(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 982 299 B1

(12) **EUROPEAN PATENT SPECIFICATION**

(45) Date of publication and mention of the grant of the patent:
08.08.2018 Bulletin 2018/32

(21) Application number: **14779903.5**

(22) Date of filing: **02.04.2014**

(51) Int Cl.:
A61B 5/08 *(2006.01)* ***A61B 5/103*** *(2006.01)*
A61B 5/0456 *(2006.01)* ***G06F 19/00*** *(2018.01)*

(86) International application number:
PCT/RU2014/000237

(87) International publication number:
WO 2014/163537 (09.10.2014 Gazette 2014/41)

(54) **METHOD FOR DETERMINING A PERSON'S SLEEPING PHASE WHICH IS FAVOURABLE FOR WAKING UP**

VERFAHREN ZUR BESTIMMUNG DER SCHLAFPHASE EINER AUFZUWECKENDEN PERSON

PROCÉDÉ POUR DÉTERMINER UNE PHASE DE SOMMEIL FAVORABLE À L'ÉVEIL

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR

(30) Priority: **05.04.2013 RU 2013116790**

(43) Date of publication of application:
10.02.2016 Bulletin 2016/06

(73) Proprietor: **Healbe Corporation**
Redwood City, CA 94063 (US)

(72) Inventors:
- **RUBIN, Mikhail Semenovich**
St.Petersburg
191119 (RU)
- **SVIRYAEV, Yury Vladimirovich**
St.Petersburg
196128 (RU)

(74) Representative: **Reichert & Lindner Partnerschaft Patentanwälte**
Bismarckplatz 8
93047 Regensburg (DE)

(56) References cited:
WO-A2-2007/143535
DE-A1- 4 209 336
JP-A- 2003 260 040
US-A- 5 280 791
US-A1- 2008 269 625

EP 2 982 299 B1

Description

FIELD OF INVENTION

[0001] The invention relates to the field of measurements of human condition parameters for diagnostic purposes, in particular to measurement of parameters characterizing human sleep.

BACKGROUND OF THE INVENTION

[0002] As is known, human sleep consists of alternating phases of the so-called non-REM and REM sleep. The above phases follow each other in cycles (typically from 4 to 6 cycles) during healthy human sleep. The experience has shown that the REM phase is the most favorable to awakening. However, a great many people wake up either to the signal of alarm clock set for a specific time, or are affected by other, random factors, which means their awakening not always occurs at an optimal sleep phase. Accordingly, to provide more comfortable living conditions for people, the development of simple, small and easy-to-use technical means designed to determine sleep phase optimal for awakening and providing control over wake-up devices generating a waking sound or other signal is important.

[0003] Various methods for determining human sleep phases, including those favorable to awakening, are known.

[0004] Medical studies have found that specific sleep phases can be identified with a sufficient confidence by registering various bioelectric signals, such as EEG characterizing the bioelectric activity of the brain, electromyogram reflecting muscle activity, or EOG characterizing changes in biopotential during eye movement. However, these methods are applicable only in healthcare institutions providing the assistance of specially trained personnel and cannot be used in everyday life. Furthermore, numerous internal and external factors affect human sleep, so one and the same person's sleep can proceed in different ways. Therefore, it becomes necessary that the phase favorable to awakening be determined for a given person on the basis of his/her current psychophysiological state and sleeping conditions.

[0005] Various methods and devices are known that are designed to awaken a person during a phase of sleep favorable thereto and based on current measurements of physiological parameters of the sleeping person.

[0006] Thus, patent RU 2061406 describes a method for waking up a person during a predetermined sleep phase. For this purpose, EEG is recorded during sleep by means of sensors to identify the current REM phase and the wake-up signal generated in a predetermined interval of time is synchronized with said EEG. EEG at REM sleep, according to the authors, is distinguished by desynchronization with the emergence of beta waves in the range of 18 Hz to 32 Hz and by low-amplitude mixed activity with theta waves present.

[0007] US Patent Application 20110230790 describes a method and device for waking up a person during a required sleep phase before a predetermined ultimate wake-up time, and for identifying the best time to go bed. REM phase is identified by the motor activity registered with accelerometer attached to human leg or arm.

[0008] US Patent Application 20050190065 describes a method for waking up a person in the sleep phase the most favorable thereto. According to the authors, REM phase is characterized by cardiac blood flow increase, poor thermoregulation of body (its temperature may rise or fall depending on the ambient temperature); vasoconstriction and reduction of vascular blood flow which can be measured by peripheral arterial blood pressure monitor; unstable and increased heart rate, blood pressure and respiratory rate.

[0009] The closest to the claimed invention is the method for waking up a person at optimal time within a preset period and during a favorable sleep phase, as described in patent DE 4,209,336. REM phase is identified by measuring heart rate, respiratory rate, bodily or head temperature, and detecting eye and body movements. Devices implementing said method can be made in the form of an armband, ear clip, chest belt, etc. A further close system and method for monitoring sleep cycles by monitoring cardiac and respiratory data, and to identify that a sleeping user is in an optimal sleep stage for awakening, such as light sleep or REM sleep, is described in US2008/0269625 A1. Additionally, a plurality of measured parameters, such as breathing patterns, heartbeat patterns, movement events and others, are weighted and combined for calculating a patient specific value F which is then compared to a predetermined reference value in order to detect pathophysiological deviations occuring during the night.

[0010] The analysis of known prior art shows that such devices are not capable of identifying the onset and termination of REM sleep with sufficient reliability or said devices create a practical inconvenience to a sleeping person due to a significant number of sensors attached to the person.

SUMMARY OF THE INVENTION

[0011] The task to be solved by the present invention is to provide a simple and reliable method for identifying a sleep phase favorable to awakening, i.e., REM sleep, and capable of being embodied a device easily attached onto a person and not disturbing person's sleep.

[0012] The method in accordance with the present invention enables the identification of human sleep phases favorable to awakening by registering a pulse wave signal and movement of human limbs using, respectively, a pulse wave sensor and at least one motion sensor attached onto a person during sleep, with said pulse wave signal serving as a basis for calculating the values RR intervals and respiratory rate; wherein the onset and termination of a sleep phase favorable to awakening are identified by function increment $F(\Delta t_i)$ whose values are determined over given time intervals Δt_i, where i is the serial number of the time interval; said function increments being expressed as:

$$F(\Delta t_i) = -K_1 P_1 - K_2 P_2 - K_3 P_3 + K_4 P_4 + K_5 P_5 + K_6 P_6, \quad (1)$$

where: P_1 is the mean value of RR intervals over time interval Δt_i ;

P_2 is the minimum value of RR intervals over time interval Δt_i ;

P_3 is the maximum value of RR intervals over time interval Δt_i ;

P_4 is standard deviation of RR intervals over the preceding time interval of 3-20 min;

P_5 is the mean value of respiratory rate over time interval Δt_i ;

P_6 is the average number of detected limb movements over the preceding period of 0.5 - 10 minutes;

K_1 - K_6 are weight coefficients characterizing the contribution of corresponding parameter P_1 - P_6 to function value $F(\Delta t_i)$.

