NURSING SUPPORT SYSTEM AT HOME IN THE NIGHT

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Abstract: This paper describes a new nursing support system at home in the night. The system non-restrictively monitors patients on the bed. An air mattress laid out on the bed, a fine pressure to detect the pressure in the air mattress and filters are the components of the system. The human body movements such as the heart beat, respiration, snoring, turning over and coughing directly to the pressure in the mattress and causes of the body movements can be discriminated by the proper filtering.

Physical conditions of the patient can be diagnosed by bio-information above. When he is in an emergent situation, he might turn over very frequently. The continuos monitoring helps to find his sudden physical change, which considerably reduce the effort of nursing. Further when the patient is in a normal condition, the continuos measurement of the bio-information above provides the important health information.

Keywords: nursing support system, non-restrictive, air-mattress, quality of sleep, artificial neural network

1. INTRODUCTION

The aging society that we have not experienced is before coming[1),2),3)]. But, the social systems as well as nursing systems that have the capacity to accept such the many old people is insufficient. In the research institutes, the developments of systems and equipments for directly supporting old people are started. Among those, the healthy monitor system at home is most important. So far as the information systems, we have already had the technical potential by the development of information infrastructure. However the satisfactory health monitoring sensors at home are not developed yet. The prerequisite functions that the health-monitoring sensor at home should have are [4)]: (1) non-restrictive to make the unconscious measuring possible, (2) the long interval measurement, (3) measurement of variety of physiology, (4) no machine operation by the users, (5) the user's identification, and (6) long time data storage. The condition (1) is most important not only to reduce the stress of patients but also to acquire the accurate bio-data[5)]. Many researchers are interested in the bio-information of human when sleeping. Especially, the body movement in sleeping is important and has investigated[6),7),8) and]. More advanced sensor to measure human bio-information in the bed was developed and employed in the research. The bed with the sensor, that was named Static Charge Sensitive Bed, can detect the heart rate, respiration, and body movement [6)]. Recently, a new type of sensor using magnetic sheet has reported [9),10)]. Further, a bed with piezo-elements to measure the body movements was reported [11)]. These converge in the location where there is a sensor, and can detect bio-information when patient is on the sensor, but might miss when he is not on the sensor.

This paper describes a sensor which satisfies the 6 prerequisite conditions for the health monitoring sensor at home and can measure heart rate, respiration, snoring, and body movement and coughing. The sensor can catch bio-information of the patient whose posture is arbitrary on the bed. In addition, a method to evaluate the quality of the sleep from those bio-information is proposed.

2. PROBLEM DESCRIPTION

2.1 Conditions and assumptions

Fig.1 shows a situation for the bio-measurement. One patient is on the bed. He may sit down or lie down by any posture. No restraint exists except he is just on the bed. The patient on the bed breathes,

and his heart beats. When sleeping, he might turn over, snore and cough. The heart rate is periodic whose frequency ranges from 0.7Hz to 1.8Hz in the normal condition. Respiration frequency in normal condition ranges from 0.2Hz to 0.8Hz. The body movement due to respiration is smooth. The snoring sound is synchronizing with the respiration. The frequency of dominant power spectrum is higher than 100Hz. Turing over occurs non-periodically. Once occurred, it continues for 1 to 2 second. Coughing generates the body
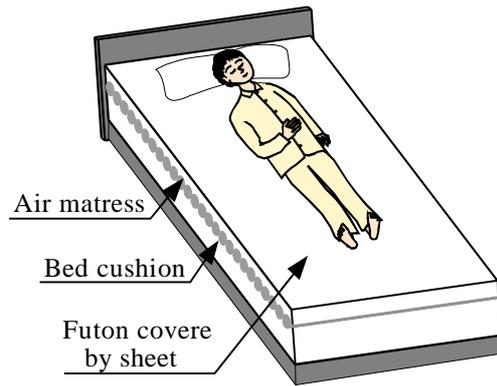
Fig.1 Situation of non-invasive bio-sensing

movement as well as sound and it occurs discontinuously.

For the patient and the measurement condition described above, we cite the following assumptions.

(A1) The heart rate and respiration rate of the patient is in the normal range.

(A2) During big body movement, other bio-information does not need to be measured.

