Age-Based Sleep Stage Estimation by Evolutionary Algorithm

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Abstract
This paper focuses on age-related change in sleep and improves our sleep estimation method by employing the feature of such relation between sleep stage and age. In particular, the wake stage increases as the age increases, while Non-REM stage decrease as the age increase. Using such distinctive features, we propose a new determination sleep stages, and introduce it into for our sleep estimation method based on Genetic Algorithms (GAs), which evolve the sleep stage for each person according to the fitness. To investigate an effectiveness of a new determination of sleep stages, we compare the estimated sleep stages of our method employing the proposed fitness function with that of Hirose’s method. The experimental results suggest that our method employed the proposed discretization of sleep stages has a capability to estimate the sleep stage accurately than Hirose’s method.

Introduction
To live and maintain a healthy life, it is essential for human being to have a good sleep, eating and egestion. In particular, a sleep shortage becomes the factor which obstructs a growth and a learning of teenagers, and a deep sleep is necessary to maintain good health of aged persons to live long. In addition, the sleep is important for people to work for productivity and efficiency. For all people, as noted above, not only health maintenance but also activity in daily life needs to get enough sleep.

To measure how deeply persons sleep, several research studies on the sleep stage estimation are studied so far. For example, Hirose proposed the sleep stage estimation method [7] that can provide an accurate estimation for each person only connecting a wristwatch-type device to human’s body. In particular, Hirose’s method learns the specific wave pattern of the heart rate by using evolutionary computation to estimate the sleep stage.

However, the incidence of each sleep stage through a night depends on “age”, but Hirose’s method does not take it into account, i.e., this method estimates the sleep stage according to the data of young health persons. To overcome this problem, this paper extends Hirose’s method by considering the “age” and aims at investigating the effectiveness of the proposed method though human subject experiments. Concretely, we focus on the age-related change in the sleep of individual, the sleep stage is determined by based the ratio of each sleep stage according to the age from statistical data.

This paper organized as follows. The related work is summarized next section. The explanation of our proposed method is described in section of age-based sleep stage estimation. The section of experiment provides experiment result and discussion. Finally, our works are summarized in conclusion.

Related Work

Rechtschaffen & Kales’s method
Historically, the sleep stage, which is represented as the wake-up stage, REM sleep stage, Non-REM sleep stages 1, 2, 3, and 4, respectively, is firstly used for medical purpose and its stage is estimated by medical specialists using data such as Electro-encephalogram (EEG), Electro-myogram (EMG), and Electro-oculogram (EOG) of humans as shown in Fig. 1. This approach is based on the
Rechtschaen & Kales's (R & K) method [5] and can estimate the sleep stage with high accuracy. What should be noted here, however, is that this type of estimation is subjective in terms of depending on medical specialists. More importantly, as shown in Fig. 1, this method requires to connect the devices to the head of humans, which derives the psychological stress. In particular, such restraints directly affect nervous peoples who cannot sleep during measurement.

**Watanabe’s method**

To solve the problem of the R & K method, Watanabe proposed the sleep stage estimation method by using the data obtained from the air mattress[9] in a bed as shown in Fig. 2. 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], Watanabe’s method estimates the sleep stage by using the heart rate obtained from the sensor in bed. Concretely, Watanabe’s method divides the heart rate into the low frequency range of the heart rate (which is lower than 135 min), the middle frequency range of the heart rate (which is between the low and high frequency range of the heart rate), and the high frequency range of the heart rate (which is higher than the half of averaged time of the peak heart rate rate), and then estimates the sleep stage of humans according to the model of low, middle, and high frequency range of the heart rate. Since Watanabe’s method estimates the sleep stage according to the model created from the heartbeat data of the small number (i.e., five) of the healthy young subjects (i.e., university students), it is difficult to perfectly.

**Hirose’s method**

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 evolutonal computation. It is 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, GA searches 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-REM stage, and proposed fitness function of GA 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.

**Table 1 Distinct change of heart rate and body movement in the REM/Non-REM sleep stages**

<table>
<thead>
<tr>
<th>Mode</th>
<th>distinctive change in the heart rate</th>
<th>distinctive change in the body movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>REM</td>
<td>Heart rate increases</td>
<td>Body movement becomes to be active</td>
</tr>
<tr>
<td>Non-REM</td>
<td>Heart rate decreases</td>
<td>Body movement becomes to be calm</td>
</tr>
</tbody>
</table>

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. 3, by using proposed method, REM/Non-REM sleep stages are determined and used as the fitness function of GA.

Age-based Sleep Stage Estimation

Fig. 4 shows the changes of a total sleep time and sleep stages according to a change of age. In this figure, the vertical axis indicates the total sleep time, while the horizontal axis indicates the age. The sleep stages are discretized to the six categories (i.e., wake, REM, sleep stage 1, 2, 3, and 4, which indicates the sleep order from the light sleep to the deep sleep). The sleep latency means the time of falling asleep. As shown in Fig. 4, the total sleep time decreases as the age increases. The important points of this figure are summarized as follows:

(a) the wake stage increases as the age increases;
(b) the deepest sleep stages as the age decreases;
(c) This figure suggests the strong relations between the age and sleep stage.

This figure suggests the strong relations between the age and sleep stage.