[0013] The certainty and reliability of identification of sleep phase favorable to awakening is defined by the fact experimentally established by the inventors that selected parameters P_1 - P_6 are informative and allow, when combined, to identify the onset and termination of REM phase. On the other hand, all these parameters are determined solely by registering pulse wave signal and movements of human limbs, which requires such sensors that would not disturb human sleep when attached onto human body. Also important is the fact that the selected parameters are members of equation (1) with certain weight coefficients K_1 - K_6 which can also be determined experimentally, thus making it possible to obtain function values $F(\Delta t_i)$ which provide a reliable identification of the onset and termination of phase favorable to human awakening.

[0014] The limits of the time interval over which the values of parameter P_4 (standard deviation of RR intervals) are measured have been established experimentally, so:

if the time interval is less than 3 minutes, the probability of the so-called Type I error ("false alarm") grows unacceptably;

if the time interval is more than 20 minutes, the probability of the so-called Type II error ("missing the target") grows unacceptably.

[0015] The time interval during which the value of parameter P_4 is measured should be selected preferably in the range from 4 minutes to 6 minutes.

[0016] The limits of the time interval during which the value of parameter P_6 (mean value of respiratory rate) is measured have also been established experimentally, so:

if the time interval is less than 0.5 minutes, the probability of Type I error grows unacceptably;
if the time interval is more than 10 minutes, the probability of Type II error grows unacceptably.

[0017] The time interval during which the value of parameter P_6 is determined should be selected preferably in the range from 4 minutes to 6 minutes.

[0018] In particular, the following values of weight coefficients for healthy people have been experimentally determined:

for parameter P_1 measured in ms, the value of weight coefficient K_1 may be selected in the range from 0.6 ms^{-1} to 3ms^{-1}, preferably from 0.9 ms^{-1} to 1.05 ms^{-1};

for parameter P_2, measured in ms, the value of weight coefficient K_2 may be selected in the range from 0.1 ms^{-1} to

0.7 ms^{-1}, preferably from 0.1 ms^{-1} to 0.2 ms^{-1};

for parameter P_3, measured in ms, the value of weight coefficient K_3 may be selected in the range from 0.01 ms^{-1} to 0.3 ms^{-1}, preferably from 0.02 ms^{-1} to 0.05 ms^{-1};

for parameter P_4, measured in ms, the value of weight coefficient K_4 may be selected in the range from 0.5 ms^{-1} to 3 ms^{-1}, preferably from 1.3 ms^{-1} to 1.5 ms^{-1};

for parameter P_5, measured in min^{-1}, the value of weight coefficient K_5 may be selected in the range from 1 min to 10 min, preferably from 1.5 min to 2.3 min;

for parameter P_6 the value of weight coefficient K_6 can be selected in the range from 5 to 50, preferably from 18 to 24.

[0019] In particular implementations of the method, pulse wave may be registered using piezoelectric sensor, strain gage, or optical sensor fixed on the wrist or forearm, while the motion detector can be represented by an accelerometer fixed on the arm or leg.

[0020] Time intervals Δt_i may be selected in the range from 1 minute to 6 minutes.

[0021] In particular, the onset of sleep phase favorable to awakening is identified if the increment of function $F(\Delta t_i)$ over time period Δt_i exceeds a first preset threshold value.

[0022] In particular, the end of sleep phase favorable to awakening is identified if the increment of function $F(\Delta t_i)$ over time period Δt_i becomes less than a second preset threshold value.

BRIEF DESCRIPTION OF DRAWINGS

[0023] The invention is illustrated by the following graphic materials:

Fig 1 shows an example of identifying REM sleep phase for one of the test subjects (8VAV), whereat Fig. 1a shows a graph of function $F(\Delta t_i)$ for one of the registered REM phases, while Fig. 1b shows a graph $\Delta F(\Delta t_i)$ of function increment $F(\Delta t_i)$, shown in Fig. 1a;

Fig. 2 shows a graph of function $F(\Delta t_i)$ over the entire sleep duration for the same test subject (8VAV) whose sleep is illustrated in Fig. 1, wherein the graph fragment shown in more detail in Fig. 1a is circled;

Fig. 3 shows a graph of function $F(\Delta t_i)$ over the entire sleep duration for another test subject (7ESA);

Fig. 4 shows a graph of function $F(\Delta t_i)$ over the entire sleep duration for yet another test subject (3SOR); and

Fig. 5 and Fig. 6 schematically show the design of an exemplary portable device made in the form of a bracelet with sensors that implements the method in accordance with the present invention, whereat Fig. 5 gives the view of the device from its inner side contacting the wrist, and Fig. 6 shows the device from the outside, where the indicator is located.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0024] A method for determining the sleep phase favorable to awakening can be implemented using two sensors: a pulse wave sensor and a sensor capable of responding to arm or leg movement, i.e., a motion sensor such as an accelerometer. The sensors can be mounted on a human body separately from each other. For example, the motion sensor can be attached to an arm or a leg, while the pulse wave sensor onto the wrist or forearm. Pulse wave sensors may be represented by piezoelectric sensors, strain gages, and optical sensors. The use of an optical sensor or photo-plethysmographic sensor sensitive to vascular blood filling of bodily areas is preferable. It is more convenient for the user if both pulse wave sensor and motion sensor are mounted in a single device, such as shown in Fig. 5 and Fig. 6 and made in the form of bracelet 1 to be worn on the wrist.

[0025] As shown in Fig. 5, the inner side of bracelet 1 carries pulse wave sensor 2 based, for example, on piezoelectric cell. Several pulse sensors may be used to ensure a reliable skin contact with the wrist area where pulse wave signal is detected. Bracelet 1 (see Fig. 6) may have indicator 3 which displays the initial settings and operation mode of the device. The device may also generate a wake-up signal during favorable sleep phase, for example, by means of a vibrator (not shown in the drawings) mounted in bracelet 1. An accelerometer (not shown in the drawings) may be mounted inside bracelet 1 for detecting arm movements of a sleeping person. Pulse wave sensor 2 and the accelerometer are connected to the measuring unit of bracelet 1, which registers pulse wave signals and accelerometer-generated signals. The registered signals are processed in a CPU which can be co-located with the measuring unit in bracelet 1 or made as a separate unit to be attached to human body or carried by person, whereat said CPU receives signals transmitted from the measuring unit by radio or some other means.