If the patient lies on the bed quietly, his heart rate and respiration rates are in normal range, except the situation when he has a nightmare by the high fever.

The duration time of turning over is from 1 to 2 second and thus the estimation of the heart rate and respiration rate from the 1 minute data yields little error. Thus these assumptions are not restrictive.

2.2 Problem description

Here we consider the following three problems.

(P1) Propose a method and a sensing system that measure the heart rate, respiration, body movement, snoring and coughing of a patient on the bed whose posture is arbitrary.

(P2) Check the validity of this system by experiment.

(P3) Evaluate quality of sleep from the above bio-information

3. PNEUMATIC METHOD

3.1 Air mattress method

Consider problem (P1). Fig.1 shows the bed with four layers as (1) cushion, (2) air mattress, (3) thin futon, (4) sheet. The air mattress (2) is one that solves the problem (P1). **Fig.2** shows an example of the air mattress. The human body movements on the air mattress cause the change in the pressure in the mattress.
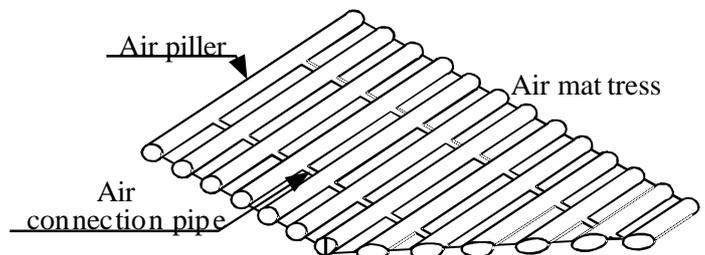
Fig.2 Air mattress

The pressure change is the summation of those due to the various body movements. The proposed air mattress method detects the bio-information from the pressure change. This method is non-restrictive. No electrodes are set to the patient. No restrictions of the posture are required, but all he has to do is just being on the bed. From the principle of the air matters method, the method requires the following three elements:

(1) Air mattress on the bed.

(2) Highly sensitive pressure sensor that detects the fine pressure change in the air mattress.

(3) Filters that separate the causes of pressure changes.

3.2 Measurement

(1) Fine pressure sensor

Fig.3 shows the pressure sensor and filters. The pressure change caused by heart rate and respiration inside the mattress is minute. As the fine pressure sensor, we employ a microphone. The microphone for audio use guarantees the characteristic for the frequency range of 50Hz to 10kHz.

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Vienna, AUSTRIA, 2000, September 25-28

(2) Discrimination of causes of body movements

Three kinds of filters <1>respiration filter, <2>heart rate filter, and <3>snoring and coughing filter are prepared. From assumption (A1), as for the cut-off frequency of the bandpass filter for heart rate and respiration are set up so that the frequency of the normal range of heart rate and respiration may pass. The snoring and coughing filter is a highpass filter whose cut-off frequency is 100Hz. Body movement caused by heart rate and the respiration is very small. If the gain of the amplifier is set so that the signal from heart rate filter and that from respiration filter are large, these outputs will be saturated by the body movements due to turning over and coughing.
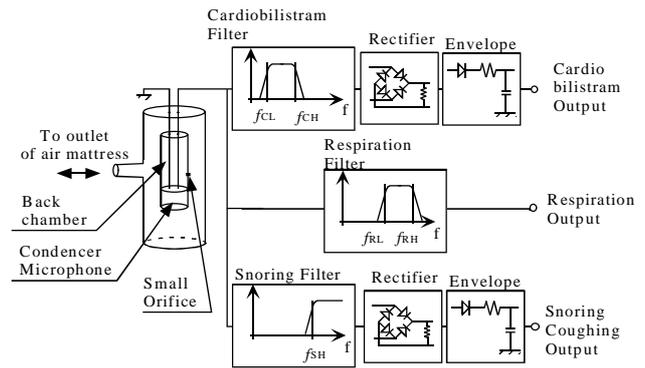

Fig.3 Fine pressure by a microphone and filters to discriminate bio-information

Thus from these fact, we can have the following discrimination procedures:

(1) Turning over is big movement, and the output of the amplifier for the <1>respiration and <2>heart rate detection are saturated. During this body movement, the respiration and heart rate cannot be measured because of the saturation as mentioned in Assumption (A2).

