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TECHNIQUE OF AUTOMATED HYPNOGRAM CONSTRUCTION

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The technique of automated sleep stage recognition and hypnogram construction has been considered. For partition of initial polysomnogram by segments obtained as a result of patient sleep monitoring the signal energy is analyzed using nonlinear energy controller. Frequency weighted energy is calculated for all registered signals then averaging and segmentation occur according to monitored signals behavior. Secondary index vector which is used at transition from segments to fixed duration periods is formed for segments. One or another sleep stage is finally assigned to the period by correlation analysis. Accuracy of the developed algorithm is connected with quantity of considered secondary indices, maximally detailed description of sleep stage characteristics and realization of training by manually prepared examples.

Rapid development of computer science and microtechnology during last decades made it possible to apply diagnostic equipment allowing recording continuously and processing wide range of physiological indices. It gave, in its turn, a possibility to specialists to investigate in detail life activity of human body in different states including sleep [1–3]. At the present the majority of scientists and doctors pay much attention to sleep quality and man state in this period of his life. It is known that in sleep many chronic and pathologic diseases which can be poorly diagnosed or often can not be diagnosed at all at wakefulness appear. Man health and efficiency depends on sleep quality. The importance of sleep for healthy living is a conventional fact. The first attempts of recording physiological indices by primitive equipment were made more than 100 years ago. Since that time a number of standards and agreements was developed in this field. In particular, in 1968 a manual Rechtschaffen & Kales (*R&K*) was published and was accepted as a standard [4]. Sleep stages and typical features of each of them were described in it in detail. It was suggested to divide sleep into five stages: stages with slow eye movement *I, II, III, IV* and stage of rapid eye movement (REM). When studying sleep a wide set of physiological indices is recorded. They are different in their nature:

- electroencephalogram (EEG) – brain transistance;
- electrocoulogram (ECG) – eye-bulb movement in two derivations relative to counterlateral referents;
- electromyogram (EMG) – muscle tonus;
- electrocardiogram (ECG);

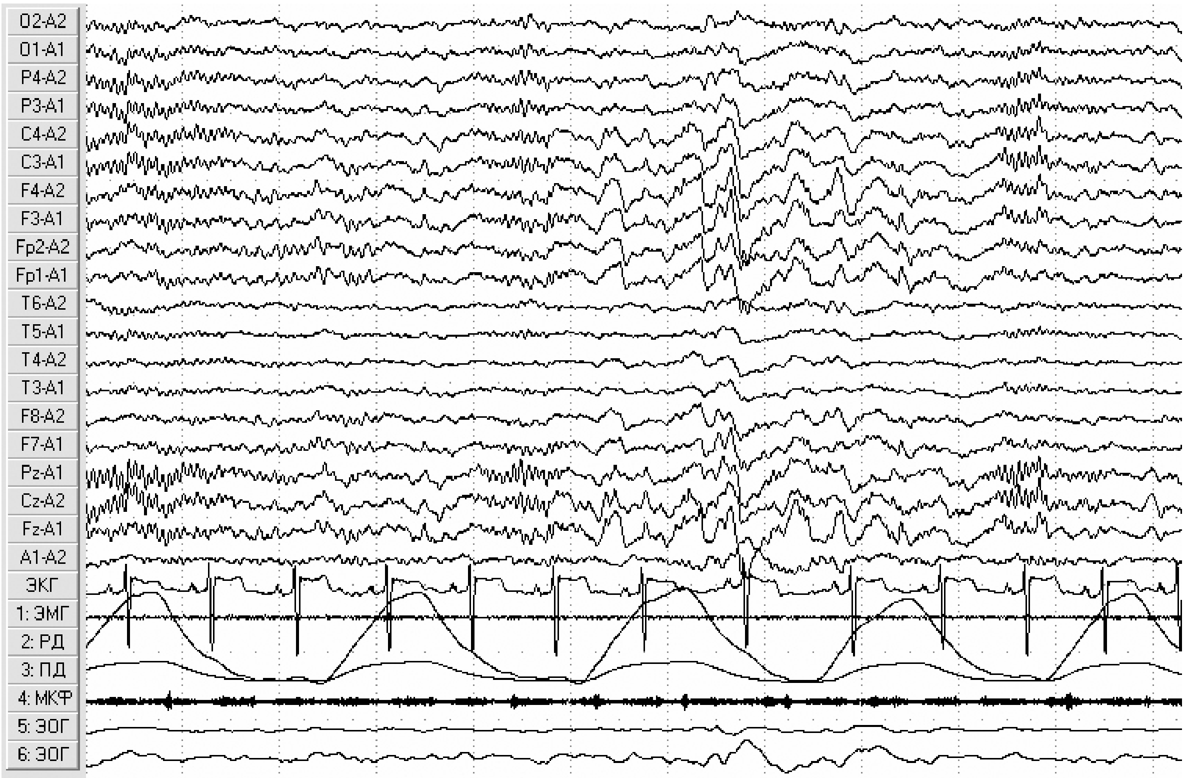

Fig. 1. *Basic set of physiological indices recorded in sleep. At EEG signals obtained from derivations Cz-A2 and Pz-A1 «sleep spindles» (Fig. 2) being factors II, III and IV of sleep stages are well seen*

- breath parameters – recorded by a sensor set at a special belt in the region of chest or stomach, breath recursion (BR) in chest or abdominal region or by a sensor of breath stream (BS) from nose;
- snore – recorded by a special microphone (MCP);
- galvanic skin response (GSR);
- change of oxygen content in blood (SpO_2);
- blood pressure and other indices.