[0026] The values of RR intervals and respiratory rate are determined in human sleep based on registered pulse wave signal. Since a pulse wave signal is a periodic signal that varies in synchronism with heartbeat, the time intervals between any characteristic points on pulsogram (e.g., peak value of the signal or its derivative) correspond exactly to RR intervals. Instrumental methods for determining heart rate or RR intervals from a pulse wave signal are well known to those skilled in the art. It is also known that, alongside with the above-mentioned periodic variations corresponding to blood filling dynamics at each cardiac cycle, pulse wave signal includes a low frequency component corresponding to respiratory cycle. Instrumental methods of determining the respiratory rate based on low-pass filtering of respiratory component out of pulse wave signal are well known to those skilled in the art.

[0027] Thereafter, using the obtained data, i.e., values of RR intervals and respiration rate, the following parameters are periodically measured at in preset time intervals Δt_i:

P_1 - the mean value of RR intervals;

P_2 - the minimum value of RR intervals;

P_3 - the maximum value of RR intervals;

P_5 - the mean respiratory rate.

[0028] The time interval Δt_i over which said parameters are measured is selected in the range from 1 minute to 6 minutes. Here, i is the serial number of i -th time interval.

[0029] Furthermore, parameter P_4 is determined as the standard deviation of RR intervals over the preceding time interval of 3 minutes to 20 minutes, preferably from 4 minutes to 6 minutes.

[0030] The mean number of limb movements P_6 over the preceding time interval from 0.5 minutes to 10 minutes, preferably from 4 minutes to 6 minutes, is another parameter needed for final identification of REM sleep phase. Since the occurrence of motor activity is informative by itself for identification of REM sleep, all limb movements detected by accelerometer over a 10 seconds period are taken for one movement.

[0031] Thereafter, function value $F(\Delta t_i)$ is determined by formula:

$$F(\Delta t_i) = -K_1 P_1 - K_2 P_2 - K_3 P_3 + K_4 P_4 + K_5 P_5 + K_6 P_6,$$

where: K_1 - K_6 are weight coefficients characterizing the contribution of corresponding parameter P_1 - P_6 to the value of $F(\Delta t_i)$.

[0032] Table 1 below shows the value ranges of weight coefficients K_1 - K_6, as well optimal value thereof.

Table 1. Weight Coefficient Values

Parameters, units of measurement	Weight coefficients			
	Designation	Weight coefficient values		
		min	max	optimal
P_1, ms	K_1	0.6 ms^1	3 ms^1	1 ms^1
P_2, ms	K_2	0.1 ms^1	0.7 ms^1	0.14 ms^1
P_3, ms	K_3	0.01 ms^1	0.3 ms^1	0.03 ms^1
P_4, ms	K_4	0.5 ms^1	3 ms^1	1.4 ms^1
P_5, min^{-1}	K_5	1 min	10 min	2 min
P_6	K_6	5	50	22

[0033] Informative parameters P_1 - P_6 were established, and their weight coefficients K_1 - K_6 for healthy people were obtained experimentally based on polysomnographic clinical studies. Statistically valid methods accepted in medical practice and described, for example, in the article "Polysonmography" (http://www.zonasna.ru/serv002.html) were used for checking the accuracy of REM sleep identification. Weight coefficients K_1 - K_6 were selected so that the function values $F(\Delta t_i)$ in REM and non-REM phases display a maximum difference from each other.

[0034] The increment $\Delta F(\Delta t_i)$ of function $F(\Delta t_i)$ over time Δt_i is used to identify the onset and termination of REM sleep. If the difference between the current function value $F(\Delta t_i)$ and its previous value $F(\Delta t_{i-1})$ exceeds the first preset threshold value, the onset of REM sleep is identified. If said difference is less than the second preset threshold value, the termination of REM sleep is identified.

[0035] Fig. 1 - Fig. 4 show examples of function $F(\Delta t_i)$ obtained for different test subjects during their sleep. Optimal weight coefficients K_1 - K_6 given in Table 1 were selected in the course of studies to calculate function values $F(\Delta t_i)$. Fig. 1 - Fig. 4 demonstrate a smoothed form of function $F(\Delta t_i)$.

[0036] The measuring resolution of accelerometer and pulse wave sensor signals amounted 0.1 in the testing process. All limb movements detected over 10-second time interval were considered to be a single movement and were averaged over the period of 5 min. Function values $F(\Delta t_i)$ were calculated every minute, in other words, value Δt_i was taken to be 1 minute for each *i* -th time interval. The first threshold value L_1 was selected in the range from 20 to 30, while the second threshold value L_2 was selected in the range from -30 to -20.

[0037] Fig. 1a shows a fragment of function $F(\Delta t_i)$ which includes one of REM phases registered during the sleep of one of the test subjects (8VAV). As is seen, function value $F(\Delta t_i(\Delta t_i)$ rises sharply at 202-th minute of sleep, which indicates the onset of REM sleep, whereas at 210-th minute said function value $F(\Delta t_i)$ falls abruptly, which indicates the termination of REM sleep.

[0038] Fig. 1b shows a graph of increment $\Delta F(\Delta t_i)$ of function $F(\Delta t_i)$ from Fig. 1a. As is seen, the increment value $\Delta F(\Delta t_i)$ considerably exceeds the first threshold value L_1 with the onset of REM sleep, and becomes noticeably lower than the second threshold value L_2 with REM sleep termination.

[0039] The example illustrated in Fig. 1 is presented in Table 2 in the form of parameter values P_1 - P_6, function values $F(\Delta t_i)$ and function increment $\Delta F(\Delta t_i)$. The lines with parameter values presented in bold type in Table 2 correspond to REM sleep onset and termination in test subject.

Table 2.

