SOMNOLENCE DETECTION USING ELECTROENCEPHA-LOGRAM

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ABSTRACT

One of the tasks performed by analysis of electroencephalogram (EEG) is the problem of recognizing the state of somnolence, characterized by lower level of attention and the extension of reaction time to any external stimuli. In this paper we propose a method for detection of such state, based on an analysis of the EEG signal's power spectra. Classification is realized by using fuzzy logic. Four classifiers are designed, which are based on a fuzzy inference system (FIS), that are differ in IF-THEN rule's bases. The approximation of membership function (MF) is implemented using fuzzy clustering (FC). Classification results are very dependent on the applied rules and on the choice of the analyzed frequencies.

1. INTRODUCTION

The brain electrical activity is recorded by electroencephalography (EEG). Analysis of EEG signals is used for various purposes in clinic and research. EEG allows not only to diagnose epilepsy or brain death, but also to determine the physiological condition of the person, such as somnolence. It is possible due to the fact that all the changes in the psychophysiological state of man are manifested in the signals of his brain. The subject residing in drowsiness state cannot adequately respond to external stimuli. In the case of human operator, for example, a driver, this can lead to accident and make the threat to human life. Therefore the problem of sleepiness state recognizing is very topical nowadays [1].

2. EXPERIMENTAL DATA

EEG signals were recorded with experimental laboratory system LAB BIOPAC (Biopac Systems, Inc., USA) with sampling frequency 200 Hz. Two EEG channels P4 and T6 were selected from International 10-20 System of Electrode Placement. The signals of these electrodes contain fewer numbers of artifacts. Moreover, this region of brain shows good expression of alpha activity which is an important feature of the relaxation (the state of rest with closed eyes). The acquisition time of each signal varies between 12 and 18 minutes. At the beginning of the experiment the subjects (10 healthy young people) solve mathematical problem (summation of two-digit numbers), then it follows opening and closing of the eyes by turns. The subjects were lying at rest with closed eyes at all remaining time. For further processing 30 segments of the signals have been selected, each of signal lasts

21s. These segments contain the transition from the state of alertness to a state of relaxation.

Moreover, in MATLAB there have been a simulation of EEG signal, which is a sum of 20 signals with frequencies 1-20 Hz and time-varying amplitude. This signal simulates a situation of transition from the state of vigilance to somnolence through relaxation and inversely.

3. METHOD

3.1. TIME-FREQUENCY ANALYSIS

EEG signals have nonstationary character. Therefore it is appropriate to examine its spectral composition in time-frequency domain using the short-time Fourier transform (STFT). Time-frequency analysis consists of measuring the spectra of signals from the short segment identified with window. In this work the Hann window is used with 75% overlap. The power spectrum of EEG signals can be estimated as:

$$S_i(k) = \frac{1}{N}\left|F_{w_i}(k)\right|^2 \qquad (1)$$

where N is the length of time, $F_{w_i}(k)$ is the spectrum of individual segment signal $f_{w_i}(n), n = \overline{0, N-1}$, usually derived using the discrete Fourier transform (DFT).

Thus the result of the STFT is a 2D spectrum (spectrogram), which can be imagined as a function depending not only on frequency but also on the position in time. Changes of the psychophysiological state are reflected by increasing or decreasing of signal energy in certain spectral components. Spectrogram is analyzed for detection of the somnolence state.

3.2. FUZZY CLASSIFIERS DESIGN

Classification algorithm is based on the processing of the power spectral components. Many authors describe the influence of psychophysiological state on the EEG signal parameters ([1], [2]). Information about the dependence of the power spectrum in the certain bands on the actual state of man is summarized in Tab.1.

	Vigilance	***Relaxation***	***Somnolence***
Delta (1-2 Hz)	H	L	H
Delta (3-4 Hz)	L	L	H
Theta (5-8 Hz)	L	L	H
Alpha (9-13 Hz)	M or L	H	L
Beta (14-20Hz)	H	L	L
Note: H-high, L-low, M-medium energy in the correspond band			

