Hybrid approch for detection of event in sleep EEG

V.V. Shete*, Aswini Charithmath, D.S.Bormane and V.D. Mytri

MITCOE, Pune.

ABSTRACT

The wide variety of waveforms in EEG signals and the high non-stationary nature of many of them is one of the main difficulties to develop automatic detection systems for them. In sleep stage classification a relevant transient wave is the K-complex. This report comprehends the developing of new Fuzzy_Neural algorithm in order to achieve an automatic K-complex detection from EEG raw data. The Fuzzy c-means algorithm is used for the rough and rapid recognition of K-complex and the Neural Network classifier does the exact evaluation on the detected K-complex. This Pattern recognition technique is a hardware independent solution for the biomedical signal processing field. This represents a significant criterion for the objective assessment of a patient's sleep quality.

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Introduction

The transient analysis of sleep EEG signal has been subject to much research these days. Various soft computing techniques such as Neural Networks, Fuzzy logic, Feature based approach, Statistical k-means approach, Wavelet Transform are used for the study of transients in sleep EEG. All of these methods require the definition of a set of features that adequately describe the waveform to be detected.

Here Fuzzy_Neural system is discussed in detail. For several decades now, disturbed sleep has no longer been considered as a disturbance of one's state of health, but has been taken seriously due to the restrictions in social and professional functionability caused by it. In order to assess the quality of sleep, one needs to record the sleep structure as exactly as possible, i.e., the dynamic, partly repetitive sequence of different stages of sleep.[1][2]

These stages are mainly characterized by electro-encephalographic (EEG) phenomena and in recent years, tremendous advances have been made to determine these sleep stages automatically by computer. The fact that the automatic detection of the sleep stages using conventional methods has been unsatisfactory up until now, is mainly due to the transient Sleep phenomena of the EEG, like the K-complexes, sleep spindles, which are characteristic for light sleep (stage 2). Contrary to this, the application of intelligent systems such as Fuzzy logic and neural networks shows a safe and reliable recognition of the signal patterns.

The electroencephalogram (EEG) is a bioelectrical signal that reflects electrical activity emitted by neurons within the brain. This electric recording from the brain activity show continuous time-varying voltage oscillations with typical amplitudes from 10 to 500 V and a frequency range of from 0.5 to 40 [Hz] . These oscillations within the brain are called brainwaves. To measure these brainwaves electrodes are employed and the most used system to place these electrodes to amplify and monitoring the electric signal, correspond to an international standardized system called the International Federation 10-20 system.

The sample EEG signal is shown in figure 1.From the signal it is clear that, the signal is non linear, non stationary and contains the artifacts and some noise.
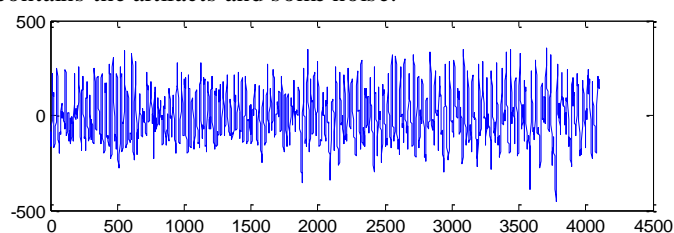

Fig 1: sample EEG signal

Sleep Analysis

Sleep is a naturally recurring state characterized by reduced or absent consciousness, relatively suspended sensory activity, and inactivity of nearly all voluntary muscles. It is distinguished from quiet wakefulness by a decreased ability to react to stimuli, and is more easily reversible than being in hibernation or a coma. Sleep is a heightened anabolic state, accentuating the growth and rejuvenation of the immune, nervous, skeletal and muscular systems. It is observed in all mammals, all birds, and many reptiles, amphibians, and fish. The purposes and mechanisms of sleep are only partially clear and are the subject of intense research. Sleep is often thought to help conserve energy, but decreases metabolism only about 5–10%.

When we sleep, our bodies go through various stages. A device called the electroencephalogram (EEG) allows researchers to measure brain patterns and establish the various stages of sleep that we go through. Research has established that our brain is not passive during sleep and that certain stages are crucial to our physical as well as mental and emotional well-being. Sleep may seem like one long state of unconsciousness, but sleep is actually made up of several distinct stages. These stages are split up into to general categories: REM or Rapid Eye

Movement, and NREM, or Non Rapid Eye Movement. One sleep cycle including all stages is about 90-110 minutes.Sleep analysis mainly depends upon two relevant transient phenomena in EEG namely K-complexes and sleep spindles.