Sleep Duration, in min.	P_1, ms	P_2, ms	P_3, ms	P_4, ms	P_5, min	Number of Movements	P_6 over 5 min.	$F(\Delta t_i)$	$\Delta F(\Delta t_i)$
185	92	1201	1422	-	14	0	-	-	
186	1273	1200	1421	-	15	1	-	-	
187	1272	1199	1420	-	15	0	-	-	
188	1272	1198	1418	-	15	0	-	-	
189	1272	1199	1418	92	15	0	0.2	-1319	
190	1274	1198	1419	92	15	0	0.2	-1321	-1.9
191	1273	1201	1419	94	14	0	0	-1324	-3.0
192	1272	1202	1421	92	14	0	0	-1326	-2.0
193	1272	1200	1422	92	14	0	0	-1326	0.3
194	1271	1202	1421	92	14	0	0	-1325	0.8
195	1272	1201	1421	92	14	0	0	-1326	-0.9
196	1272	1202	1422	92	15	0	0	-1324	1.8
197	1272	1202	1420	93	15	0	0	-1323	1.5
198	1271	1198	1422	92	15	0	0	-1323	0.1
199	1272	1199	1421	92	15	0	0	-1324	-1.1
200	1272	1200	1418	92	15	0	0	-1324	0.0
201	1273	1197	1418	92	16	0	0	-1322	1.4
202	**1206**	**1015**	**1290**	**89**	**18**	**0**	**0**	**-1226**	**96.1**
203	1207	1011	1290	88	19	0	0	-1226	0.2

(continued)

Sleep Duration, in min.	P_1, ms	P_2, ms	P_3, ms	P_4, ms	P_5, min	Number of Movements	P_6 over 5 min.	$F(\Delta t_i)$	$\Delta F(\Delta t_i)$
204	1207	1012	1290	89	19	0	0	-1225	1.3
205	1208	1012	1290	89	19	0	0	-1226	-1.0
206	1207	1010	1290	90	18	0	0	-1225	0.7
207	1207	1012	1290	89	19	0	0	-1225	0.3
208	1206	1013	1290	88	19	0	0	-1225	-0.5
209	1207	1012	1290	89	19	0	0	-1225	0.5
210	**1367**	**1290**	**1500**	**97**	**14**	**1**	**0.2**	**-1424**	**-199.6**
211	1369	1300	1505	98	16	0	0.2	-1422	1.9
212	1369	1290	1501	99	15	0	0.2	-1421	0.9
213	1367	1290	1498	100	14	0	0.2	-1420	1.5
214	1367	1285	1498	99	13	0	0.2	-1422	-2.7
215	1367	1290	1500	100	15	0	0	-1422	0.2

[0040] Fig. 2 is a graph of function $F(\Delta t_i)$ over the entire sleep duration for the same test subject (8VAV). As follows from function values $F(\Delta t_i)$, there occurred four REM phases during the sleep of the test subject.

[0041] Fig. 3 shows a graph of function $F(\Delta t_i)$ for another test subject (7ESA). As follows from the graph, four REM phases favorable to awakening were similarly registered during subject's sleep. The subject woke up by himself during the last REM phase.

[0042] The number of REM phases may vary during sleep. For example, Fig. 4 shows that three REM phases occurred during the sleep of another test subject (3SOR).

[0043] The graph also shows that different REM phases feature different absolute values of function $F(\Delta t_i)$ throughout sleep duration and that REM sleep onset and termination can be reliably identified only by the increment of said function.

[0044] A series of tests showed that the method according to the present invention enabled the identification of 73 out of 76 REM sleep phases in 20 test subjects, which testifies to its high reliability of identification of human sleep phase favorable to awakening. The parameters of function $F(\Delta t_i)$ selected therein were also defined by the necessity to use a minimum number of sensors fixed on the wrist to provide comfortable sleeping conditions.

Claims

1. A method for determining a human sleep phase favorable to awakening, the method comprising:

registering a pulse wave signal and an occurrence of limb movements of the human during sleep using a pulse wave sensor and at least one motion sensor attached to a body of the human;
measuring values of RR intervals and a respiratory rate; and
determining values of function $F(\Delta t_i)$ over preset time intervals Δt_i and determining an onset and termination of the sleep phase favorable to awakening based on an increment of function $F(\Delta t_i)$, where i is a serial number of a time interval, wherein:

$$F(\Delta t_i) = -K_1 P_1 - K_2 P_2 - K_3 P_3 + K_4 P_4 + K_5 P_5 + K_6 P_6,$$

wherein: P_1 is a mean value of the RR intervals over a time interval Δt_i;
P_2 is a minimal value of the RR intervals over the time interval Δt_i ;
P_3 is a maximal value of RR intervals over the time interval Δt_i;
P_4 is a standard deviation of the RR intervals over a preceding time interval of 3 to 20 min;
P_5 is a mean value of the respiratory rate over the time interval Δt_i ;
P_6 is an average number of human limb movements over a preceding time period ranging from 0.5 minutes

to 10 minutes; and
K_1 - K_6 are weight coefficients characterizing contribution of parameters P_1 - P_6 to the values of the function $F(\Delta t_i)$.

2. The method of Claim 1, comprising selecting a time interval over which a value of parameter P_4 is measured in a range from 4 minutes to 6 minutes.

3. The method of Claim 1, comprising selecting a time interval over which parameter value P_6 is measured in a range from 4 minutes to 6 minutes.

4. The method of Claim 1, wherein the value of weight coefficient K_1 for parameter P_1, measured in ms, is selected in the range from 0.6 ms^{-1} to 3 ms^{-1}; the value of weight coefficient K_2 for parameter P_2, measured in ms, is selected in the range of 0.1 ms^{-1} to 0.7 ms^{-1}; the value of weight coefficient K_3 for parameter P_3, measured in ms, is selected in the range of from 0.01 ms^{-1} to 0.3 ms^{-1}; the value of weight coefficient K_4 for parameter P_4, measured in ms, is selected in the range from 0.5 ms^{-1} to 3 ms^{-1}; the value of weight coefficient K_5 for parameter P_5, measured in min^{-1}, is selected in the range from 1 min to 10 min; and the value of weight coefficient K_6 for parameter P_6 is selected in the range from 5 to 50.

5. The method of Claim 4, comprising selecting the value of the weight coefficient K_1 in a range from 0.9 ms^{-1} to 1.05 ms^{-1}.

6. The method of Claim 4, comprising selecting the value of the weight coefficient K_2 in a range from 0.1 ms^{-1} to 0.2 ms^{-1}.

7. The method of Claim 4, comprising selecting the value of the weight coefficient K_3 in a range from 0.02 ms^{-1} to 0.05 ms^{-1}.

8. The method of Claim 4, comprising selecting the value of the weight coefficient K_4 in a range from 1.3 ms^{-1} to 1.5 ms^{-1}.