Tab. 1: Dependence spectral energy on the human condition

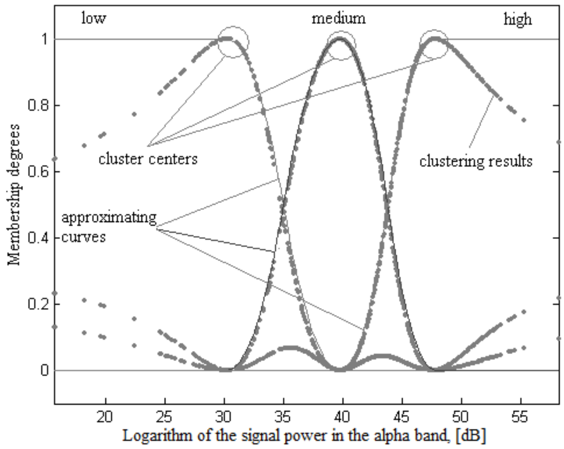
Vigilance is a state when a person has open eyes and solves a mathematical problem. Relaxation is a state of rest with closed eyes. Somnolence can be described as a state with closed eyes, characterized by attention declining and reduced level of information assessment. The value of alpha band energy is a good marker of the relaxation state, as we can see from Tab.1. However, it is impossible to distinguish the states of somnolence and vigilance only by the changes in the energy of alpha range. For this purpose it is appropriate to use either the analysis of beta and theta bands or analysis of two delta rhythm components [1].

There are many different methods of classification. The most common among them is the method using neural network. For this purpose fuzzy logic can be successfully applied. The classification method proposed in this work uses two techniques: FC and FIS.

The first step, which should be done for FIS designing is to provide an appropriate MF, on the base of which further fuzzification of input data is realized. We have no information about the distribution of power spectra values required for the construction of MF cause the results of FC are used for determination of the limit values in the energy spectrum (high, low and medium in Tab.1). The Fuzzy C-Means algorithm is used for FC of the input data, which are classified into 2 or 3 clusters. Coordinates of the clusters centers can be used for approximation of MF with a "classical" curve. For example the Gaussian curve can be approximated as a combination of Z- and S-function (see eq.2 and Fig.1), where *a, b, c* are the abscissa of the center for the 1st, 2nd and 3rd cluster respectively. The results of clustering and the MF for the 2nd classifier are shown on Fig.1.

$$\mu(x) = \begin{cases} 0, x \le a \\ 2\left(\dfrac{x-a}{b-a}\right)^2, a \le x \le \dfrac{a+b}{2} \\ 1-2\left(\dfrac{x-b}{b-a}\right)^2, \dfrac{a+b}{2} \le x \le b \\ 1-2\left(\dfrac{x-b}{c-b}\right)^2, b \le x \le \dfrac{b+c}{2} \\ 2\left(\dfrac{c-x}{c-b}\right)^2, \dfrac{b+c}{2} \le x \le c \\ 0, x \ge c \end{cases} \qquad (2)$$

After a definition of MF it follows the construction of the FIS, the core of which is a rule's base. Fuzzy inference process begins with fuzzification of the input variables. Then it comes implication from the antecedent to the consequent, aggregation of the consequents across the IF-THEN rules, and defuzzification. In this study Mamdani's fuzzy inference method is used. Defuzzification is performed using centroid method. More information about fuzzy logic techniques can be found in [3]. Four classifiers with different rule's bases are designed. The two classifiers use only alpha band of the EEG signal's spectrogram. Thus they allow only detecting a person's relaxation state (see Tab.1). The alpha energy of the 2nd classifier is divided into 3 clusters (low, high and medium) unlike to the 1st one, which divides energy into 2 classes (low and high). As distinct from previous, the 3rd classifier is supplemented with rules for the delta band, which makes it possible to distinguish the 3 states: vigilance, relaxation and somnolence. In this case the delta energy is divided into 2 and alpha energy into 3 classes. The 4th classifier FIS includes the rules for the processing of the whole spectrum.



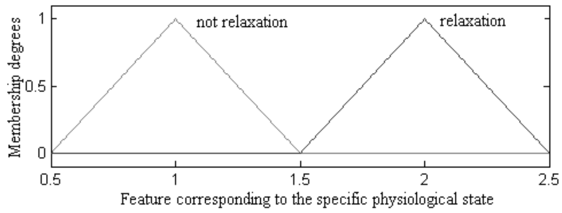


Fig. 1 MF of antecedent's (left) and consequent's (right) rules for the 2nd classifier

IF-THEN rules bases for all classifiers are shown in the following table:

FIS1: *IF* E_α=L *THEN* S=NR *IF* E_α=H *THEN* S=R	**FIS2:** *IF* E_α=L *THEN* S=NR *IF* E_α=M *THEN* S=NR *IF* E_α=H *THEN* S=R
FIS3: *IF* E_α=H *THEN* S=R *IF* E_α=M *THEN* S=V *IF* E_δ=H & E_α=L *THEN* S=SM *IF* E_δ=L & E_α=L *THEN* S=V	**FIS4:** *IF* E_α=H *THEN* S=R *IF* E_δ=L & E_θ=L & E_α=L & E_β=H *THEN* S=V *IF* E_δ=L & E_θ=L & E_α=M & E_β=H *THEN* S=V *IF* E_δ=H & E_θ=H & E_α=L *THEN* S=SM

