122**). From pulse data in which DC fluctuation component has been eliminated, the pulse-interval calculator **130** detects the time when a sequence of pulses with an interval that matches the pulse interval threshold appears, and obtains pulse interval data (step S**124**).

[0061] The pulse-interval calculator **130** saves the pulse interval data (step S**130**) only when there is no body movement (No at step S**104**) and the subject is in a state of sleep (Sleep at step S**108**).

[0062] The pulse-interval calculator **130** converts the pulse interval data to a frequency spectral distribution according to a frequency analysis method such as FFT method (step S**132**). The autonomic-nervous index calculator **132** calculates autonomic-nervous indices LF and HF from a plurality of power spectra values in the pulse interval data that has been converted into a frequency spectral distribution at step S**132** (step S**150**). The pulse-variation calculator **134** calculates pulse variation (step S**151**). The autonomic-nervous indices LF and HF, and the pulse variation are associated with time of their detection and stored in the storage unit **106**.

[0063] The sleep-state judging unit **144** performs a sleep-state judgment process (step S**152**), i.e., judges sleep state based on the autonomic-nervous indices LF and HF and the pulse variation. The sleep-state judging unit **144** stores the sleep state associated with time of detection in the storage unit **106**. The display unit **104** displays the sleep state (step S**154**), and amount of body movement during sleep (step S**156**). The awakening control unit **154** performs awakening-time control process (step S**160**), and the process ends.

[0064] The sleep-state judgment process performed at step S**152** of FIG. **7** is explained in detail with reference to FIG. **8**. The cycle-frame setting unit **140** sets a cycle frame (step S**200**). The cycle-frame according to the embodiment is of **120** minutes. Therefore process procedure from step S**202** to step S**206** is performed with respect to data obtained during a period of 120 minutes.

[0065] The autonomic-nervous indices LF and HF obtained at step S**150** and the pulse variation obtained at step S**151** each stored in association with an identical detection time are plotted in plane coordinates of a scatter plot (step S**202**). If the storage unit **106** stores therein awakening data associated with a detection time identical to the detection time corresponding to the plot (Yes at step S**204**), the plot is removed from the scatter plot (step S**206**). Thus, it is possible to judge sleep state of the subject from the data obtained only when the subject is in a state of sleep. Therefore, sleep state can be judged more accurately.

[0066] In the plane coordinate, X coordinate represents LF/HF, and Y coordinate represents pulse variation. It is also possible that X coordinate represents LF and Y coordinate represents HF. Steps S**202** to S**206** are repeated until all data are plotted on the scatter plot (Yes at step S**208**). In the embodiment, 120 sets of data (data plots) are plotted on the scatter plot.

[0067] The state of sleep is judged by clustering the data plots on the scatter plot (step S**210**). Specifically, the data plots are grouped into two clusters using K-means algorithm (step S**212**). A cluster whose center is closer to the origin of the plane coordinate is assigned cluster identifier (ID) **1** as a first cluster. A cluster whose center is away from the origin of the plane coordinate is assigned cluster ID **2** as a second cluster. K-means algorithm is used in the embodiment for clustering to reduce load of data processing. However, it is possible to use other methods such as fuzzy c-means (FCM) method, and entropy method.

[0068] A cluster ID is assigned to data plotted on the scatter plot (step S**214**). A data plot not assigned a cluster ID is assigned a cluster ID indicating awakening data (step S**216**). Total of 100 data plots each assigned a cluster ID are sorted in time series (step S**218**).

[0069] Sleep state is judged according to cluster IDs, which have been assigned to the sorted data plots (step S**220**). Specifically, sleep state during the detection time corresponding to data that is assigned cluster ID **1** is judged as NREM sleep. Sleep state during the detection time corresponding to data that is assigned cluster ID **2** is judged as REM sleep. Thus, clustering makes it possible to judge sleep state accurately.

[0070] When 120 minutes of cycle frames are set at setting intervals of one minute, a particular point of time is included in a plurality of cycle frames. In such a case, different judgments can be derived in the respective cycle frames for that particular point of time. From the point of view of real-time performance, it is desirable that the judgment be derived from a cycle frame in which the particular point of time is at the rearmost end thereof. In other words, after elapse of a predetermined period of time, sleep state at a particular point of time is judged based on a cycle frame that ends the particular point of time.

