Sleep Stage Estimation Using Synthesized Data of Heart Rate and Body Movement

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Abstract

A light sleep has a tendency to frequently cause active body movements during sleep but a conventional estimation method for the sleep stage, which employs an evolutionary computation, has not consider that. In this paper, we focus on a relationship of body movement and heart rate. Specifically, our method is an extension of conventional method but employs a synthetic wave by a heart rate wave a body movement wave. Our experiments show the proposed method derives better estimation accuracy of sleep stage than the conventional method in the experimental data of personal sleep except in a few data. The conclusion is the synthetic wave leads to a correct sleep stage with the strong relationship between the body movement and the depth of personal sleep, however, in a few cases, which have no or weak relationship, it fails to judge the stage of deep sleep.

Introduction

A good night sleep is necessary to maintain a personal health. The estimation techniques of the sleep stage will be an important one to understand the depth of the personal sleep and to manage the health. Several researches tried to estimate the sleep stage that is classified as the level of sleep depth. Rechtschaffen & Kales method estimates the sleep stage by medical specialists using the biomedical data such as Electro-encephalogram(EEG), Electro-myogram(EMG), and Electro-oculogram(EOG) [5]. In this method, people need to wear electric sensors to sample the data. Watanabe proposes the non-restraint estimation method that uses only an air mattress as a sensor to sample the heart rate data [9]. This method uses a fixed filter that extracts the ingredients of middle frequency heart rate wave, next estimates the sleep stage using the filtered wave of heart rate. However, data of each personal sleep has different characteristics of frequency ingredient that should be extracted, hence Watanabe method is limit in that its approach cannot adjust to each personal data.

Hirose proposed the estimation method [7] that derives high estimation accuracy for each person only using a wristwatch-type device to human body.

In particularly, firstly, Hirose method converts a wave of heart rate data to frequency ingredients; secondly, generates a filter by a genetic search to determine which frequency should be extracted for the estimation; finally, it estimates the sleep stage from the filtered wave. However, Hirose method fails to estimate the sleep stage on the data which has different characteristic of the sleep, i.e. difference of extracting frequency data in different day.

To overcome the problem of Hirose methods, we proposed estimation method [6] that extends the Hirose method but that employs robust genetic search that can search a suitable filter that extracts essential frequency ingredients with no influence on plural days. Our method estimates the sleep stage for each individual heart rate.

However, estimation only using heart rate data at genetic search, i.e. Hirose's method and Tajima's method is difficult to estimate sleep stage of REM, Stage3 and Stage4. This cause is what those method is not considered cycle of body movement linked depth of the sleep.

In this paper, to improve the estimation accuracy of Tajima method, we extend Tajima method that estimates the sleep stage using the body movement data. As the same frame work of Tajima method (or Hirose method), our method generates filter used not only for heart beat but for the body movement. For this purpose, as the same frame work of Hirose method, the proposal firstly converts a wave of body movement data to frequency ingredients by FFT, then it searches the filter by the genetic search that is employed by Tajima method. Secondly it generates a synthetic wave that synthesizes the filtered wave of heart beat and body movement.

This paper organized as follows. The sleep stage estimation based genetic search is summarized next section. The explanation of our proposed method is described in section of Estimation using body movement in genetic search. The section of experiment provides experiment result and discussion. Finally, our works are summarized in conclusion.

Sleep Stage Estimation System (Hirose method)

Hirose proposed the sleep stage estimation method by using the data obtained from the air mattress [9] in a bed as shown in Fig. 1. This method employs the unrestrained pneumatic bio measurement (*i.e.*, heart rate, respiration, snoring, and body movement) in bed. Since several reports suggested that the heart rate has the strong relation to the sleep stage [2, 3, 7], Hirose's method estimates the sleep stage by using the heart rate & the body movement obtained from the sensor in bed. Concretely for accurate sleep stage estimation by specializing the individual sleep stage, Genetic Algorithms (GAs) [1] are applied. The GAs are powerful and broadly applicable to stochastic search and optimization techniques based on evolutional computation. They are especially appropriate for problems with large and complex search-spaces, where the global optimum cannot be found within a reasonable amount of time using traditional techniques. Each solution, which is corresponding to one multiple band-pass filter, search to extract the specific frequencies of the heartbeat that are necessary to estimate the sleep stage. In detail, GAs search for the filter to determine which frequency of the heartbeat should be extracted by representing it in bit string (0 or 1). In addition, Hirose focused on the distinctive changes of heart rate data and the body movement data in REM / Non-