9. The method of Claim 4, comprising selecting the value of the weight coefficient K_5 is selected in a range from 1.5 min to 2.3 min.

10. The method of Claim 4, comprising selecting the value of the weight coefficient K_6 is selected in a range from 18 to 24.

11. The method of Claim 1, wherein the pulse wave sensor is a piezoelectric sensor, a strain gauge, or an optical sensor attached to a wrist or a forearm.

12. The method of Claim 1, wherein the at least one motion sensor is an accelerometer attached to an arm or leg.

13. The method of Claim 1, wherein the time intervals Δt_i are selected in a range from 1 minute to 6 minutes.

14. The method of Claim 1, comprising identifying the onset of the sleep phase favorable to awakening if the increment of function $F(\Delta t_i)$ over the time period Δt_i exceeds a first preset threshold value.

15. The method of Claim 1, comprising identifying the termination of the sleep phase favorable to awakening if the increment of function $F(\Delta t_i)$ over the time period Δt_i becomes smaller than a second preset threshold value.

Patentansprüche

1. Verfahren zum Bestimmen einer zum Wecken günstigen Schlafphase eines Menschen, wobei das Verfahren Folgendes umfasst:

Erfassen eines Pulswellensignals und eines Auftretens von Extremitätenbewegungen des Menschen während des Schlafs unter Verwendung eines Pulswellensensors und wenigstens eines Bewegungssensors, der an einem Körper des Menschen angebracht ist;
Messen von Werten von RR-Intervallen und einer Atemfrequenz; und
Bestimmen von Werten einer Funktion $F(\Delta t_i)$ über voreingestellte Zeitintervalle Δt_i und Bestimmen eines Anfangs und eines Endes der zum Wecken günstigen Schlafphase basierend auf einer Erhöhung der Funktion $F(\Delta t_i)$, wobei i eine laufende Nummer eines Zeitintervalls ist, wobei:

$$F(\Delta t_i) = -K_1P_1 - K_2P_2 - K_3P_3 + K_4P_4 + K_5P_5 + K_6P_6 ,$$

wobei: P_1 ein Mittelwert der RR-Intervalle über ein Zeitintervall Δt_i ist;
P_2 ein Mindestwert der RR-Intervalle über das Zeitintervall Δt_i ist;
P_3 ein Höchstwert von RR-Intervallen über das Zeitintervall Δt_i ist;
P_4 eine Standardabweichung der RR-Intervalle über ein vorangehendes Zeitintervall von 3 bis 20 min ist;
P_5 ein Mittelwert der Atemfrequenz über das Zeitintervall Δt_i ist;
P_6 eine durchschnittliche Anzahl von menschlichen Extremitätenbewegungen über einen vorangehenden Zeitraum im Bereich von 0,5 Minuten bis 10 Minuten ist; und
K_1 bis K_6 Gewichtungskoeffizienten sind, welche den Anteil der Parameter P_1 bis P_6 an den Werten der Funktion $F(\Delta t_i)$ kennzeichnen.

2. Verfahren nach Anspruch 1, umfassend Auswählen eines Zeitintervalls, über das ein Wert des Parameters P_4 gemessen wird, in einem Bereich von 4 Minuten bis 6 Minuten.

3. Verfahren nach Anspruch 1, umfassend Auswählen eines Zeitintervalls, über das der Parameterwert P_6 gemessen wird, in einem Bereich von 4 Minuten bis 6 Minuten.

4. Verfahren nach Anspruch 1, wobei der Wert des Gewichtungskoeffizienten K_1 für den Parameter P_1, gemessen in ms, im Bereich von 0,6 ms^{-1} bis 3 ms^{-1} ausgewählt wird; der Wert des Gewichtungskoeffizienten K_2 für den Parameter P_2, gemessen in ms, im Bereich von 0,1 ms^{-1} bis 0,7 ms^{-1} ausgewählt wird; der Wert des Gewichtungskoeffizienten K_3 für den Parameter P_3, gemessen in ms, im Bereich von 0,01 ms^{-1} bis 0,3 ms^{-1} ausgewählt wird; der Wert des Gewichtungskoeffizienten K_4 für den Parameter P_4, gemessen in ms, im Bereich von 0,5 ms^{-1} bis 3 ms^{-1} ausgewählt wird; der Wert des Gewichtungskoeffizienten K_5 für den Parameter P_5, gemessen in min^{-1}, im Bereich von 1 bis 10 min ausgewählt wird; und der Wert des Gewichtungskoeffizienten K_6 für den Parameter P_6 im Bereich von 5 bis 50 ausgewählt wird.

5. Verfahren nach Anspruch 4, umfassend Auswählen des Werts des Gewichtungskoeffizienten K_1 in einem Bereich von 0,9 ms^{-1} bis 1,05 ms^{-1}.

6. Verfahren nach Anspruch 4, umfassend Auswählen des Werts des Gewichtungskoeffizienten K_2 in einem Bereich von 0,1 ms^{-1} bis 0,2 ms^{-1}.

7. Verfahren nach Anspruch 4, umfassend Auswählen des Werts des Gewichtungskoeffizienten K_3 in einem Bereich von 0,02 ms^{-1} bis 0,05 ms^{-1}.

8. Verfahren nach Anspruch 4, umfassend Auswählen des Werts des Gewichtungskoeffizienten K_4 in einem Bereich von 1,3 ms^{-1} bis 1,5 ms^{-1}.

9. Verfahren nach Anspruch 4, umfassend Auswählen des Werts des Gewichtungskoeffizienten K_5 in einem Bereich von 1,5 min bis 2,3 min.

10. Verfahren nach Anspruch 4, umfassend Auswählen des Werts des Gewichtungskoeffizienten K_6 in einem Bereich von 18 bis 24.

11. Verfahren nach Anspruch 1, wobei der Pulswellensensor einen piezoelektrischer Sensor, ein Dehnungsmessstreifen oder ein optischer Sensor ist, der an einem Handgelenk oder einem Unterarm angebracht ist.

12. Verfahren nach Anspruch 1, wobei der wenigstens eine Bewegungssensor ein Beschleunigungsmesser ist, der an einem Arm oder Bein angebracht ist.

13. Verfahren nach Anspruch 1, wobei die Zeitintervalle Δt_i in einem Bereich von 1 Minute bis 6 Minuten ausgewählt werden.

14. Verfahren nach Anspruch 1, umfassend Erkennen des Anfangs der zum Wecken günstigen Schlafphase, wenn die Erhöhung der Funktion $F(\Delta t_i)$ über den Zeitraum Δt_i einen ersten voreingestellten Schwellenwert überschreitet.