The first three stages: EEG, ECG and EMG (Fig. 1) are obligatory signals for constructing hypnogram the rest ones are secondary and in some cases may increase reliability of detecting sleep stages or validity of diagnostics of these or those diseases.

At the present the task of sleep stage recognition and automated construction of hypnogram was solved by many researches with different success [1, 3, 5]. The main complexity of this task is in the fact that *R&K* standard was made and stated in the form of references for clinicians using signal visual analysis and operating verbal characteristics which hardly can be numerically and formalized estimated. Besides, signals which should be processed and patterns which should be recognized are effected by a great number of outside perturbation actions (artifacts) and changed depending on patient individual features such as age, life style, different diseases, reaction on environmental influence. In this connection the task of development and implementation of suggested algorithm may be estimated as actual one and requiring application of new peculiar data processing techniques and software engineering for its solving.

The analysis of achievements in the field of automation of sleep stage recognition process allows making conclusion on the fact that the new technique should possess the following characteristics:

- high validity of hypnogram construction (coincidence with hypnogram constructed by experts by common decencies on the basis of the same data);
- possibility of algorithm functioning in real time (at the present a possibility of developing independent device for sleep monitoring is studied by a number of research organizations);
- possibility of algorithm adaptation to different classification of sleep stages and rules of hypnogram construction;
- algorithm applicability to the data obtained from different groups of patients (for example, physiological sleep patterns of different age groups of tested humans may considerably differ, in particular, infants, as a rule, has not five but only two sleep stages).

The method of hypnogram automated construction developed and described further uses mathematical device of various fields of theoretical informatics. Some of applied methods, in particular the method of EEG segmentation by weighted-frequency energy described below, are new ones and at the present they are studied for compliance to efficiency and validity criteria.

Segmentation of initial data of polysomnographic research was carried out by the analysis of EEG-signal by nonlinear energy operator as it is described in [3, 6]. The so-called «Weighted-frequency energy» G is computed by the following formula:

$$G(n)=\left|\sum_{m=n-N+1}^{n}\Psi(m)-\sum_{m=n+1}^{n+N}\Psi(m)\right|,$$

where N is the window size; n is the number of counting; $\Psi(n)=x_{n-1}x_{n-2}-x_n x_{n-3}$.

Computing G it is reasonable to use the adaptive threshold T calculated independently for each counting in its neighborhood with size L:

$$T(n)=\max\left[\frac{G_{NLEO}(n-L/2)}{(n+L/2)}\right].$$

In this case G is calculated in the following way:

$$G(n)=\begin{cases}G_{NLEO}(n) \text{ при } G_{NLEO}(n)\geq T(n)\\ 0 \text{ при } G_{NLEO}(n)<T(n)\end{cases}.$$

Extremums G allow detecting with rather high reliability the areas where signal spectral characteristics are changed significantly. And, on the contrary, – recording areas where G is stationary may be considered as segments which may be fully referred with high reliability degree to one sleep stage.

The following parameters are calculated for each segment:

- for EEG – statistical distribution of values of amplitude excursion of selected waves for each frequency range;
- for EMG – amplitude values characterizing muscle tonus;
- for ECG – values of amplitudes which are later used for detecting «rapid» and «slow» eye movements.

On the basis of distribution analysis of values of EEG signal amplitude excursion *delta, theta, alpha, beta indices* are calculated for waves exceeding certain thresholds by amplitude according to sleep classifier criteria – as a ratio of sum time lag during which waves of analyzed rhythm exceeding wave threshold by amplitude were observed to general age duration.

To increase accuracy of stage REM recognition for which there is no accurate list of typical features of EEG-signal change in *R&K* standard the analysis of signal complexity estimating its entropy is assumed to be used. As it is known, during REM stage a man dreams that is characterized by EEG-signal compound and unsteady in frequency and amplitude. Signal complexity may be estimated, in particular, by Lempel-Ziv algorithm by analogy with the method used for estimating sleep depth at anesthetization and described in detail in the article [7].