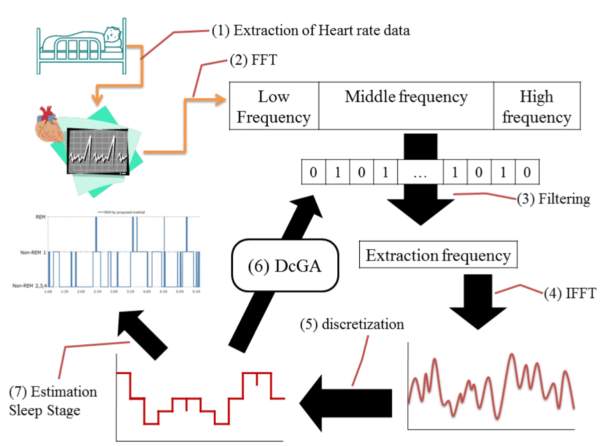

Fig. 1 Flame work of estimation based genetic search

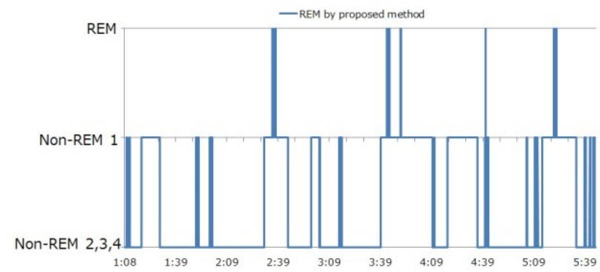

Fig. 2 determinate REM / Non-REM sleep stage by using Hirose's method

REM stage, and proposed fitness function of GAs to estimate sleep stages [4]. In REM stage the heart rate increases erratically, while in Non-REM stage the heart rate decreases. In REM stage the body moves intensively, while in Non-REM stage the body hardly moves. In addition, the body moves strenuously when the sleep stage changes from Non-REM 3 to Non-REM 1 or from REM stage to Non-REM 1. In view of these distinctive changes of heart rate and body movement, the sleep stage is determined by using following requirements.

Req. 1: The standard deviation of body movement among 60 seconds more than one among a night.

Req. 2: The linear of heartbeat by least squares method among 10 minutes more than the average of heartbeat among a night.

If both requirements are satisfied, the sleep stage determined as REM or Wake stages. If both requirements are not satisfied, the sleep stage determined as Non-REM stage 3 which is light sleep stage. If both requirements are not satisfied, the sleep stage is determined as Non-REM stage which is deep sleep (e.g., Non-REM stage 2, 3, or 4). Concretely, as shown Fig. 2, by using proposed method, REM/Non-REM sleep stages are determined and used as the fitness function of GAs.