15. Verfahren nach Anspruch 1, umfassend Erkennen des Endes der zum Wecken günstigen Schlafphase, wenn die Erhöhung der Funktion $F(\Delta t_i)$ über den Zeitraum Δt_i kleiner als ein zweiter voreingestellter Schwellenwert wird.

Revendications

1. Procédé pour déterminer une phase du sommeil humain favorable au réveil, lequel procédé comprend :

l'enregistrement d'un signal en ondes pulsées et d'une survenue de mouvements des membres du sujet humain pendant le sommeil à l'aide d'un capteur d'ondes pulsées et d'au moins un capteur de mouvement fixé au corps du sujet humain ;
la mesure des valeurs des intervalles RR et de la fréquence respiratoire ; et
la détermination de valeurs de la fonction $F(\Delta t_i)$ sur des intervalles de temps prédéterminés Δt_i et la détermination d'un début et d'une fin de la phase du sommeil favorable au réveil sur la base d'un incrément de la fonction $F(\Delta t_i)$ où i est un numéro d'ordre d'un intervalle de temps, dans lequel :

$$F(\Delta t_i) = -K_1P_1 - K_2P_2 - K_3P_3 + K_4P_4 + K_5P_5 + K_6P_6,$$

où : P_1 est une valeur moyenne des intervalles RR sur un intervalle de temps Δt_i;
P_2 est une valeur minimale des intervalles RR sur l'intervalle de temps Δt_i;
P_3 est une valeur maximale des intervalles RR sur l'intervalle de temps Δt_i;
P_4 est un écart-type des intervalles RR par rapport à un intervalle de temps précédent compris entre 3 et 20 min ;
P_5 est une valeur moyenne de la fréquence respiratoire sur l'intervalle de temps Δt_i;
P_6 est un nombre moyen de mouvement des membres du sujet humain sur une période de temps précédente comprise entre 0,5 minute et 10 minutes ; et
K_1 à K_6 sont des coefficients de pondération caractérisant la contribution des paramètres P_1 à P_6 aux valeurs de la fonction $F(\Delta t_i)$.

2. Procédé selon la revendication 1, comprenant la sélection d'un intervalle de temps sur lequel la valeur du paramètre P_4 est mesurée dans une plage de 4 minutes à 6 minutes.

3. Procédé selon la revendication 1, comprenant la sélection d'un intervalle de temps sur lequel la valeur du paramètre P_6 est mesurée dans une plage de 4 minutes à 6 minutes.

4. Procédé selon la revendication 1, dans lequel la valeur du coefficient de pondération K_1 pour le paramètre P_1, mesurée en ms, est choisie dans la plage de 0,6 ms^{-1} à 3 ms^{-1}, la valeur du coefficient de pondération K_2 pour le paramètre P_2, mesurée en ms, est choisie dans la plage de 0,1 ms^{-1} à 0,7 ms^{-1}, la valeur du coefficient de pondération K_3 pour le paramètre P_3, mesurée en ms, est choisie dans la plage de 0,01 ms^{-1} à 0,3 ms^{-1}, la valeur du coefficient de pondération K_4 pour le paramètre P_4, mesurée en ms, est choisie dans la plage de 0,5 ms^{-1} à 3 ms^{-1}, la valeur du coefficient de pondération K_5 pour le paramètre P_5, mesurée en min^{-1}, est choisie dans la plage de 1 min à 10 min, et la valeur du coefficient de pondération K_6 pour le paramètre P_6 est choisie dans la plage de 5 à 50.

5. Procédé selon la revendication 4, comprenant la sélection de la valeur du coefficient de pondération K_1 dans une plage de 0,9 ms^{-1} à 1,05 ms^{-1}.

6. Procédé selon la revendication 4, comprenant la sélection de la valeur du coefficient de pondération K_2 dans une plage de 0,1 ms^{-1} à 0,2 ms^{-1}.

7. Procédé selon la revendication 4, comprenant la sélection de la valeur du coefficient de pondération K_3 dans une plage de 0,02 ms^{-1} à 0,05 ms^{-1}.

8. Procédé selon la revendication 4, comprenant la sélection de la valeur du coefficient de pondération K_4 dans une plage de 1,3 ms^{-1} à 1,5 ms^{-1}.

9. Procédé selon la revendication 4, comprenant la sélection de la valeur du coefficient de pondération K_5 dans une plage de 1,5 min à 2,3 min.

10. Procédé selon la revendication 4, comprenant la sélection de la valeur du coefficient de pondération K_6 dans une plage de 18 à 24.

11. Procédé selon la revendication 1, dans lequel le capteur d'ondes pulsées est un capteur piézoélectrique, une jauge extensométrique ou un capteur optique attaché à un poignet ou à un avant-bras.

12. Procédé selon la revendication 1, dans lequel l'au moins un capteur de mouvement est un accéléromètre attaché à un bras ou à une jambe.

13. Procédé selon la revendication 1, dans lequel les intervalles de temps Δt_i sont choisis dans une plage de 1 minute à 6 minutes.

14. Procédé selon la revendication 1, comprenant l'identification du début de la phase de sommeil favorable au réveil si l'augmentation de la fonction $F(\Delta t_i)$ sur la période de temps Δt_i dépasse une première valeur de seuil prédéfinie.

15. Procédé selon la revendication 1, comprenant l'identification de la fin de la phase de sommeil favorable au réveil si l'augmentation de la fonction $F(\Delta t_i)$ sur la période de temps Δt_i passe en dessous d'une deuxième valeur de seuil prédéfinie.