K-complex as a prominent waveform having a well delineated negative sharp wave which is immediately followed by a positive component. The total duration of the complex should exceed 0.5 seconds.It has relatively sharp amplitude more the $\pm75\mu V$.K-complex event occure in all the stages of sleep but maily in sleep stage 2 it occures with sleep spindles.There fore K-complexes are used to recognize sleep stage 2.Figure 2 shows the K-complex and sleep spindle event.[1][2]
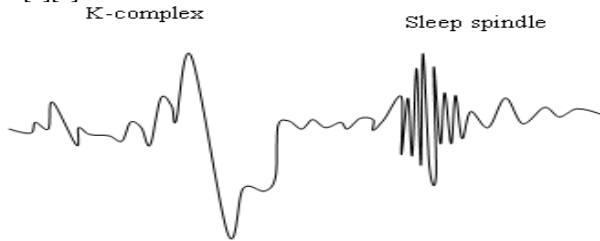

Fig 2: K-Complex and Sleep Spindle

Methodology

EEG Data Aquisition

The developing of this work was carried out using EEG raw data from recordings corresponding website www.physionet.org. These recordings are stored in EDF format. Four sleep EEG signals are taken. These recordings were obtained in 1994 from subjects who had mild difficulty falling asleep but were otherwise healthy, during a night in the hospital, using a miniature telemetry system with very good signal quality. Subjects and recordings are more extensively described in the 2000 IEEE-BME paper cited above.

The raw data was noisy and contains power line interference. Band stop filter with cut off frequencies 59Hz to 60Hz is used to remove the line frequency. Later the Savitzky− Golay filter is used to smooth the signal. Since the frequency of K-complex event is 0.2 to 5 Hz, this frequency is extracted using a band stop filter with a cut off frequency of 0.2 and 5 Hz.The Savitzky−Golay smoothing filter is a filter that essentially performs a local polynomial regression (of degree k) on a series of values (of at least k+1 points which are treated as being equally spaced in the series) to determine the smoothed value for each point. The main advantage of this approach is that it tends to preserve features of the distribution such as relative maxima, minima and width, which are usually 'flattened' by other adjacent averaging techniques.

Fuzzy Module

Fuzzy logic is a form of many-valued logic or probabilistic logic; it deals with reasoning that is approximate rather than fixed and exact. In contrast with traditional logic theory, where binary sets have two-valued logic: true or false, fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic incorporates a simple, rule-based approach to solving a control problem rather than attempting to model a system mathematically.

In order to detect the K-complexes in sleep EEG, unsupervised classification called Fuzzy c-means clustering is used. Clustering refers to a broad spectrum of methods which try to subdivide a data set X into c subsets (clusters), which are pair wise disjoint, all nonempty and reproduce X via union.

In the most general case, clusters are defined as groups of points that are "similar" according to some measure of

similarity. Usually, "similarity" is defined as proximity of the points according to a distance function. Eucledian Distance is used to measure the similarity between the objects of the classes.

Classes in which each member has full membership are called discontinuous or discrete classes. On the other hand, classes in which each member belongs in some extent to every cluster or partition are called continuous classes. Continuous classes are a generalisation of discontinuous classes where the indicator function of conventional sets theory, with values 0 or 1, is replaced by the membership function of fuzzy sets theory, with values in the range of 0 to 1.

Fuzzy c-means algorithm. for K-complex detection in sleep EEG is given below.

Fuzzy clustering allows each feature vector to belong to more than one cluster with different membership degrees (between 0 and 1) and vague or fuzzy boundaries between clusters.The FCM algorithm is as follows,

Let x_i be a vector of values for data point g_i.

1. Initialize membership $U^{(0)} = [\ u_{ij}\ ]$ for data point g_i of cluster cl_j by random

2. At the k-th step, compute the fuzzy centroid $C^{(k)} = [\ c_j\ ]$ for $j = 1, .., nc$, where nc is the number of clusters, using

$$c_j = \frac{\sum_{i=1}^{n}(u_{ij})^m x_i}{\sum_{i=1}^{n}(u_{ij})^m}$$

where m is the fuzzy parameter and n is the number of data points.

3. Update the fuzzy membership $U^{(k)} = [\ u_{ij}\ ]$, using

$$u_{ij} = \frac{\left(\dfrac{1}{\|x_i - c_j\|}\right)^{\frac{1}{(m-1)}}}{\sum_{j=1}^{n_c}\left(\dfrac{1}{\|x_i - c_j\|}\right)^{\frac{1}{(m-1)}}}$$

The similarity measure is calculated using the Euclidean Distance as shown below.

$$d(g_1, g_2) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}$$

4. If $\|U^{(k)} - U^{(k-1)}\| < 0.01$, then STOP, else return to step 2.

5. Determine membership cutoff

For each data point g_i, assign g_i to cluster cl_j if u_{ij} of $U^{(k)} > \alpha$

Using this algorithm effectively, K-complexes can be detected. [3][4].