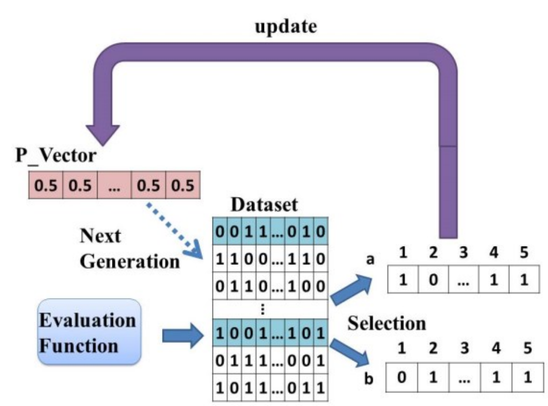

Fig. 3 DcGA algorithm

Robust extracting frequency data

Hirose's method using by GA, but Tajima's method using by DcGA[6]. DcGA is probability model GA what is extended cGA[8]. At first, the probability of each bit in the probability model is set to 0.5 as the initial value. Next, DcGA selects two data from the filtering dataset. After comparing the fitness of those data were evaluated in advance for judging the winner and loser, the data has higher fitness is set to winner while the other one is set to loser. Finally, the probability model is updated as follows: (1) $1/n$ is added to the corresponding probability when the winner's bit is equal to 1 and loser's bit is 0, where n is a constant parameter which controls the updated rate, (2) $1/n$ is decreased from the probability when the winner's bit is 0 and loser's bit is 1, and (3) the probability is not updated when winner's bit is equal to lower's bit. Fig. 3 shows the algorithm of DcGA in detail.

Estimation using body movement in genetic search

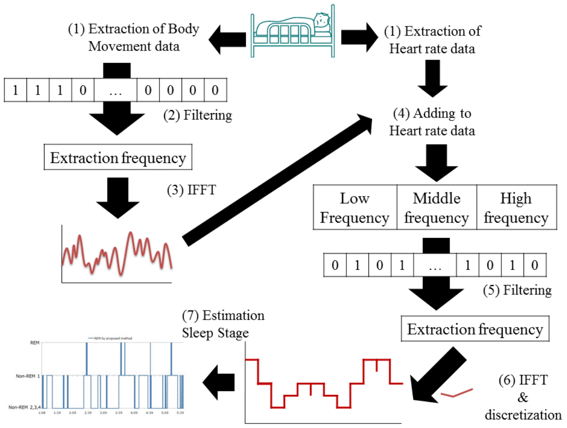

Fig. 4 Estimation using body movement

Fig. 4 shows the frame work of estimation using body movement in genetic search. Difference of previous method is what add body movement data to heart rate data. Concretely, this method is applied as following sequence.

(1) Records the body movement data and heart rate from the mattress sensor.
(2) Calculates the frequency of the body movement data by Fast Fourier Transfer (FFT), and low frequency of the body movement data should be extracted.
(3) Inverse Fast Fourier Transfer (IFFT) is executed to derive the wave pattern from the extracted frequency of the body movement data.
(4) Adding the extracted frequency of the body movement data to heart rate data.
(5) Each solution (corresponding to multiple band-pass filters) search to determine which frequency of the heart rate of adding body movement data (new heart rate) should be extracted.
(6) Inverse Fast Fourier Transfer (IFFT) is executed to derive the wave pattern from the extracted frequency of the new heart rate and sleep stages is determined by proposed method.
(7) The fitness of all solutions is calculated by comparing estimated sleep stage with fitness function
(8) The deletion and generation operations in GA process are executed to create appropriate filters and generation counter add 1. If generation counter is equal to limit of generation, system output filters, and sequence is over. If generation counter is smaller than limit of generation back to (5).

Experiment

Experimental setting

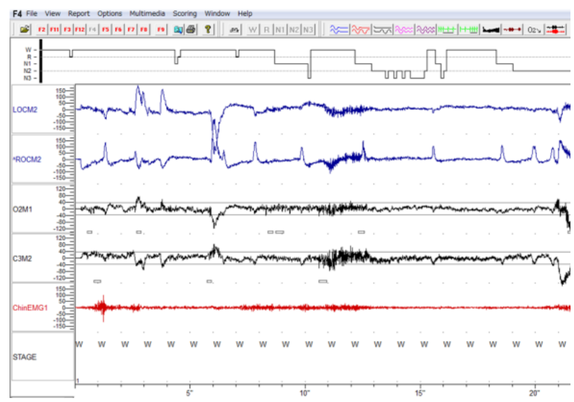

Fig. 5 Monitoring EEG, EMG, and EOG by Alice PDx

In order to investigate effectiveness of proposed method, as preliminary experiment toward for people, the following methods are conducted by using the data of some adult (i.e., 5 person, 21data) in our experiment and its results are compared with Alice PDx as a kind of the electro-encephalograph as the correct results in Fig. 5.