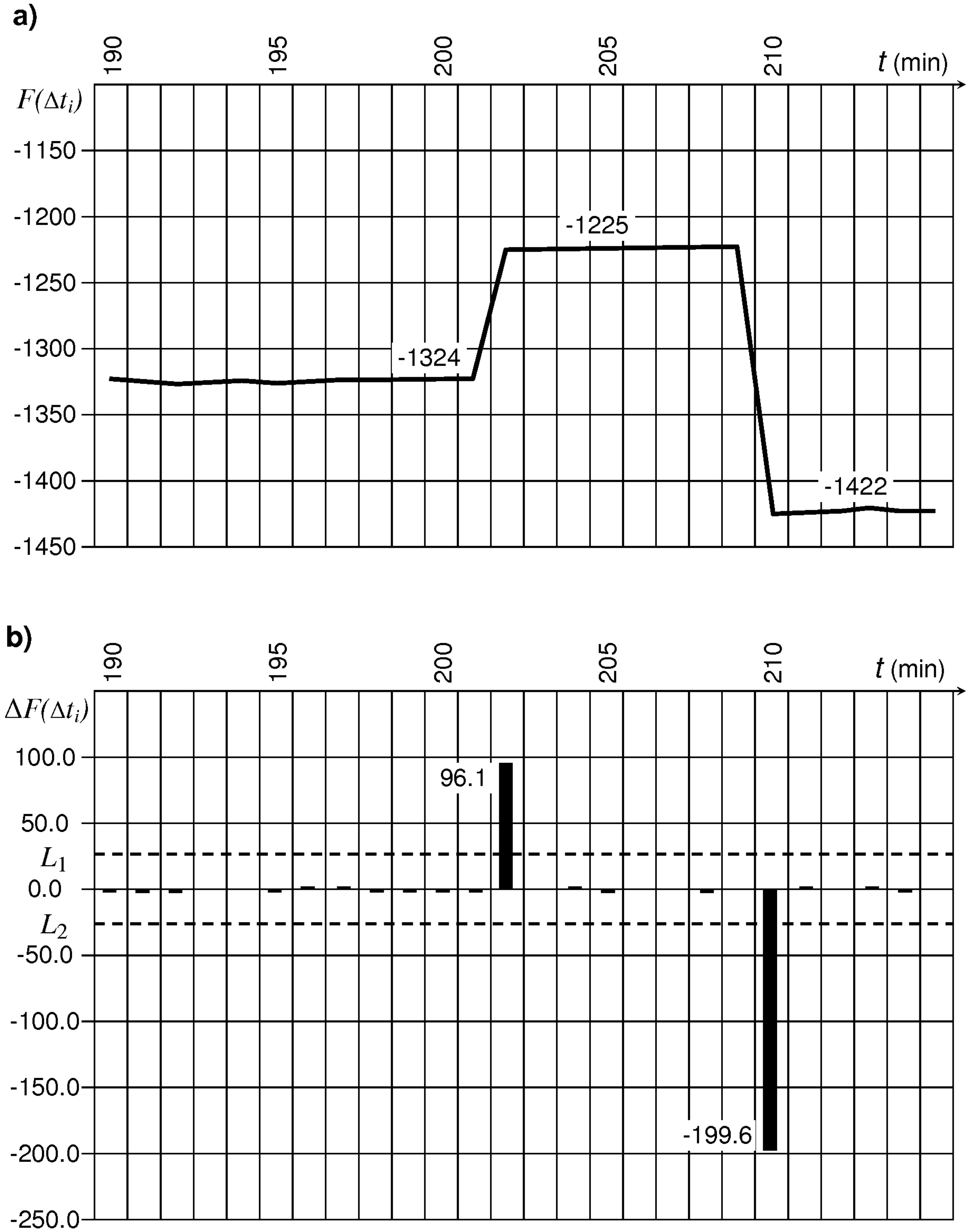
a)
190
195
200
205
210
t (min)
F(Δti)
-1150
-1200
-1250
-1300
-1350
-1400
-1450
-1225
-1324
-1422
b)
190
195
200
205
210
t (min)
ΔF(Δti)
100.0
50.0
L1
0.0
L2
-50.0
-100.0
-150.0
-200.0
-250.0
96.1
-199.6

Fig. 1

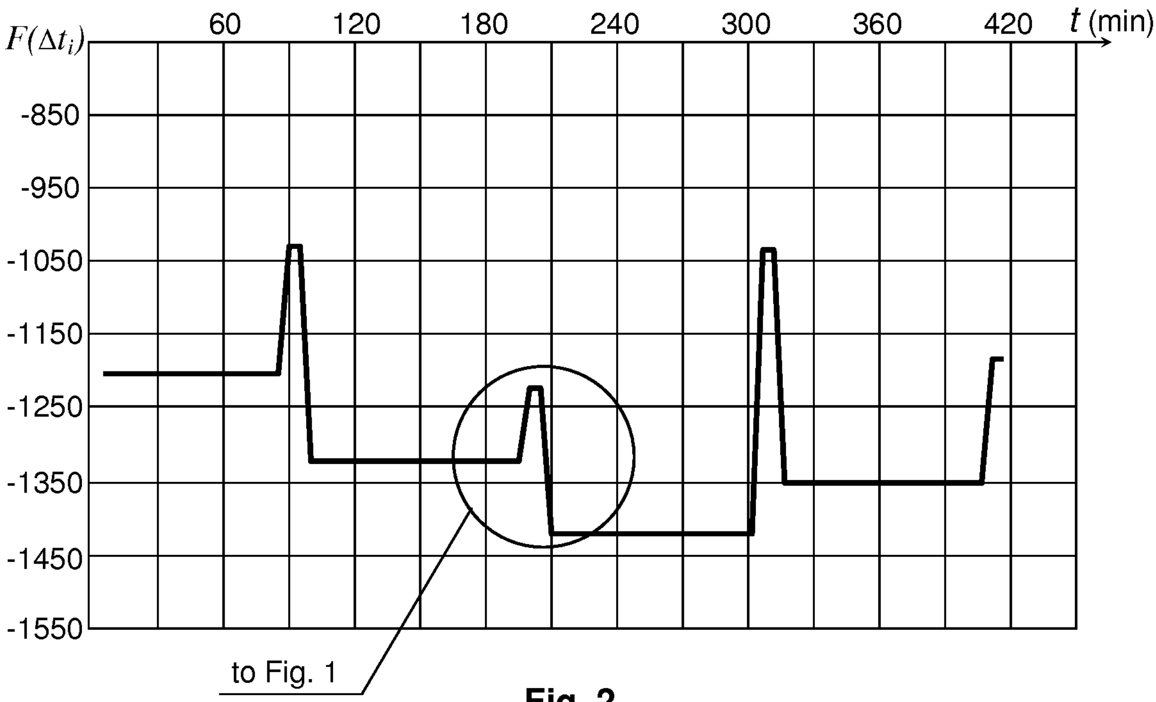
F(Δti)
60
120
180
240
300
360
420
t (min)
-850
-950
-1050
-1150
-1250
-1350
-1450
-1550
to Fig. 1

