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Full Length Research Paper

Use of K-means clustering in migraine detection by using EEG records under flash stimulation

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In this study, a new migraine analysis method was proposed by using EEG (electroencephalography) signals under flash stimulation in time domain. EEG signal is one of the most complex biomedical signals due to its complex nature. Therefore, these types of signals are commonly pre-processed before the analysis procedure. Since, pre-processing techniques affect the analysis results positively or negatively, the achievements of these pre-processing techniques are very important. Flash-stimulated and non-stimulated EEG signals obtained from healthy subjects and migraine patients. First, a digital band pass FIR (Finite Impulse Response) filter is used to select beta band of the T5-T3 channel EEG signals. Then a time domain based pre-processing technique, histogram, was employed to obtain the features. Histogram differences in the case of flash stimulation (or non-stimulation) calculated and used as features for the healthy subjects and migraine patients. These features are applied to a k-means clustering algorithm to see clustering results of the proposed technique. Silhoutte clustering results show that, a good clustering performance is evaluated as 86.6% correct clustering rate (CCR) with the used techniques in migraine analysis. Results provide a good insight in this area for future studies.

Key words: Migraine, EEG, K-means cluster, histogram.

INTRODUCTION

Migraine is a widespread brain disorder, women (between 23 and 29%) and men (between 15 and 20%) suffer from it in the world (Waters and O'Connor, 1975). Bright lights, loud noises, certain odors, stress and changes in sleep patterns may be some triggering factors of migraine but the cause of migraine cannot be explained definitely yet (Kutlu et al., 2010). Migraine can only be diagnosed according to IHS (International Headache Society) criteria now. These criteria are associated to patient's symptoms evaluated by expert neurologist. Although, several researches tried to develop the automatic diagnosis methods of migraine, definite migraine diagnosis method has not been accepted by authority yet (Marinis et al., 2007; Ozkul et al., 2001; Benna et al., 1985).

In these researches, some biomedical devices/techniques have been used to detect migraine (Akben et al., 2011; Gozke et al., 2004; Bowyer et al., 2001), but the most preferred biomedical device to detect migraine is the electroencephalograph (EEG). Since migraine is known as a brain disorder and the aim of EEG is measuring the electrical activity of the brain, researchers have shown that analysis of the EEG records can be used for diagnosis of migraine patients (Marinis et al., 2007; Ozkul et al., 2001; Akben et al., 2011; Tommaso et al., 2005). Recent studies related to migraine detection reported that, some stimulation methods such as flash stimulation, laser stimulation have been used as a triggering technique (Akben et al., 2011; Valeriani et al., 2003). Since the application of the flash

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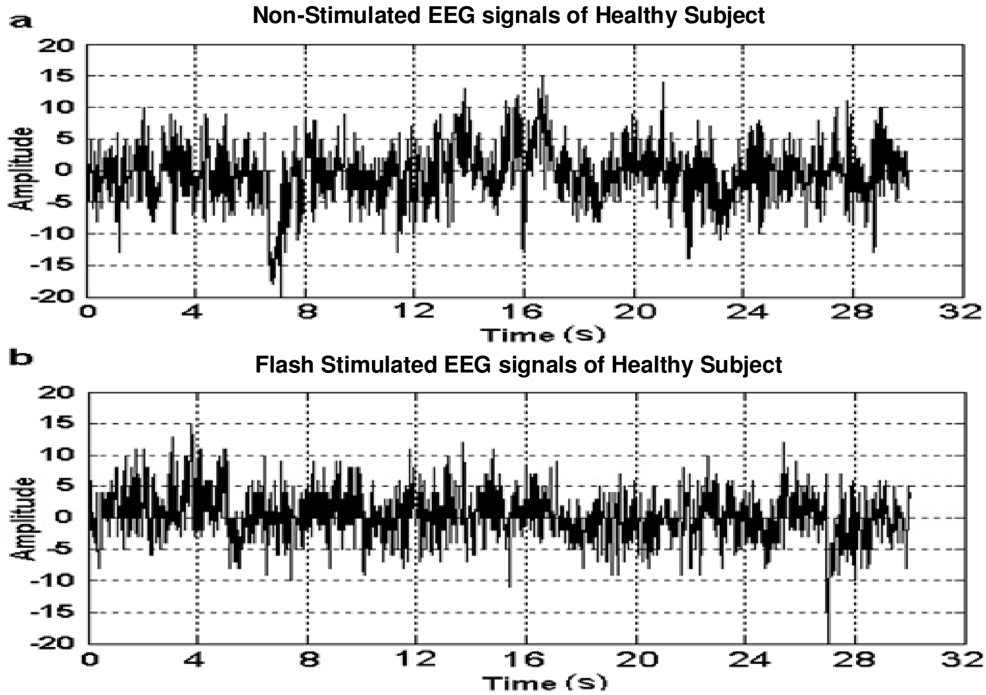