(2) Coughing can be detected by the saturation of the <1> respiration filter and <3> heart rate filter and the no-zero output form the snoring and coughing filter. During this body motion, the respiration and heart rate cannot be measured because of the saturation as mentioned in Assumption (A2).

(3) Heart rate can be measured when no turning over and no coughing occur. Spectrum has conspicuous peak in the frequency range from 0.7Hz to 1.8Hz, the range of the heart rate or around its double frequency. The heart rate frequency can be obtained from the spectrum.

(4) Respiration can be measured when no turning over and no coughing occur. Spectrum has conspicuous peak in the frequency range from 0.2Hz to 0.8Hz, the range of the respiration. The respiration frequency can be obtained from the spectrum.

4. EXPERIMENTS

4.1 Experimental systems

Here we consider the Problem (P2).

(1) Air mattress

Air mattress has length=2m, width=0.8m, radius of cylinder=0.1m, diameter of the connecting pipe =5mm, whole mattress is composed of 24 cylindrical mattresses.

(2) Fine pressure sensor

The basic detector to catch the pressure is a condenser microphone (PRIMO EM121). In order to expand the lower frequency ranges a closed chamber with diameter of 8mm and the length of 20mm is set to the back of the microphone. The closed area covered by the chamber requires orifice to compensate the temperature drift. Instead of setting orifice, we use a small leak of the pressure detecting plate.
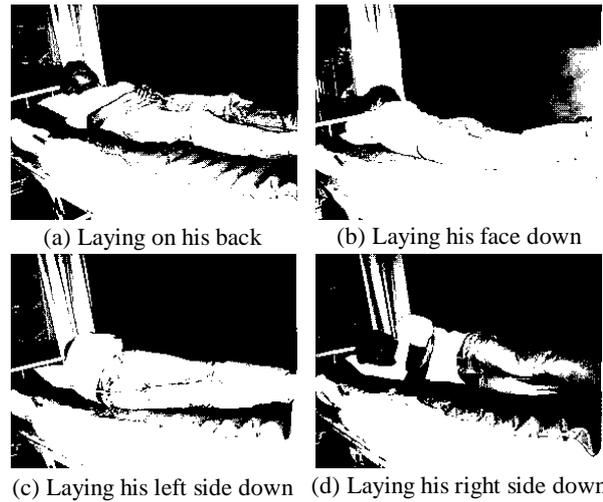
(3) Filters

Following four filters are prepared;<1>Heart rate filter: bandpass filter with cut-off frequencies 6Hz-10Hz The envelope is obtained by rectifying and low pass filtering the out put from the bandpass filter,<2>Respiration filter: bandpass filter with cut-off frequencies 0.16Hz-0.6Hz,<3>Snoring and cough filter: high pass filter whose cut-off frequency is 100Hz. The envelope is obtained by rectifying and low pass filtering the out put from the high pass filter,<4>Test filter of the air mattress: band-pass filter with cut-off frequencies 0.16Hz and 10Hz.

4.2 Basic experiments

Here we check if the proposed sensor detect the bio-information by experiments.

(1) Heart rate and respiration

Photo.1 shows postures (a) lying on his back, (b) lying face down, (c) lying his left side down, (d) lying his right side down. **Fig.4** shows the data of heart rate and respiration and spectrum of those calculated by FFT algorithm for the data with 0.1sec sampling time for the interval of 51.2second. The spectrum of the heart rate signals, depending on the posture show conspicuous peak at the frequency of twice of the heart rate. This is because heart rate is periodic and impulsive. From Assumption (A1), the normal frequency of heart rate is in the range of 0.7Hz to 1.8Hz, and thus the twice is 1.4Hz to 3.6Hz. Therefore the peak in the range of 0.7Hz to 1.8Hz corresponds to the heart rate frequency and the peak in the range of 1.4Hz to 3.6Hz corresponds to that of twice from which the heart rate frequency

(a) Laying on his back (b) Laying his face down

(c) Laying his left side down (d) Laying his right side down

Phot.1 Patient on the air mattress

can be detected. From the figures of respiration in Fig.4, the first peak always shows the respiration freq