Table 1 . Experiment data

	Number of data	Sex	Age
A	9	M	20s
B	4	M	20s
C	2	M	20s
D	5	M	20s
E	1	M	20s

method 1: only using heart rate data
method 2: Proposed method : heart rate and body movement data

Table 1. shows using number of data, Sex and Age in experiment.
And using sleep data's long is 4.5 hours from starting sleep.
Evaluation criteria is concordance rate of sleep stage of Alice PDx and sleep stage of estimating.

Result

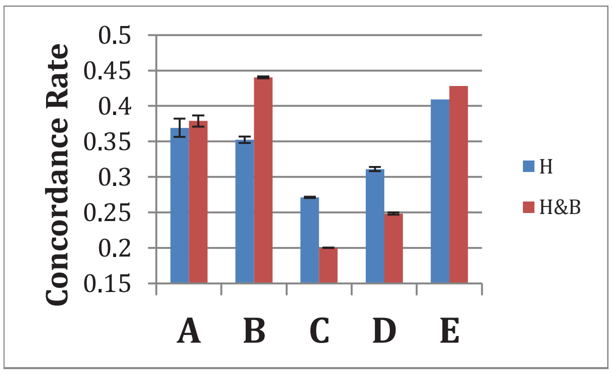

Fig. 6 Each people of concordance rate in 6 sleep stage phases

The results of each people shown in Fig. 6 and 7, and those figures are 6 sleep stage phases. Fig. 6's vertical and horizontal axes indicate the concordance rate and each person, Fig. 7's vertical and horizontal axes indicate the concordance rate and every data of each person. Left is only using heart rate data and right is using heart rate data and body movement data. Deflection of the number of the data is not have any problem, because variance value of each person is small.

As shown Fig. 5, the proposed method is better concordance rate than only using heart rate data in the A, B and E, but concordance rate of A and E are same value.

As shown Fig. 7, the proposed method is better concordance rate than only using heart rate data, specifically in 0618, 0806 and 0625, and worse than in 0626 and 0622.

Discussion

Fig. 8 is shown sleep data in 0621. This data is high value of concordance rate in all results of only using heart rate. Full line is Alice PDx data and dotted line is data of only using heart rate data. It's shown this data follows the sleep stage of Alice PDx.

Fig. 9, 10 are shown one hour sleeping data in 0625 when concordance rate of data of only using heart rate data was bad and concordance rate of data of proposed method was good. Full line is Alice PDx data, dotted line is data of only using heart rate data and broken line is heart rate data in Fig. 9, and Full line is Alice PDx data, dotted line is proposed method of sleep stage and broken line is body movement data in Fig. 10.

Sleep stage of estimating only using heart rate dosen't follow sleep stage of Alice PDx in sleep time 3 to 4.5. Sleep stage of proposed method follow sleep stage of Alice PDx, it is because proposed method uses characteristic of body movement data.