Figure 1. EEG Signals in time domain. a) Non-stimulated EEG signal of healthy subject. b) Flash stimulated EEG signal of healthy subject.

stimulation is easy when recording the EEG, mostly flash stimulation triggering method is used in clinical laboratory (Ozkul et al., 2001; Tommaso et al., 2003; Hishikawa et al., 1967).

Furthermore, in these former researches, EEG signals were analyzed by using 1 to 30 Hz frequency band. The spectrum of EEG signals between this 1 to 30 Hz frequency interval have four basic frequency bands, namely, delta (0.5 to 4 Hz), theta (4 to 8 Hz), alpha (8 to 13 Hz) and beta (13 to 30 Hz) bands (Adeli et al., 2003). All of these researches proposed that, analysis of the EEG signals in frequency domain under flash stimulation can reveal the characteristics of migraine (Akben et al., 2011; Tommaso et al., 2005; Tommaso et al., 2003). But there is not so much study proposed, related to migraine detection in time domain (Drake et al., 2005). Due to the fact that, EEG signals are more complex, signals of healthy subjects are resembled to signals of migraine patients, and analyzing the EEG signals in time domain is quite difficult as shown in Figures 1 and 2.

In this research, our aim is to detect the migraine by using a time domain preprocessing method known as histogram by using EEG signals under flash stimulation. The histogram results of the data are used as input to the k-means clustering. K-means clustering is an unsupervised technique. Result of this research gives important novelty to migraine detection methods by using EEG. Since, the former important researches related to migraine detection offered that, considerable electrical activity changes has determined in EEG's T5-T3 channel under flash stimulation (Akben et al., 2011; Tommaso et al., 2005), in this study T5-T3 channel and beta band of the EEG signal is selected and used. To select beta band digital band pass FIR (Finite Impulse Response) filter is used to eliminate the other frequency components of EEG signals. Histogram of flash stimulated and non-stimulated filtered data, calculated to get the features for healthy and migraineur subjects' EEG signals.

Data acquisition

Subjects

In this study, the analyzed EEG data was taken from Neurology Department of the Medical Faculty of Kahramanmaras Sutcu Imam University. 15 migraineurs and 15 healthy subjects were used for the analysis. Migraine patients are diagnosed by expert neurologists according to the International Headache Society diagnostic criteria patients and they were all in the interictal state. According to the same criteria, no patients had taken any drug before the recordings. Both migraineur and healthy subject groups' age range are between 20 to 40 years old. EEG Recordings of migraineur had been taken in pain-free phase.