(a) Laying on his back

(b) Laying his face down

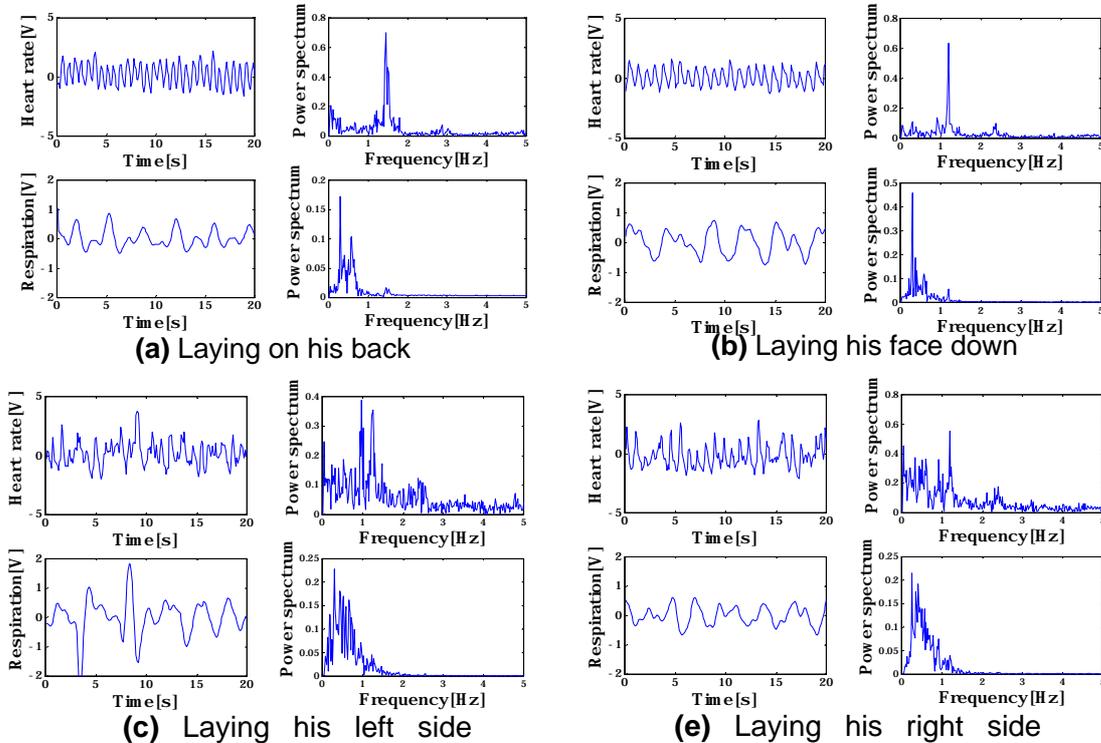**(c)** Laying his left side

(e) Laying his right side

Fig.4 Time series data and spectrum of the signals from the heart rate, for various postures shown in

4.3 Eight hour experiment

Sampling interval was 1minute and the spectrum was calculated by the data of interval 51.2second with sampling time 0.1second.

<1>The heart rate frequency is obtained from the fundamental or the first harmonic frequencies. The respiration frequency is obtained from the fundamental frequency.

<2>The snoring output is set 1, when the snoring and cough filter has no-zero output and the heart rate filter and the respiration filter are not saturated. Otherwise the output is set to 0.

The turning over output = 1 when the heart rate frequency and the respiration filter saturate and the snoring and cough filter has zero output.

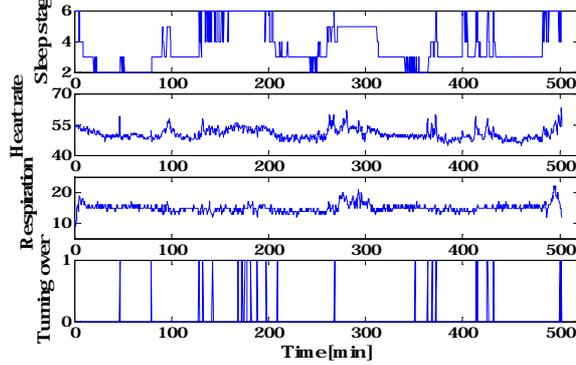<3>The coughing out put is set to 1, when the heart rate frequency and the respiration filter saturate and

Fig.5 Heart rate and respiration with the judgement of the quality of sleep. Units of heart rate and respiration rate are [1/min]

the snoring and cough filter has non-zero output. Otherwise the output=0.