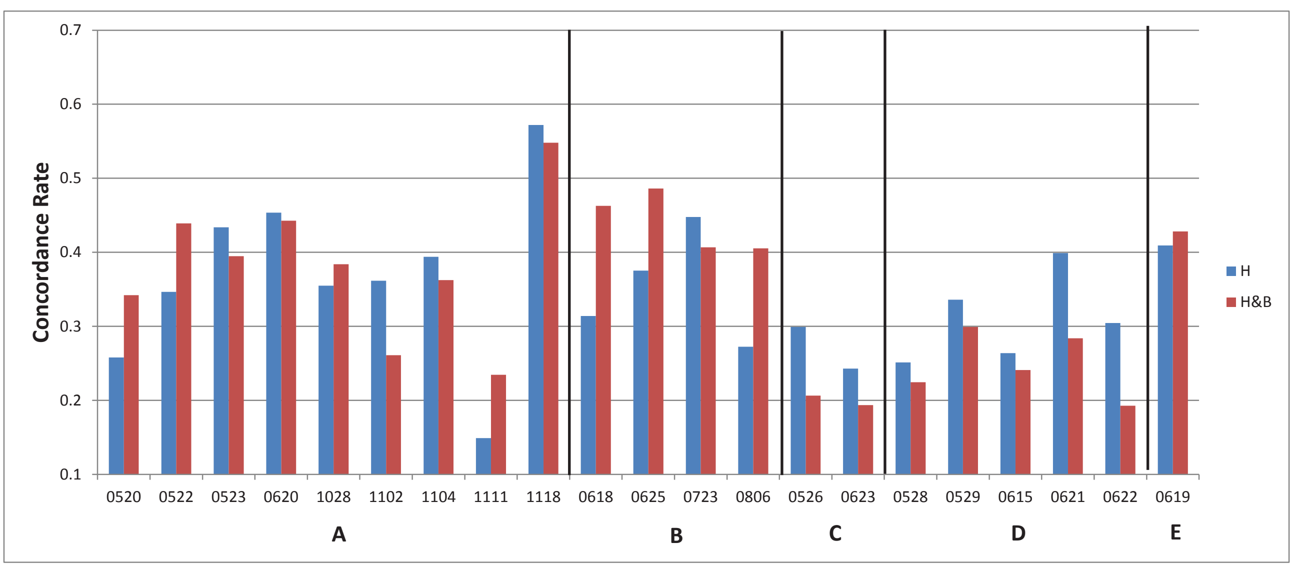

Fig. 7 Every data of concordance rate In 6 sleep stage phase

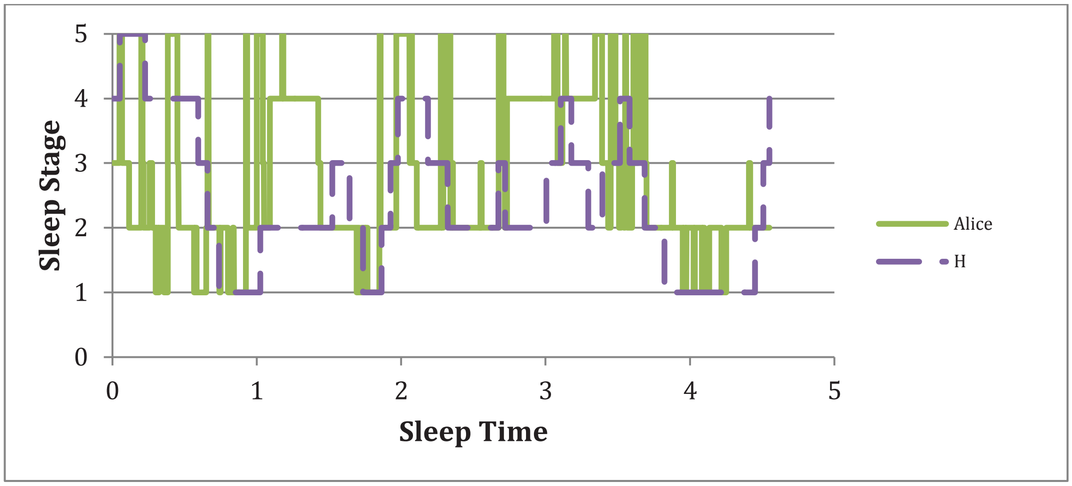

Fig. 8 Alice and estimation sleep stage only using heart rate data in 0621

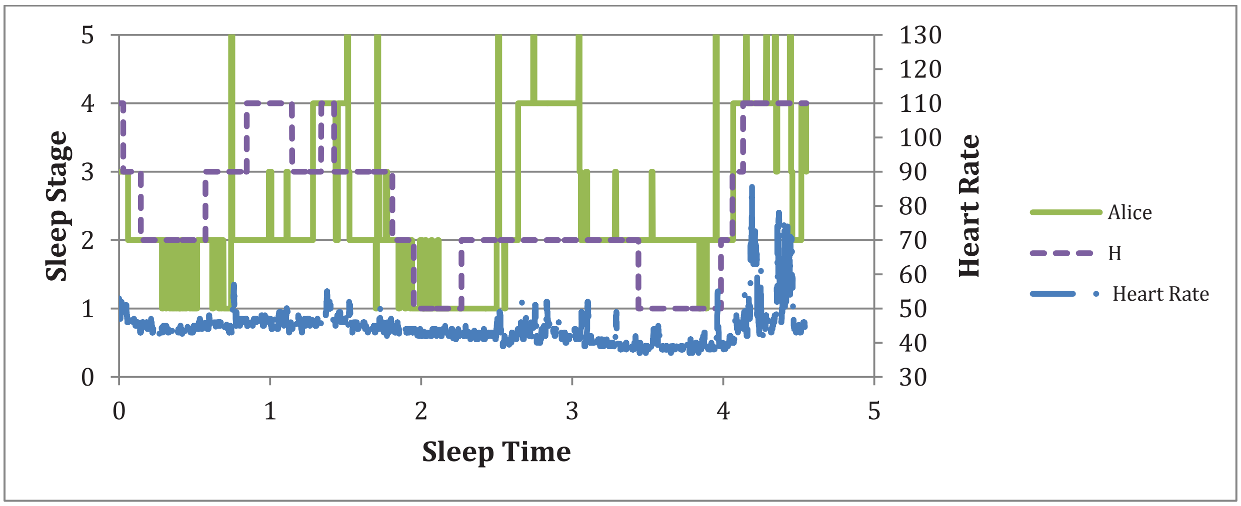

Fig. 9 Heart Rate data, Alice and estimation sleep stage only using heart rate data in 0625

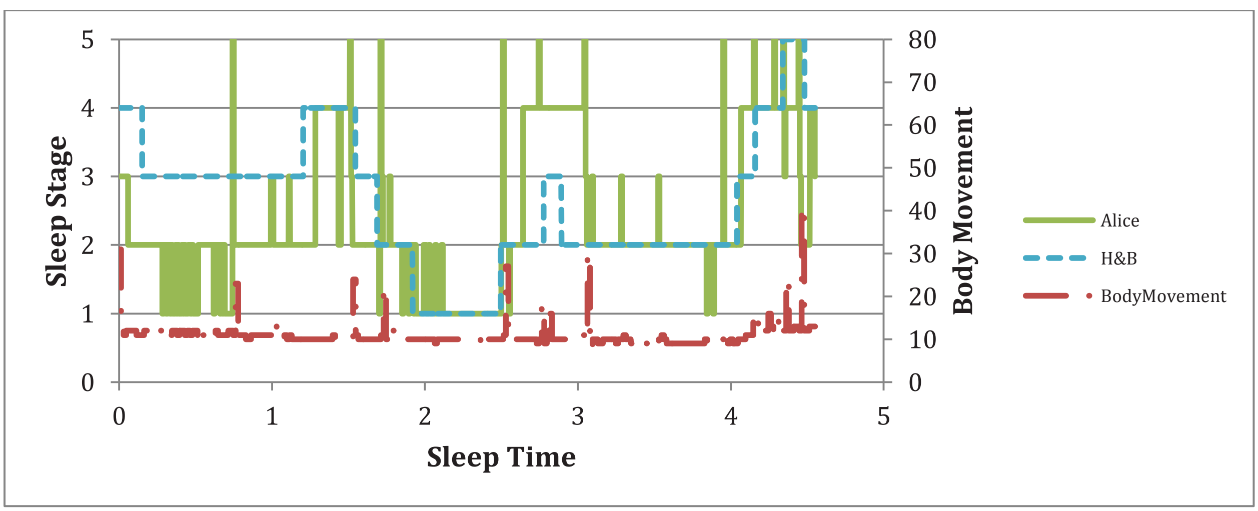

Fig. 10 Body Movement data, Alice and estimation sleep stage using body movement data in 0625

Conclusion

This paper proposed the genetic search-based method of sleep stage estimation using the body movement data. In detail, our method estimates a light stage using synthetic data of adding low frequency of body movement data is extracted to heart rate data. To investigate the effectiveness of the proposed method, we tested on the experimental data that is personal sleep data and compared the estimation accuracy of the proposed method and of the conventional method with the electro-encephalograph as actual sleep stage. The results show that the proposed method derived better accuracy than the conventional method fails to achieve high estimation accuracy in some experimental data as a few cases which have no relationship of body movement to actual sleep stage.

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