# Automatic Estimation of Light Sleep Level during Short Nap

Bei Wang[1], Takenao Sugi[2], Xingyu Wang[1], Shuichiro Shirakawa[3], Masatoshi Nakamura[4]

[1]*Department of Automation, East China University of Science and Techonology, Shanghai, China*
[2]*Department of Electrical and Electronic Engineering, Saga University, Saga, Japan*
[3]*National Centre of Neurology and Psychiatry, Tokyo, Japan*
[4]*Research Institute of Systems Control, Institute for Advanced Research and Education, Saga University, Saga, Japan*
*(Tel: 86-21-64253581; Fax: 86-21-64253386)*
*(wangbeish@gmail.com)*

***Abstract:*** Short nap is a good relaxation way when people feel sleepy and tired during the day time. An automatic light sleep level estimation technique was presented for short nap sleep evaluation. Parameters were extracted from the polysommnographic sleep record. Sleep stages of open eyes awake, close eyes awake, and stage 1 were determined automatically based on the conditional probability. The conditional probability indicated the possibility of occurrence of sleep stages during short nap. The light sleep level was estimated based on the continuous change of conditional probability of awake. The developed technique can be usable for comfortable short nap sleep control.

***Keywords***: light sleep level, short nap, conditional probability**.**

## I. INTRODUCTION

Sleep is essential for the normal functioning of all the systems of our body. Sleep is fundamental for healthy, which is related to the circadian rhythms. Usually, sleep time or sleep/wake cycle is controlled by environmental factors and internal factors. Comfortable environment control has significant affect to ensure good sleep for human health.

Daytime prophylactic nap is an effective relaxation way which can avoid the decline of working efficiency and attention level [1]. This kind of short nap sleep has positive effects on performance level, while it also has negative effects as sleep inertia. The suitable latency of a short nap is suggested about 20 minutes to maintain the daytime arousal level [2]. However, the proper time of short nap is uncertain by various factors. The environment factors included the temperature, sound, etc. The internal factors were mainly the individual difference on mental and physical functions. Therefore, automatic control of short nap sleep time which can be adaptive to persons is necessary to be developed.

In this study, an automatic estimation technique for light sleep level during short nap was developed. The ultimate purpose is to control the sleep time for an effective short nap. The sleep stages of open eyes stage awake O(W), close eyes stage awake C(W) and stage 1 (S1) during short nap were determined automatically. The main method for sleep stage determination was based on the expert knowledge-based multi-valued decision making, which had been developed in our previous study [3]. The algorithm was modified in order to obtain the changing of conditional probability for sleep stages. The changing of conditional probability was adopted to estimate the light sleep level during short nap sleep.

## II. METHOD

### 1. Data acquisition

The sleep data of five subjects were adopted for light sleep level analysis. The overnight sleep recording of two subjects was selected for training to obtain the parameter distribution for sleep stage discrimination. Another three were for testing to calculate the conditional probability which representing the possible occurrence of each sleep stage.

All of the sleep data were recorded based on the polysommnographic (PSG) measurement including four electroencephalogram (EEG), two electrooculargram (EOG) and one electromyogram (EMG). EEGs were recorded by using cup electrodes fixed to the scalp at points C3, C4, O1, and O2 with the reference of earlobe A1 and A2 according to the International 10-20 System [4]. EOG was recorded by using three cup electrodes which were pasted near the eyes to record the vertical and horizontal eye movements. Two cup electrodes were attached near chin to record the muscle activity of EMG.

## 2. Visual inspection

The continuous sleep data was divided into consecutive 30-second epoch. Sleep stages were inspected visually for each epoch by a qualified clinician (F. Kawana) in Toronomon Hospital.

The light sleep states were inspected mainly according to EEG characteristics [5]. SW was scored to open eyes awake O(W) and close eyes awake C(W) according to the alpha activity (8-13 Hz) in O1/A2 and O2/A1 channels. S1 was scored with low voltage slow wave activity of 2-7 Hz in C3/A2 and C4/A1. Eye movements were disappeared and muscle activities were depressed when vigilance level was gradually declined.

## 3. PSG parameters

The parameters for sleep stage determination were extracted from the periodograms of neurological signals of EEG, EOG and EMG. Table 1 showed the definition of three parameters. $D_\alpha$ was calculated in EEG channels as the ratio of the amount of alpha components (8-13Hz) to the amount of total frequency components (0.5-25Hz). $A_{HF}$ was calculated in EEG channels as six times of the square root of the amount of high frequency components (25-35 Hz). $S_{L-R}$ was calculated in EOG channels as the amount of eye movement. Those parameters were selected which can discriminate the parameter distribution among the sleep stages of O(W), C(W) and S1.