Fig. 2

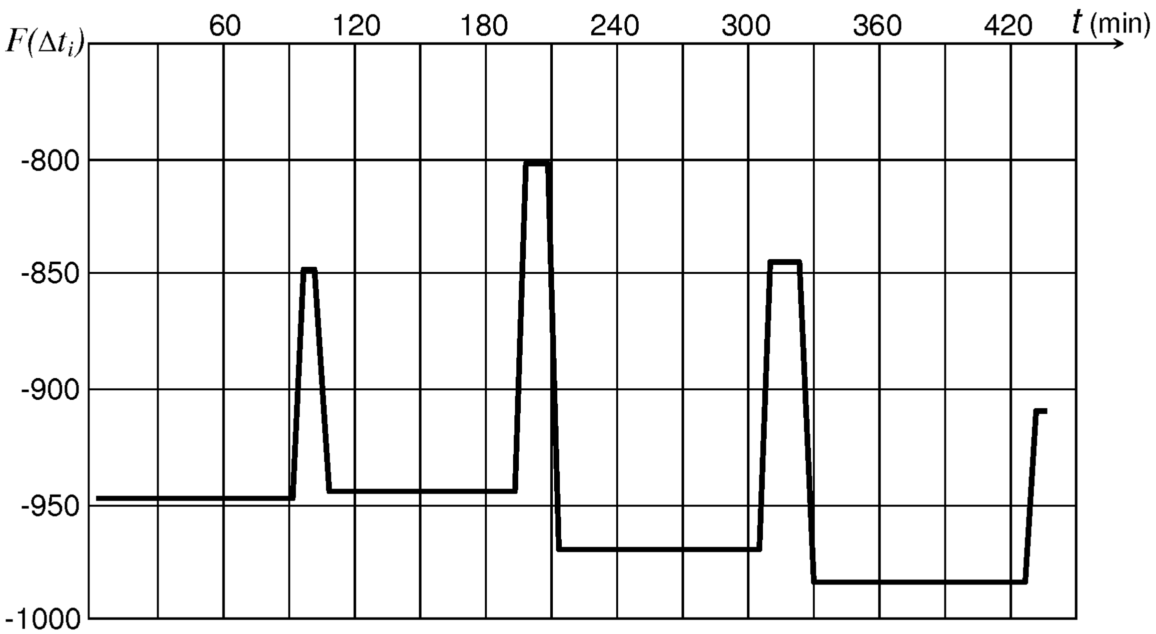
F(Δti)
60
120
180
240
300
360
420
t (min)
-800
-850
-900
-950
-1000

Fig. 3

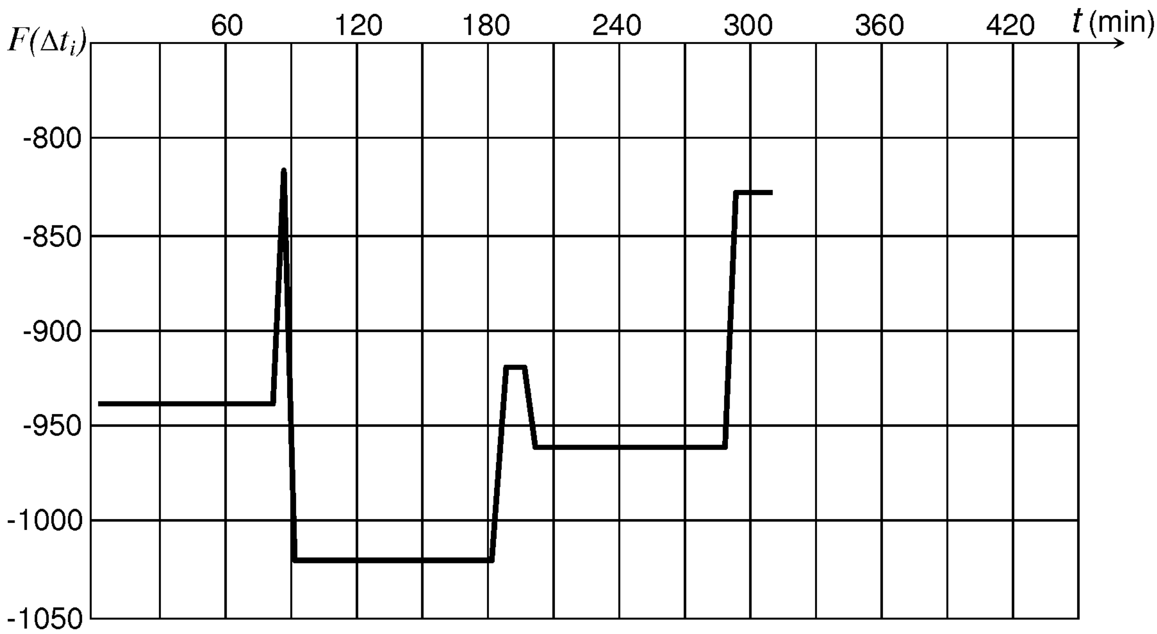

Fig. 4

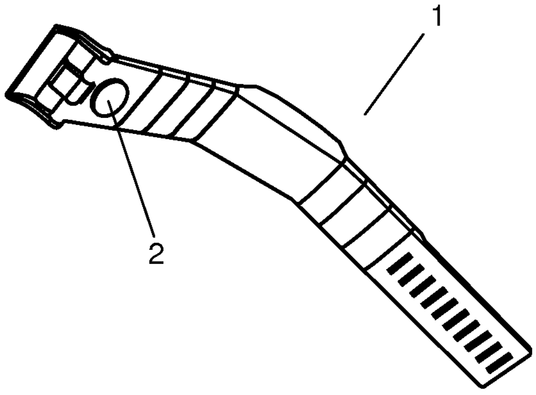

Fig. 5

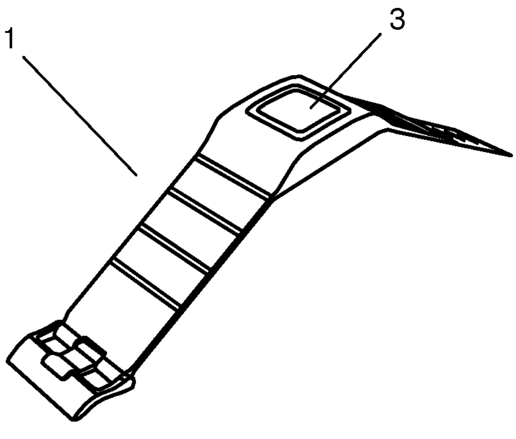

Fig. 6

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- RU 2061406 **[0006]**
- US 20110230790 A **[0007]**
- US 20050190065 A **[0008]**
- DE 4209336 **[0009]**
- US 20080269625 A1 **[0009]**