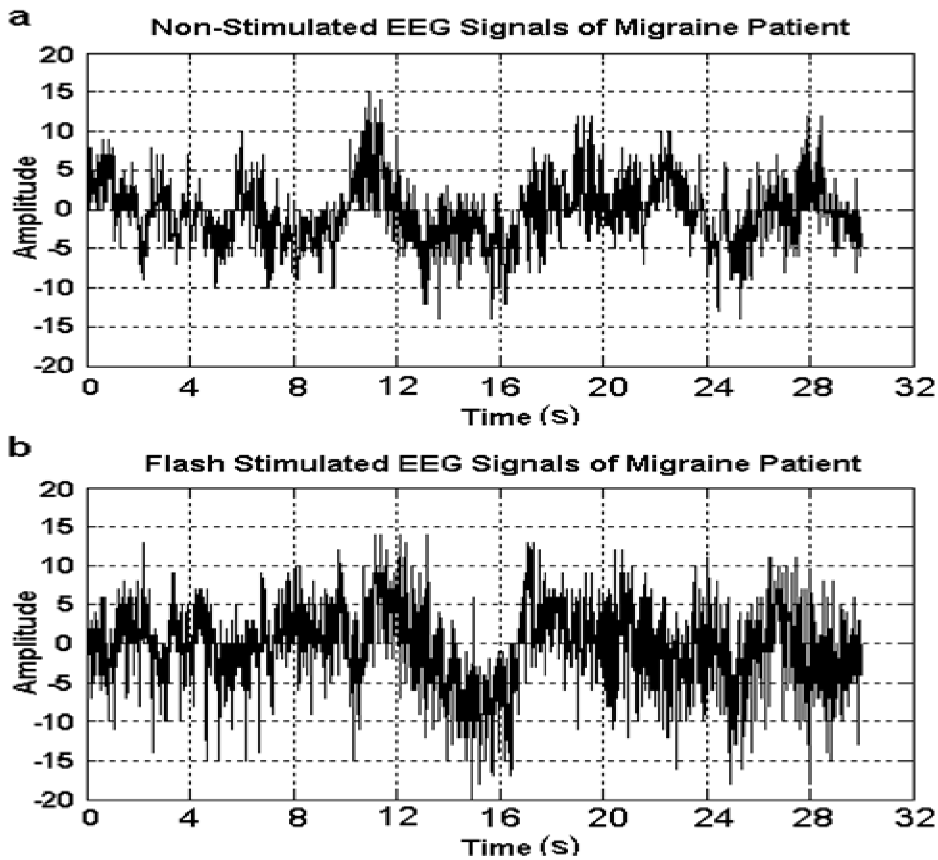

Figure 2. EEG signals in time domain. a) Non-stimulated EEG signal of migraine patient. b) Flash stimulated EEG signal of migraine patient.

Data recording

All of EEG records were obtained by using an 18-Channel Nicolet One Machine. Electrodes were placed according to the international 10 to 20 system at Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, C4, T4, T5, P3, Pz, P4, T6, O1 and O2. The sampling frequency of EEG signal acquisition system is 256 Hz. Each recording process took 20 min which has periods of 2 min for hyperventilation and 30 s for flash stimulation. The bipolar T5-T3 channel was selected for analysis and the flash stimulation frequency was selected as 4 Hz (Akben et al., 2011a; Akben et al., 2011b).

Since in two recently important researches related to migraine detection was based on magnitude increasing and phase synchronization of alpha band, this band was selected over T5-T3 channel of EEG (Akben et al., 2011; Tommaso et al., 2005). Regarding the results of these researches, one can say that this channel of EEG can be the most important channel to detect the migraine. That is why in this study, T5-T3 channel of EEG was selected for the analysis.

METHODS

Digital FIR filter

In signal processing, there are many instances in which an input signal to a system contains additional noise or unnecessary content which can reduce the quality of the desired portion. In such cases, the useless samples can be removed or filtered out. Finite Impulse Response (FIR), filters are one of the main types of filters used in digital signal processing. Since they do not have any feedback FIR filters are said to be finite. Therefore, if you send an impulse through FIR filter, then the output will invariably become zero, as soon as the impulse runs through the filter. The difference equation that defines the output of an FIR filter in terms of its input is:

$$y[n] = b_0 x[n] + b_1 x[n-1] + \ldots + b_N x[n-N] \quad (1)$$

where $x[n]$ is the input signal, $y[n]$ is the output signal, b_i are the filter coefficients, and N is the filter order. An N^{th} order filter has (N+1) terms on the right-hand side; these are commonly referred to as taps (Oppenheim et al., 1999). This equation can also be expressed as a convolution sum of the coefficient sequence b_i with the input signal:

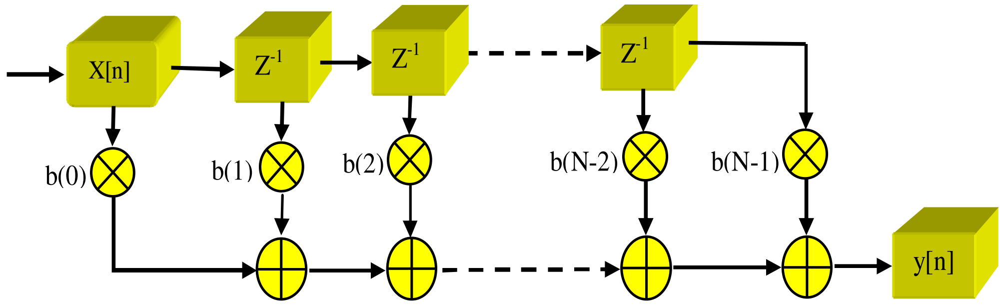

Figure 3. General structure of FIR filter (Proakis and Manolakis, 2006).