The parameter distributions were constructed for sleep stages. Cauchy distribution was adopted to estimate the parameter distribution, as

$$f(y|\zeta) = \frac{b}{\pi((y-a)^2 + b^2)}, \qquad (1)$$

Table 1. Parameter definition

| | Definition |
|---|---|
| Duration [%] | $D_\alpha = \frac{S_\alpha}{S_T} \times 100\%$ |
| Amplitude [$\mu V$] | $A_{HF} = 6\sqrt{S_{HF}}$ |
| Amount [$\mu V^2$] | $S_{L-R}$ |

*α: 8-13 Hz, T: 0.5-25 Hz, HF: 25-35Hz, L-R: 2-10 Hz

where $y$ is parameter, $\zeta$ is sleep state, $a$ and $b$ are location and scale parameters of Cauchy distribution. $a$ and $b$ were determined by least square method applying to the histogram of parameters.

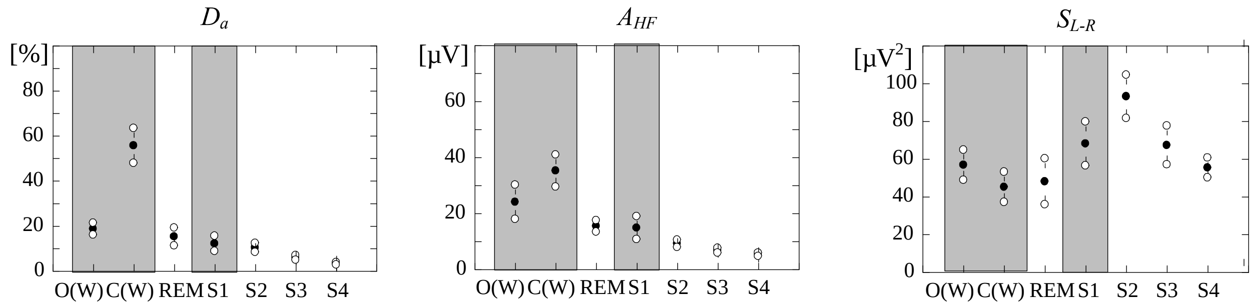
## 4. Conditional probability

The conditional probability was calculated based on the Bayes rule as,

$$P_{k|k}(\zeta^i) = \frac{f(y_k | \zeta^i) P_{k|k-1}(\zeta^i)}{\sum_{j=1}^{n} f(y_k | \zeta^j) P_{k|k-1}(\zeta_j)}, \qquad (2)$$

where $P_{k|k-1}(\zeta^i)$ is the predicted probability, $y_k$ is a parameter vector and $f(y_k|\zeta^i)$ is the joint probability density function of parameters in $y_k$ for stage $\zeta^i$ .

The conditional probability of O(W), C(W) and S1 were calculated for every 5-second segment. The average value of each conditional probability among the six 5-second segments was adopted as the conditional probability for one 30-second epoch. The higher value between the conditional probabilities of stage O(W) and C(W) was adopted as the conditional probability of awake $P_W$. $P_W$ was adopted to estimate the light sleep level during short nap sleep.




(a) Ratio of alpha components (8-13 Hz) calculated on O1/A2 and O2/A1 channels

(b) Amplitude of high frequency components (25-35 Hz) on C3/A2 and C4/A1 channels

(c) Amount of eye movement (2-10 Hz) on LOC/ROC channel

Fig.1. Probability density function of parameter for each sleep stage

## III. RESULTS

### 1. Parameter distribution

The overnight sleep recordings of two subjects were utilized to obtain the parameter distribution. The probability density functions of Cauchy distribution for three parameters were given in Fig.1. The horizontal axis was stages and vertical axis was probability. The empty circle indicated the location parameter of Cauchy distribution while full circle the scale parameter of Cauchy distribution.

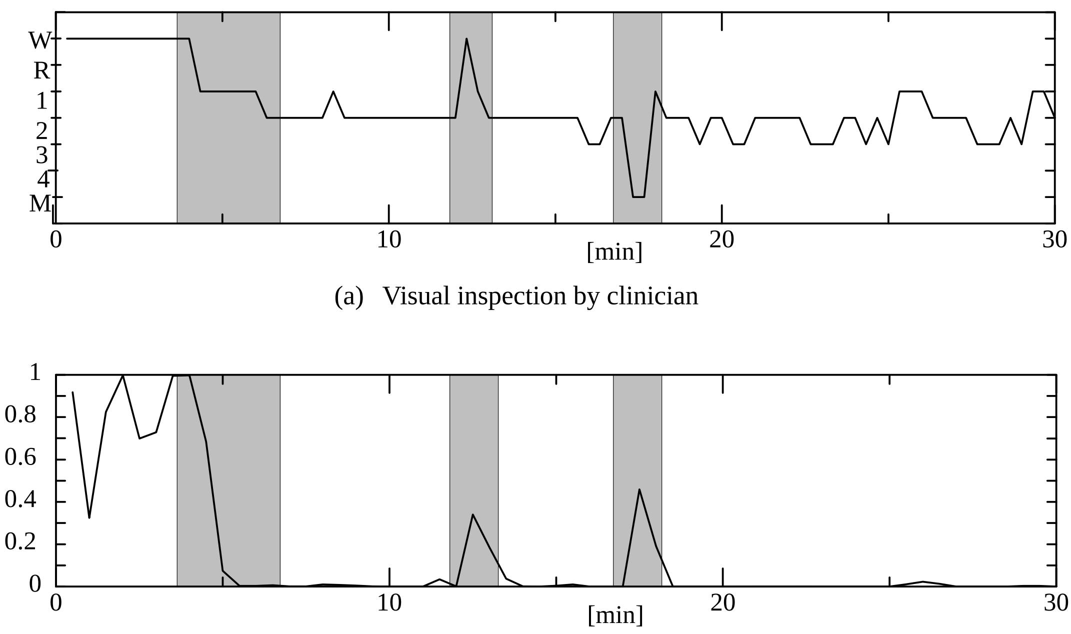
Since the training data were overnight sleep recording, the parameter distributions for all the sleep stages were illustrated, where W was stage awake, R was rapid eye movement stage, S1, S2, S3 and S4 were non-rapid eye movement of sleep stage 1, 2, 3 and 4, M was body movement. The darken parts represented the parameter distribution for O(W), C(W), and S1. The duration of alpha activity showed higher values for stage C(W). The amplitude of HF activity indicated C(W) and O(W) were separated from S1. The amount of eye movement of S1 was higher. The combination of those three parameters was utilized to calculate the conditional probability of each sleep stage for test subjects.