Under the condition above, we automatically measured the bio-information for eight hours. First, we used both the conventional sensor and the new air mattress sensor and found the both outputs coincide. As well as the above measurement, we measure the electroencephalogram. The signal of electroencephalogram, was analyzed and the quality of sleep is graded by a medical doctor, who is the researcher of human sleeping. Fig.5 shows the result. During this experiment the patient has no snoring and coughing. In Fig.5, the depth grade of the sleep is given as follows; " awakening" = WAKE, "rapid eye movement stage" = REM, "1st stage (shallow) sleeping" = 1, "2nd stage (relatively shallow) sleeping" = 2, "3rd stage (relatively deep) sleeping" = 3 and "4th stage (deep) sleeping" = 4. Further degree from awaking to deep sleep is simply given by 6 to 1. From the data in **Fig.5**, we have the following observations.

4.4 Evaluation of sleep quality

Here we describe experimental result to evaluate the depth of sleep. The depth is estimated only by the bio-data from the air mattress sensor. We employed an artificial neural network to relate the bio-data from the sensor i.e., cardio rate, respiration rate, and turning over to the depth of the sleep. Among variety of artificial neural networks, we selected the Elman network, which has been successfully applied to recognition of time series data. **Fig.6** shows the input and output scheme from which the number of input vital signs is 5 and that of output is 1, the sleep stage (depth). The number of the neurons in the hidden layer is 25.
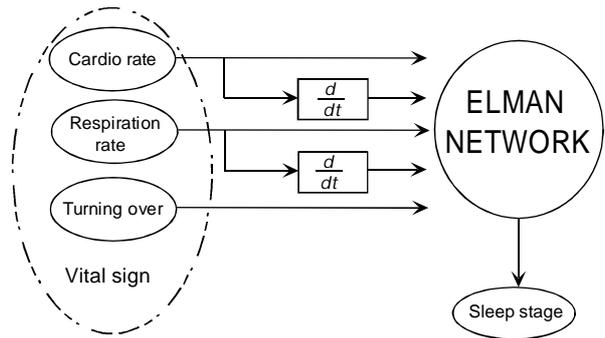**Fig.7 (a)**

Fig.6 Estimation of sleep dept

shows the estimated depth of the sleep by the learned neural network, whereas **Fig.7 (b)** shows that estimated by a medical doctor from the EEG. These show very similar estimates except in the shallow sleep stage. This means, without using the EEG which is very expensive and yields heavy stress to the patient, we can estimated the quality of sleep only by the air mattress sensor presented here.
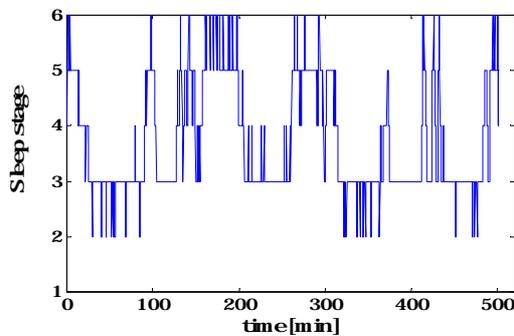
(a) By the neural network
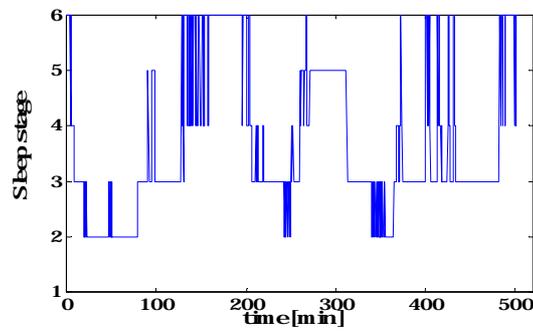
(b) By the medical doctor

Fig.7 Estimate by the neural network

5. CONCLUSIONS

A new bio-sensing method by the air mattress was presented. The pressure in the air mattress laid on the floor of a bed and under the futon changes according to the body motion due to heart rate, respiration, turning over, snoring and coughing. Discrimination of the causes of pressure changes provides the above five bio-information in the non-restrictive manner.

The proposed system non-invasively and non-restrictively estimate the quality of sleep without using the EEG.

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