Neural Network Module

Neural Network is a set of connected INPUT/OUTPUT UNITS, where each connection has a WEIGHT associated with it. Neural Network learning is also called CONNECTIONIST learning due to the connections between units.

It consists of artificial neural networks which are nonlinear signal processing devices,built from elementary processing devices called neurons. Different EEG signal features are extracted based on the amplitude and duration measurement. Signal features are used as an input to the MLFNs. Back Propagation rule (BPN) is used to train the network.

The main Idea of backpropagation algorithm is to distribute the error function across the hidden layers, corresponding to

their effect on the output. It works on feed-forward networks. Use sigmoid units to train, and then we can replace with threshold functions. The feed forward neural network is shown in figure 3. [5][6][7]
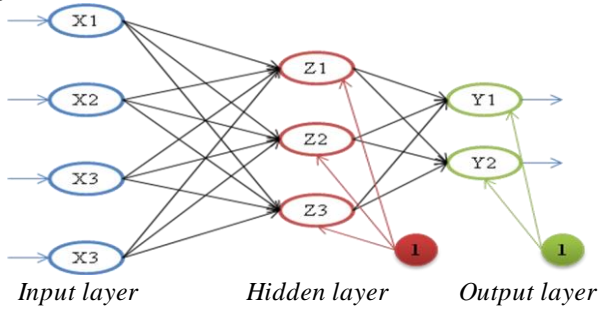

Input layer   Hidden layer   Output layer
Fig 3: Artificial Neural Network

Fuzzy_Neural Sytem

Fuzzy-Neural modeling procedure is used for the detection of K-complexes in sleep EEG. This intelligent detection system mainly has three modules
• Preprocessing Module
• Fuzzy Module
• Neural Module

The Block Diagram of the Fuzzy_Neural system is shown in figure 4. A Fuzzy_Neural detector is used to detect the number of K-complexes present in the total sleep EEG signal. Details about the preprocessing block and the fuzzy_Neural detector is explained below.

The Fuzzy block act as a pre detector, which does the rough and rapid recognition of K-complex. The Neural network block takes the exact evaluation of the k-complexes. [8]
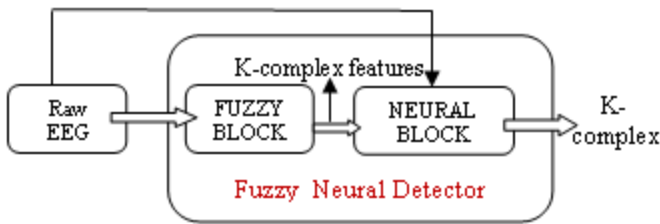

Fig 4 : Block Diagram of Fuzzy_Neural System

Fuzzy_Neural Algorithm For K-Complex Detection
Preprocessing Stage:

-- The sleep EEG database is downloaded from the physonet website. It is in EDF format

-- The database is converted into ascii format for Matlab compatibility. The duration of the EEG signal is 8 hours.

-- The total signal is manually divided into 5 sleep stages based on the R&K rules of American std.

   -- Denoizing of the signal is done using Golay Filter.

Fuzzy Block: (Fuzzy c-means algorithm)

-- Denoized EEG signal is taken as input to the fuzzy c-means algorithm.

-- The reference k-complex and non-kcomplex features are assumed.

-- The assumed features are [Maximum amplitude, Minimum Amplitude, time period]. These features are extracted based on the maximum amplitude, minimum amplitude and time duration between the starting and end time period of the segmented signal.

Two classes are defined as follows,
 Class I: K-complex
Class II: Non K-complex and others
The stage 2 signal is segmented equally.

-- Assuming the isolated signal belongs to either of the two class mentioned above, Fuzzy c-means algorithm is used to design the discrimination rule.

FCM steps are as follows,

• Initialize the cluster centers & compute the cluster 'u_{ij}' which represents the degree of belongingness of element to the two classes I & II

x= [features of k-comp & non K-comp]
c=cluster centers
u=membershipdegree

$$u_{ij} = \frac{1}{\sum_{k=1}^{C}\left(\frac{\| x_i - c_j \|}{\| x_i - c_k \|}\right)^{\frac{2}{m-1}}} \quad \text{......... eq (1)}$$

• Compute the new center of the two classes according to the following equation

$$c_j = \frac{\sum_{i=1}^{N} u_{ij}^m x_i}{\sum_{i=1}^{N} u_{ij}^m} \quad \text{..........eq (2)}$$

• Compute the membership degrees of isolated segment for the two classes using the equation (1) and according to the final centers of the classes.

• Assign the new pattern to the class with maximum membership degree if it is greater than a (0.9), else reject this pattern (ambiguity rejection).