### 2. Light sleep level estimation

Another three subjects were utilized for testing. In Fig.2, the conditional probability of awake $P_W$ was shown comparing with the visual inspection.

Fig.2 (a) showed the visual inspection by clinician. Fig.2 (b) showed the conditional probability of awake obtained by expert knowledge-based multi-valued decision making method. The horizontal axis was time. The vertical axis was sleep stages. The beginning 30 minutes of sleep data before falling to deep sleep were extracted from the whole recording. The conditional probability $P_W$ was rather high when visual inspection was stage awake. $P_W$ was decreased when stage awake changed to stage 1 and stage 2. When the body movement was inspected by clinician, the corresponding conditional probability $P_W$ also has higher value. The darken parts showed that the changing of conditional probability was consistent with visual inspection. At the beginning of recording, the conditional probability slightly varied when visual inspection was kept to be stage awake.

The result of another two test subjects were shown in Fig.3 and Fig.4. The continuous changing of conditional probabilities $P_W$ was given respectively.




(a) Visual inspection by clinician

(b) Conditional probability of stage awake

Fig.2. Light sleep level estimation based on conditional probability by expert knowledge-based multi-valued decision making method for subject A.

Although the visual inspections were not given for these two subjects, the sleep stage changing can be estimated according to the continuous changing of conditional probability of stage awake $P_W$. The higher value indicated higher vigilance level which might be stage awake. The lower value indicated lower vigilance level where sleep was transited to stage 1 and stage 2.

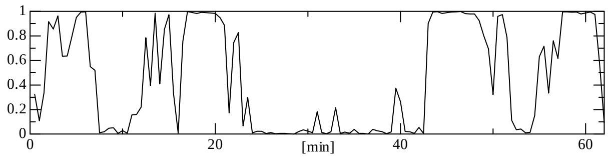



Fig.3. Light sleep level estimation for subject B.

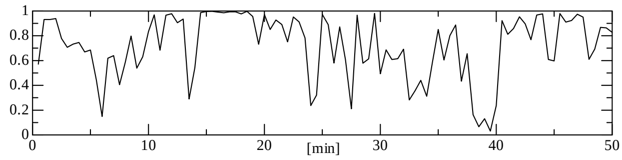



Fig.4. Light sleep level estimation for subject C.

## IV. DISCUSSION

### 1. Light sleep level estimation

Adequate regulation of the sleep state is significant to ensure an effective short nap. During the short nap sleep, it is better to wake up from light sleep stage. The automatic sleep stage determination by expert knowledge-based multi-valued decision making method was effective for overnight sleep stage determination. It was also usable to obtain the continuous change of conditional probability.

In this study, the conditional probability of sleep stage was calculated continuously to indicate the light sleep level during short nap. The result showed that the conditional probability of awake is useful for light sleep level estimation. For further study, the relationship between light sleep level and conditional probability of all the sleep stages needs to be considered together to construct an effective parameter for light sleep level estimation in order to improve the accuracy.

### 2. Comfortable sleep circumstance control

The developed technique can be usable for comfortable sleep circumstance control especially to ensure an effective short nap. When conditional probability of awake was decreased, the sleep stage may be transited to light sleep stage 1 and stage 2.

Based on the light sleep level estimation result, subject can be waked gradually from light sleep by using proper environment controlling technique. Therefore, comfortable short nap sleep control can be realized.

## V. CONCLUSION

Short nap sleep data was analyzed based on the expert knowledge-based multi-valued decision making method. The conditional probability of awake was utilized for light sleep level estimation during short nap. The developed technique can be usable for effective short nap control.

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