When the secondary indices are calculated a vector consisting of main features listed before is formed for each segment: parameters of EEG, EMG and ECG. Then the transfer from segments to ages is carried out that allows approximating maximum the described method operation to operation of expert following *R&K* standard. In the article [3] the method in which cluster analysis of segments is carried out and sleep stages are assigned to segments is described. However, such approach does not allow fully implementing the automated construction of hypnogram by *R&K* standard (as this standard is directed to the work with ages of fixed length) and requires expert participation at final stage. It is more reasonable to transfer to ages after parameters calculation for all segments and then features of presence of sleep spindles, K-complexes, saw-tooth waves and REM are calculated for each age.

K-complexes (according to their description in [2]) are recognized by analyzing their time parameters and in this case duration and amplitude of each complex component is estimated and this wave is tested for belonging to the class of K-complex (Fig. 2).

To detect rapid eye movements the correlation between data obtained from two ECG derivations accounting additional analysis of the first derivative (ECG rate change) is computed as direct frequency separation into SEM and REM is difficult, as a rule due to nonsinusoidal asymmetric form of ECG at REM.

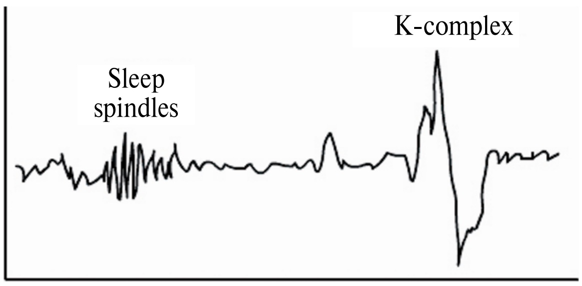

Fig. 2. *Typical features of sleep stages II, III and IV [2]*

Saw-tooth waves, features of paradoxical sleep and sleep spindles (Fig. 2) indicating the fact that a man is in sleep stage *II* or *III* are searched by nonharmonic analysis allowing detecting by spline interpolation the presence of waves in specified frequency range in the form convenient for analysis.

When the vector containing the described features is formed for each age all ages are sequentially classified by correlation analysis computing minimal distance in feature space between the vector describing each age and model vector determined for each sleep stage.

System adjustment to real-life environment is provided when for each parameter according to which the estimation is carried out a weighting factor determining value of this parameter for the examined sleep stage is computed. The autopatch of these factors is possible when changing the constructed hypnogram by expert at correctness analysis of automated determination of sleep stages.

To debug and test the algorithm described in this article the software module for digital electroencephalograph-analyzer EEGA-21/26 «Encefalan-131-03» produced serially by «Medikom-MTD» and intended for wide range of neurophysiologic researches was developed. The module implements the stages of automated recognition of sleep stages given in the article and arranges special-purpose marks on sleep stage borders. For further performance analysis of algorithm functioning the results are given in the form of classical hypnogram (Fig. 3). Algorithm is adjusted using the data base of clinical polysomnographic researches accumulated by us.

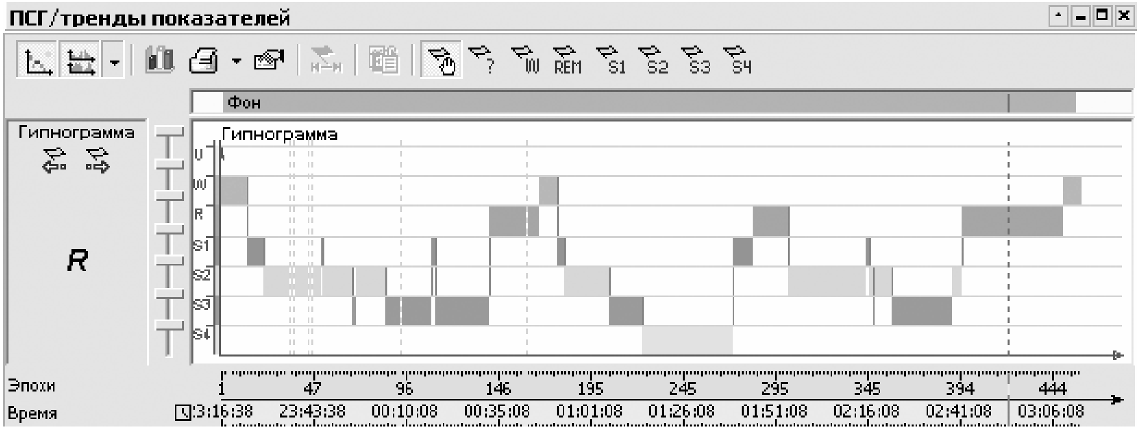

Fig. 3. *The example of constructed hypnogram where U are the unrecognized ages; W is the wakefulness; R is the stage of REM; S1-S2 are stages I-IV respectively. Astronomical time and a number of age are displayed on a scale in bottom part of the window*

It should be noted that this method is rather perspective and allows, according to our preliminary estimations, obtaining the results acceptable in accuracy and reliability for testing different sleep disturbances as well as supporting possibility of adjusting algorithm to different age group. The authors express cautious hope to the fact that use of this method simplifies significantly and expedites work of specialists who have to implement regularly visual processing of hours-long recordings of neurophysiologic data for hypnogram construction.

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