By applying determination of 6 sleep stages according to age by focusing on the sleep stage tendency described in the previous section, we propose the age-based sleep stage estimation method by adjusting the ratio of each sleep stage according to the age. Concretely, our proposed method calculates the 6 sleep stages by extracting the wave pattern of the heart rate data according to Hirose’s method, and modifies the ratio of each sleep stage according to the age. The detailed explanation for the proposed method is described as follows and Fig 5.

1. The extracted wave pattern from heart rate data is sorted in the descending order of its amplitude.
2. The sorted wave pattern is discretized from the wake, REM, sleep stage 1, 2, 3, and 4 in decreasing order of its amplitude according to the ratio of each sleep stage depending the age of a person.
3. The sorted and discretized wave pattern is re-ordered in chronological order.

Sequence of proposed method employed System

To estimate the sleep stage, GA is applied as following sequence and shown Fig. 6:

1. Records the heart rate and body movement data from the mattress sensor.
2. Calculates the frequency of the heart rate data by Fast Fourier Transfer (FFT).
3. Each solution (corresponding to multiple band-pass filters) search to determine which frequency of the heart rate should be extracted;
4. Inverse Fast Fourier Transfer (IFFT) is executed to derive the wave pattern from the extracted frequency of the heart rate and sleep stages is determined by proposed method;
5. The fitness of all solutions is calculated by comparing estimated sleep stage with fitness function.
6. 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 (3).

**Experiment**

**Experimental setting**

In order to investigate effectiveness of proposed method, as preliminary experiment toward for people of variety ages, the following methods are conducted by using the data of some adult (i.e., 8 person in 20s, one person in 30s, and one person in 40s) in our experiment and its results are compared with Alice PDx as a kind of the electroencephalograph as the correct results.

method 1: Hirose’s method  
method 2: proposed method

In addition, for investigation of the relation between the age and ratio of each sleep stage, method 2 is applied each ratio of sleep stage corresponding to age, which is statistical data from [7] as shown table 2.

Note that The Alice PDx enables patients to be tested outside of the lab without compromising study results and helps clinicians avoid the costs associated with retesting and can monitor EEG, EOG, and EMG by attaching sensors as shown Fig. 8.

The evaluation criteria are the accuracy rate of estimated

<table>
<thead>
<tr>
<th>Sleep stage</th>
<th>age</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wake</td>
<td></td>
<td>0.04</td>
<td>0.10</td>
<td>0.14</td>
<td>0.20</td>
</tr>
<tr>
<td>REM</td>
<td></td>
<td>0.21</td>
<td>0.20</td>
<td>0.17</td>
<td>0.17</td>
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<tr>
<td>Stage 1</td>
<td></td>
<td>0.07</td>
<td>0.06</td>
<td>0.07</td>
<td>0.13</td>
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<tr>
<td>Stage 2</td>
<td></td>
<td>0.50</td>
<td>0.51</td>
<td>0.50</td>
<td>0.45</td>
</tr>
<tr>
<td>Stage 3</td>
<td></td>
<td>0.09</td>
<td>0.07</td>
<td>0.05</td>
<td>0.03</td>
</tr>
<tr>
<td>Stage 4</td>
<td></td>
<td>0.09</td>
<td>0.06</td>
<td>0.06</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Fig. 6 Overview of sleep stage estimation by using proposed method and Genetic Algorithm

Fig. 7 Monitoring EEG, EMG, and EOG by Alice PDx

Fig. 8 Results of experiment (30s man)

Fig. 9 Results of experiment (40s man)
sleep stages, which is compared with the electro-encephalograph from the viewpoint of the six discretized stages.

**Result and Discussion**

The results of each case shown in Fig. 8, 9, and 10, where the vertical and horizontal axes indicate the accuracy (how correctly estimates the sleep stages) and the age which is applied the ratio of sleep stage, respectively and the solid and dash lines indicate accuracy rate of method 2 and method 1, respectively.

As shown Fig 8, in case of 30s men, the proposed method is better accuracy rate than Hirose’s method in the sleep stage ratio of 20s and 40s, but is lower performance in other ages. This result suggests that the sleep of subject approximates the statistical data.

As shown Fig 9, in the case of 40s men, the proposed method is lower performance than Hirose’s method in the sleep stage ratio of 40s, but is better in the sleep stage ratio of 20s and 60s. From this result, it is necessary to apply 30s and 50s sleep stage ratio.

Fig 10 shows the result of experiment which all of subject in their 20s. The performance of proposed method is better than Hirose’s method excluding one result. In particular, the cases of applying the ratio of sleep stage in 20s are good in average. These results suggest that determination of sleep stage based on age-related change in sleep is effective to estimate sleep stage more accurately. However, on the other hands, lower performance of proposed method than Hirose’s method suggests that sleep stage is related to not only age but also sleeping time, physical condition, environment (e.g., bedclothes, light, temperature of a room), and so on.

**Conclusion**

This paper proposed the age-based sleep stage method by extending the Hirose’s method to introduce the ratio of each sleep stage. To investigate the effectiveness of the proposed method, the estimated sleep stage of some adult data as preliminary experiment is compared with that of Hirose’s method from the viewpoint of an accuracy of estimation calculated by the electro-encephalograph. From experimental result, the accuracy of the proposed method is better than that of Hirose’s method in average. Since this research conducted the human subject experiments with
only some adults, the experiments of many persons with various ages and should be tackled as the future works.

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References