[0071] The awakening-time control process performed at step S**160** of FIG. **7** is explained in detail with reference to FIG. **9**. If the current time is within an awakening time range preset based on awakening time (Yes at step S**300**), the judging-frame setting unit **142** sets a judging frame in a cycle frame that includes the current time (step S**302**). If the current time is, for example, 07:00 o'clock, a judging frame of seven minutes from 06:53 o'clock to 07:00 o'clock is set in a cycle frame of 120 minutes ending at 07:00 o'clock. The change-timing detecting unit **146** calculates the proportion of REM sleep in the judging frame set by the judging-frame setting unit **142** (step S**304**). Sleep state is specified every one minute in the judging frame as shown in FIG. **10**. Because the judging frame is of seven minutes, seven judgment results are obtained.

[0072] Referring back to FIG. **9**, if the proportion of REM sleep is equal to or larger than a threshold from the judgment results in the judging frame (Yes at step S**306**), it is judged that the subject is currently in REM sleep and is yet to enter NREM sleep. The threshold is set in advance, for example, to 60%. The threshold can be arbitrary, and need not be limited to 60%.

[0073] If the proportion of REM sleep is smaller than the threshold from the judgment results in the judging frame (No at step S**306**), the judging-frame setting unit **142** judges whether the current time is the last end of the awakening time range or not (step S**308**). If the current time is the last end of the awakening time range (Yes at step S**308**), the awakening control unit **154** starts awakening process (step S**320**). On the other hand, if the current time is not the last end of the awakening time range (No at step S**308**), the process control returns to step S**302** and the judging-frame setting unit **142** sets a judging frame.

[0074] After one minute, the cycle frame is changed (step S**310**), and the judging frame is also changed (step S**312**). That is, both the cycle frame and the judging frame are delayed by one minute. When a judging frame ending at 07:00 o'clock is set at step S**302**, a cycle frame and a judging frame are respectively set at steps S**310** and S**312** such that both the frames end at 07:01 o'clock.

[0075] The proportion of NREM sleep in the judging frame set at step S**312** is calculated (step S**314**). If the proportion of NREM sleep is equal to or larger than the threshold (Yes at step S**316**), the change-timing detecting unit **146** specifies the current time as a time when sleep state has changed from REM sleep to NREM sleep (step S**318**). This threshold is identical to the threshold used at step S**306**. However, it is possible to set different thresholds to check the proportion of REM sleep and NREM sleep. The awakening control unit **154** starts awakening process (step S**320**).

[0076] If the proportion of NREM sleep is smaller than the threshold (No at step S**316**), i.e., the subject is judged to already be in REM sleep, the judging-frame setting unit judges whether the current time is the last end of the awakening time range or not (step S**308**). If the current time is not the last end of the awakening time range (No at step S**308**), the process control returns to step S**302** and the judging-frame setting unit **142** sets the judging frame and the cycle frame.

[0077] Further, if all judgment results of step S**306**, S**308** and S**316** are YES, the starting awakening process (step S**320**) is eventually performed, and the awakening-time control process ends (step S**160**).

[0078] As another example, if the proportion of REM sleep is smaller than the threshold (No at step S**306**), it is also allowable to wait until the sleep state of the subject changes from NREM sleep to REM sleep. In this case, after the subject has entered REM sleep, timing of a change from REM sleep to NREM sleep is specified by the process from step S**310** to step S**318**. Awakening is started at this timing.

[0079] As described above, with reference to changes in the proportion of NREM sleep and REM sleep in judgment frames, it is possible to accurately specify timing of a change from REM sleep to NREM sleep.

[0080] According to experiments conducted on different subjects, it is found that if a person is awakened at the timing of the change from REM sleep to NREM sleep, the person wakes up in a comfortable manner. Therefore, in the first embodiment, awakening is started at the time the sleep state has changed from REM sleep to NREM sleep. Thus, a person can be awakened in a comfortable manner.

[0081] FIG. **11** is a block diagram of a hardware configuration of the autonomic-nervous state judging device **100**. As shown in FIG. **11**, the autonomic-nervous state judging device **100** includes a read-only memory (ROM) **52**, a central processing unit **51**, a random access memory (RAM) **53**, a communication interface **57**, and a bus **62**. The ROM **52** stores therein computer programs such as a sleep state judging program for the sleep-state judgment process and executes the computer programs to perform various processes. The central processing unit **51** controls the autonomic-nervous state judging device **100** according to the computer programs stored in the ROM **52**. The RAM **53** stores therein various types of data necessary to control the autonomic-nervous state judging device **100**. The communication interface **57** is connected to a network for communication. The bus **62** connects each of the parts.