• The detected K-complex features are given to Neural Network for exact evaluation

Neural Network Block

-- Here the Back Propagation algorithm is used to train the network.

-- The detected k-complex features are used as Target.

-- The Input vector contains the whole EEG signal.

-- After training and testing phase, accuracy of the classifier is calculated sensitivity and specificity.

Results

The complete results of implementation are shown in steps as follows,

Step 1:

The raw EEG signal is of loaded in MATLAB for the detection of K-complex in sleep EEG. Figure 4 shows raw EEG signal. This signal is of 8 hours duration with two sleep cycles. The x-axis shows the number of samples and the y-axis shows the amplitude in μv.
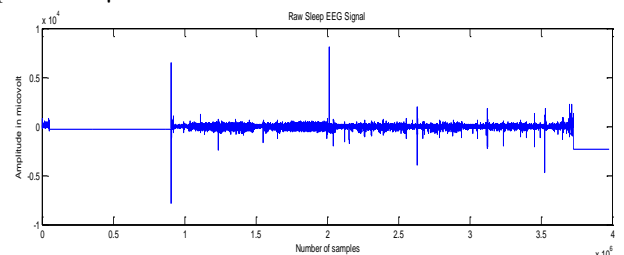

Fig 4: Raw Sleep EEG signal

Step 2:

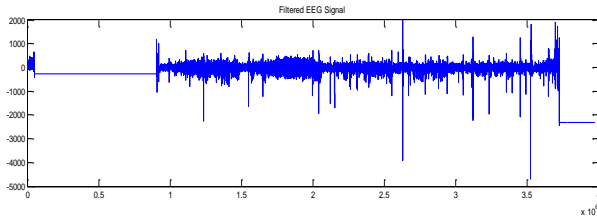The filtered EEG signal is shown in figure 5.

Fig 5: Filtered EEG signal

Step 3:

The reference features of K-complex signal are assumed based on the standard definitions. Considering these features, the FCM algorithm takes the signal as shown in figure 4 as a input. By proper segmentation of the signal, total number of K-complexes in whole EEG signal are detected. This leads to rough and rapid recognition of K-complexes. One segmented K-complex and non K-complexes are shown in figure 6. The membership degree of both the signals belongs to the K-complex class is 0.75907 and 0.340241.
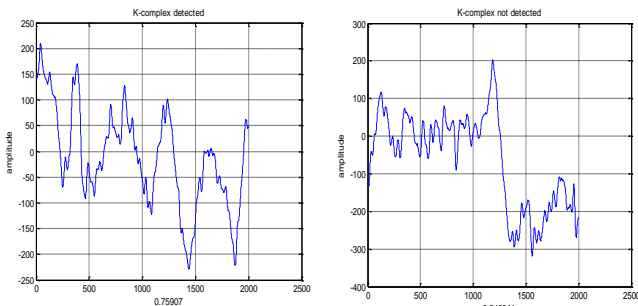

Fig 6: K-complex and non K-complex signals

Step 5 :

The ANN is trained with EEG signal as input and K-complex features as a Target vector. The comparison between actual targets and prediction is shown in figure 7. The exact number of K-complexes are detected when the ANN is trained with more number of target inputs.

Fig 7: comparison between actual targets and prediction

The performance of the Neural Network classifier is measured using sensitivity and specificity and accuracy. Sensitivity is the probability that the test says a person has the disease when in fact they do have the disease. Sensitivity measures the proportion of actual positives which are correctly identified as such. Specificity measures the proportion of negatives which are correctly identified minimum error bound known as the Bayes error rate.[9]

Sensitivity = TP/ (TP+FN)

Specificity = TN/ (TN+FP)

Accuracy= (TP+TN)/(TP+FN+TN+FS)

Where, TP- true positive, TN-true negative, FN-false negative, FP-false positive.

The sensitivity and specificity and accuracy of the classifier is shown in the following table.

Here sigan1 is the training signal and signa2 is tested signal. The total number of K-complexes obtained in the whole EEG signal is given in the below table.

Table 1: Sensitivity, Specificity and Accuracy of the classifier for tranied and tested signal

	TP	TN	FP	FN	Sensitivity	Specificity	Accuracy
Train	97	95	97	0	100%	50%	66.6%
Test	75	73	75	2	95.6%	48.8%	65.6%
Test	86	82	86	3	96.4%	49.4%	66.7%

Conclusion

In this work, fuzzy c-means algorithm and backpropagation algorithm are combined for the detection of K-complexes in the sleep EEG. The performance of the algorithm evaluated using sensitivity, specificity and accuracy. It helps to find out possible important faults that may affect the system.These automatic computerized processes provide quantitative, objective, reproducible results for every subject. The computation time is reduced here .With the help of proper selection of features of K-complex signal, desired characteristics of the sleep can be studied.

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