Tab. 2 Rule bases of the fuzzy classifiers. E_δ, E_θ, E_α, E_β is energy of the spectrum in delta, theta, alpha and beta frequencies respectively, L – low, H – high, M – medium, S – physiological state, R – relaxation, NR – not relaxation, V – vigilance, SM - somnolence

Equals sign in the rules means the membership of a certain class. The symbol "&" is a logical AND. Thus the rule *IF* E_α=L *THEN* S=NR can be interpreted as: if the energy of the alpha rhythm takes a small value, a subject condition can be described as non relaxation.

4. RESULTS

The 1st and the 2nd classifiers are tested using real EEG signals. These signals do not contain any markers of a somnolence, so the efficiency of the 3rd and the 4th classifiers can be verified by using a simulated signal.

The results of classification for two EEG signals (real and simulated) are presented in the Fig.2. The feature values (y-axes in Fig.2) correspond with x-axis values depicted in Fig.1, right.

The unknown state may occur after processing of the fuzzy classification results with a special algorithm, which reduces the number of oscillations in the output data and, if it is not possible to determine the condition for certain, defines it as unknown.

The spectrogram presented in the Fig.2 (left) shows a clear increase of energy in the period

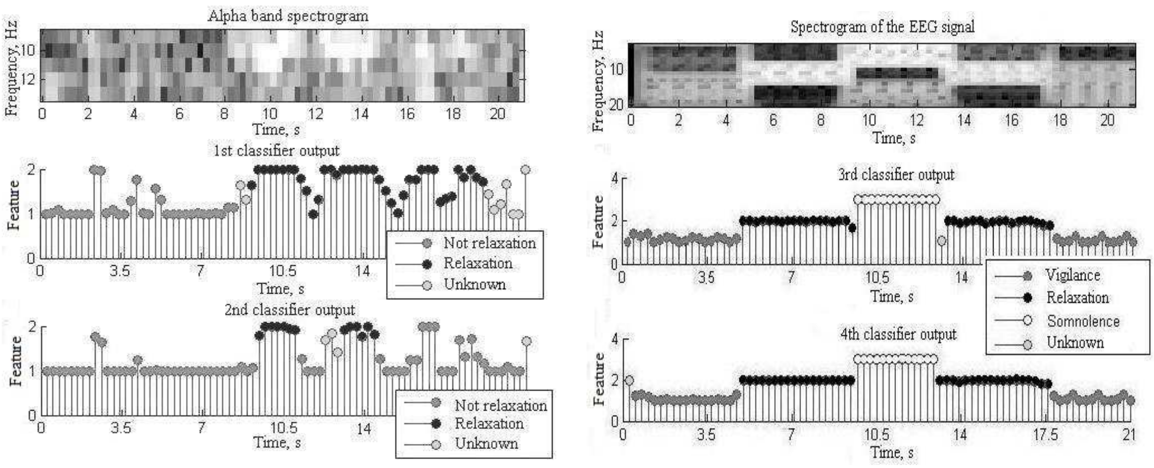


Fig. 2 Classification results: of the real signal (left) and of the simulated signal (right)

of 9-11s and 13-14s, when a subject has closed eyes. The first classifier identifies the state from 10s to 19s as relaxation, despite the fact that the person has been with opened eyes in the period approximately from 11s to 13s. The 2nd classifier makes more correct recognition. Higher detection ability of the 2nd classifier is possible due to separation of alpha rhythm by 3 clusters, which makes the decision making more effective.

To asses these classifiers the sensitivity (TPR – true-positive rate) and the specificity (TNR – true-negative rate) are calculated. The 1st classifier obtained TPR=97% and TNR=75%, the 2nd classifier attained TPR=78% and TNR=98%.

Results obtained with the 3rd and the 4th classifiers differ slightly, thus, to recognize the somnolence it is sufficient to analyse the delta and alpha frequencies.

5. CONCLUSION

In this paper the fuzzy classification method for the somnolence recognition is proposed. The algorithm is based on the processing of the EEG signal spectral components. Four classifiers with different FIS are designed. Testing has confirmed that a sufficiently good recognition accuracy can be achieved even when there is an analyzing only of a part of the frequency spectrum correspond to delta and alpha rhythm.

ACKNOWLEDGEMENT

This work was supported from MSM0021630513.

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