[0082] The sleep-state judgment program can be provided as being stored in a portable physical medium, such as a flexible disk (FD), a compact disc-read only memory (CD-ROM), and a digital versatile disk (DVD).

[0083] The sleep-state judgment program is read from the above-mentioned storage medium and is loaded into a main storing device of a computer to be executed thereon. Thus, each unit explained above can be implemented on the main storing device.

[0084] The sleep-state judgment program can be downloaded from another computer that is connected to the computer through a network such as the Internet, and executed by the computer.

[0085] According to a second embodiment of the present invention, an autonomic-nervous state judging system **2** controls awakening based on sympathetic or parasympathetic predominance. As shown in FIG. **12**, an autonomic-nervous state judging device **101** in the autonomic-nervous state judging system **2** includes a predominance judging unit **170** in place of the sleep-state judging unit **144**.

[0086] The predominance judging unit **170** judges whether sympathetic or parasympathetic is predominant as the state of the autonomic nervous system based on the autonomic-nervous indices LF and HF and pulse variation. The awakening control unit **154** controls awakening based on the judgment by the predominance judging unit **170**.

[0087] FIG. **13** is a flowchart of an awakening process according to the second embodiment. First, the autonomic-nervous index calculator **132** calculates the autonomic-nervous indices LF and HF, and the pulse-variation calculator **134** calculates pulse variation. Next, the predominance judging unit **170** performs a predominance judgment process to judge whether sympathetic or parasympathetic is predominant based on the autonomic-nervous indices LF and HF and the pulse variation (step S**170**). In the awakening-time control process (step S**160**), awakening is started based on the judgment by the predominance judging unit **170**.

[0088] The predominance judgment process performed at step S**170** of FIG. **13** is explained in detail with reference to FIG. **14**. In the process from step S**200** to step S**218** in the predominance judgment process, data plots for each time unit are grouped into two clusters, and the data plots are each assigned a cluster ID. Incidentally, the process from step S**200** to step S**218** is identical to the process from step S**200** to step S**218** in FIG. **8** previously described for the sleep-state judgment process in the first embodiment.

[0089] At a detection time corresponding to data that is assigned cluster ID **1**, it is judged that parasympathetic is predominant. At a detection time corresponding to data that is cluster ID **2**, it is judged that sympathetic is predominant (step S**230**).

[0090] The awakening-time control process performed at step S**160** of FIG. **13** is explained in detail with reference to FIG. **15**. When the current time is within an awakening time range preset based on awakening time (Yes at step S**300**), the judging-frame setting unit **142** sets a judging frame in a cycle frame that includes the current time (step S**302**). The change-timing detecting unit **146** calculates the proportion of sympathetic predominance in the judging frame set by the judging-frame setting unit **142** (step S**330**).

[0091] If the proportion of sympathetic predominance is equal to or larger than a threshold (Yes at step S**331**), it is judged that sympathetic is currently predominant, and a shift from sympathetic to parasympathetic predominance has not occurred.

[0092] After one minute, a cycle frame is changed (step S**310**), and the judging frame is also changed (step S**312**). The proportion of parasympathetic predominance in the judging frame is calculated (step S**332**). If the proportion of parasympathetic predominance is equal to or larger than a threshold (Yes at step S**316**), the change-timing detecting unit **146** specifies the current time as a time at which a shift from sympathetic to parasympathetic predominance has occurred (step S**318**). The awakening control unit **154** starts awakening process (step S**320**), and the awakening-time control process ends (step S**160**).

[0093] The autonomic-nervous state judging system **2** has otherwise the same configuration and operates in a similar manner as the autonomic-nervous state judging system **1**.

[0094] Incidentally, the above-described embodiments are susceptible of various modifications. For example, awakening time can be controlled by detecting the timing of a change from NREM sleep to REM sleep. In the same manner, awakening time can be controlled by detecting the timing of a shift from parasympathetic to sympathetic predominance.

[0095] In addition, audio output and a vibrator are cited for use in awakening a subject by way of example and without limitation. Instead, a subject can be awakened by using an electric current or a scent. A subject can also be awakened by plying music or by controlling light at awakening time. It is also possible to control the environment in which a subject is awakened by controlling air temperature, humidity, air pressure and the like. The environment can also be controlled by generating high concentration of oxygen to activate a subject. A subject can be stimulated with heat according to the season.

[0096] Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

What is claimed is:

1. An autonomic-nervous state judging device comprising:

a measuring unit that measures, at regular intervals, an autonomic-nervous index that indicates state of autonomic nervous system of a subject in a sleep state;

a first setting unit that sets a plurality of cycle frames of a first time length, each of which includes one sleep cycle, at intervals shorter than the first time length;

a second setting unit that sets a judging frame of a second time length shorter than the first time length at a predetermined position in each of the cycle frames;

a specifying unit that specifies state of autonomic nervous system in the judging frame based on the autonomic-nervous index in corresponding one of the cycle frames; and

a detecting unit that detects time of a change in the state of autonomic nervous system specified by the specifying unit.

2. The device according to claim **1**, wherein the second setting unit sets the judging frame such that an end of the judging frame corresponds to a latest time in each of the cycle frames.

3. The device according to claim **1**, wherein the specifying unit specifies the state of autonomic nervous system at different time points at predetermined intervals in the judging frame.

4. The device according to claim **1**, wherein

the specifying unit specifies the state of autonomic nervous system based on continuity of predetermined state of autonomic nervous system in the judging frame, and

the detecting unit detects the time of a change in the state of autonomic nervous system based on a proportion of the predetermined state.

5. The device according to claim **4**, wherein

the specifying unit specifies any one of non rapid eye-movement sleep state and rapid eye-movement sleep state as the state of autonomic nervous system based on continuity of the sleep state, and the detecting unit detects time of a change from the non rapid eye-movement sleep state to the rapid eye-movement sleep state when a proportion of rapid eye-movement sleep in the judging frame exceeds a threshold.

6. The device according to claim **4**, wherein

the specifying unit specifies any one of non rapid eye-movement sleep state and rapid eye-movement sleep state as the state of autonomic nervous system based on continuity of the sleep state, and

the detecting unit detects time of a change from the rapid eye-movement sleep state to the non rapid eye-movement sleep state when a proportion of non rapid eye-movement sleep in the judging frame exceeds a threshold.

7. The device according to claim **4**, wherein

the specifying unit specifies any one of sympathetic predominance state and parasympathetic predominance state as the state of autonomic nervous system based on continuity of the predominance state, and

the detecting unit detects time of a change from the parasympathetic predominance state to the sympathetic predominance state when a proportion of sympathetic predominance in the judging frame exceeds a threshold.

8. The device according to claim **4**, wherein

the specifying unit specifies any one of sympathetic predominance state and parasympathetic predominance state as the state of autonomic nervous system based on continuity of the predominance state, and

the detecting unit detects time of a change from the sympathetic predominance state to the parasympathetic predominance state when a proportion of parasympathetic predominance in the judging frame exceeds a threshold.

9. The device according to claim **1**, further comprising a control unit that controls environment around a subject based on detected time of a change in the state of autonomic nervous system.

10. The device according to claim **9**, wherein the control unit controls the environment by using at least one of light, sound, scent, temperature, humidity, pressure, electric current, voltage, heat, oxygen, and vibration.

11. An autonomic-nervous state judging method comprising:

measuring, at regular intervals, an autonomic-nervous index that indicates state of autonomic nervous system of a subject in a sleep state;

setting a plurality of cycle frames of a first time length, each of which includes one sleep cycle, at intervals shorter than the first time length;

setting a judging frame of a second time length shorter than the first time length at a predetermined position in each of the cycle frames;

specifying unit state of autonomic nervous system in the judging frame based on the autonomic-nervous index in corresponding one of the cycle frames; and

detecting time of a change in the state of autonomic nervous system specified at the specifying.

12. A computer program product comprising a computer usable medium having computer readable program codes embodied in the medium that, when executed, causes a computer to execute:

measuring, at regular intervals, an autonomic-nervous index that indicates state of autonomic nervous system of a subject in a sleep state;

setting a plurality of cycle frames of a first time length, each of which includes one sleep cycle, at intervals shorter than the first time length;

setting a judging frame of a second time length shorter than the first time length at a predetermined position in each of the cycle frames;

specifying unit state of autonomic nervous system in the judging frame based on the autonomic-nervous index in corresponding one of the cycle frames; and

detecting time of a change in the state of autonomic nervous system specified at the specifying.

* * * * *

专利名称(译)	自主神经状态判断装置，自主神经状态判断方法和计算机程序产品

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摘要(译)

自主神经状态判断装置以预定的时间间隔测量睡眠中受试者的自主神经指数。自主神经状态判断装置设定多个预定长度的循环帧，每个循环帧包括一个睡眠周期，以及在预定位置的循环帧中的判断帧。自主神经状态判断装置基于自主神经指标指定判断框架中的自主神经系统的状态，并检测自主神经系统状态的变化的定时。