$$y[n] = \sum_{i=0}^{N} b_i x[n-i] \tag{2}$$

That is, the filter output is a weighted sum of the current and a finite number of previous values of the input. General structure of finite impulse response (FIR) filter is shown as in Figure 3. Regarding a number of useful properties of the FIR filter, such as they are inherently stable, require no feedback and they can easily be designed to be linear phase by making the coefficient sequence symmetric, it is used for filtering the EEG signals. There are different methods to find the coefficients from frequency specifications such as window design method, frequency sampling method, weighted least squares design (Rabiner and Gold, 1975; Oppenheim et al., 1999; Kaiser and Schafer, 1980). In this research, to design the filter window design method and Kaiser Filter was selected. The used FIR filter is a band-pass filter which has 13 to 30 Hz cut-off frequencies and 12 to 31 Hz band-stop frequencies. Thus, transition window was selected as 1 Hz.

Amplitude histogram

A histogram is a demonstration of statistical information which uses rectangles to show the frequency of data items in successive numerical intervals of equal size. Generally, the independent variable is plotted along the horizontal X-axis and the dependent variable is plotted along the vertical Y-axis. The data give the impression as colored or shaded rectangles of variable area. In addition to showing how often a particular value occurs in a set of data, some other information can be gathered using statistical analysis of histogram data. This information may be the 'shape' of the data, such as a 'flat' distribution or a 'bell-shaped' distribution (Pearson, 1895). Let x be an observed quantity which can have one of N values contained in the set $X = \{x_1, \ldots, x_N\}$. Measurements of the value of x are considered as a set of k elements ($S = \{s_1, \ldots s_k\}$ where at $\in X$). The histogram of the set S along the measurement x can be written as Hist(x,S) which is an ordered list, consisting of the number of occurrences of the discrete values of x among the s_k.
If it is interested only in comparing the histograms and sets of the same measurement x, Hist(S) will be used instead of Hist(x,S) without loss of generality. If $Hist_i(S)$, $1 \le i \le N$, denotes the number of elements of S that have value x_i, then:

$Hist_i(S) = [H_1(S), \ldots, H_N(S)]$ where:

$$Hist_i(S) = \sum_{t=1}^{n} C_{i,t}^{S} \tag{3}$$

and the individual costs are defined as;

$$C_{i,t}^{S} = \begin{cases} 1\ ; & s_t = x_i \\ 0\ ; & otherwise \end{cases} \tag{4}$$

The elements $Hist_i(S)$ are generally called bins of the histogram (Serratosa and Sanfeliu, 2006). A value of sample histogram is a graphical representation of data, that shows a visual impression of the magnitude distribution. A magnitude histogram consists of tabular frequencies, shown as adjacent rectangles, erected over discrete intervals (bins), with an area equal to the frequency of the magnitudes in the interval. The total area of the magnitude histogram is equal to the number of magnitude. Magnitude histogram is advantageous for analyzing a number of magnitudes (Pearson, 1895; Serratosa and Sanfeliu, 2006). In this study, magnitude histograms of both migraine patients' and healthy subjects' data are analyzed; and this analysis process was evaluated according to magnitude variation in migraine patients and healthy subjects occurred by flash stimulation. Since the magnitudes of EEG signals vary between -20 to +20 µV range, magnitudes between -20 to +20 µV were taken into evaluation. Figure 4 illustrates average histogram results of a healthy and migraine patients' EEG. Each score range was denoted by a bar of a certain color. If the Figure for healthy subjects is examined, one can see that at lower magnitudes (between magnitudes -2 to 2) frequency of flash stimulated EEG is higher than non-stimulated. On the other hand for higher magnitudes, frequency of non-stimulated EEG is higher than flash stimulated. These values were exchanged when the figure for migraine patients was examined.

K-Means clustering

K-means clustering is a conventional unsupervised learning algorithm which aims to solve the clustering problems. This is a simple and flexible method that follows an easy way to classify a given data set through a certain number of clusters (Xu and Wunsch, 2005). The main idea is to define k centroids, one for each cluster.

These centroids should be placed in a cunning way because different locations cause different result. Thus, the better choice is to place the centroids as much as possible far away from each other. The next step is to take each point belonging to a given data set and associate it to the nearest centroid. When no point is pending, the first step is completed and an early groupage is done. At this point, k new centroids are re-calculated as barycenters of the clusters resulting from the previous step. After these k new centroids are obtained, a new binding has to be done between the same data set points and the nearest new centroid.

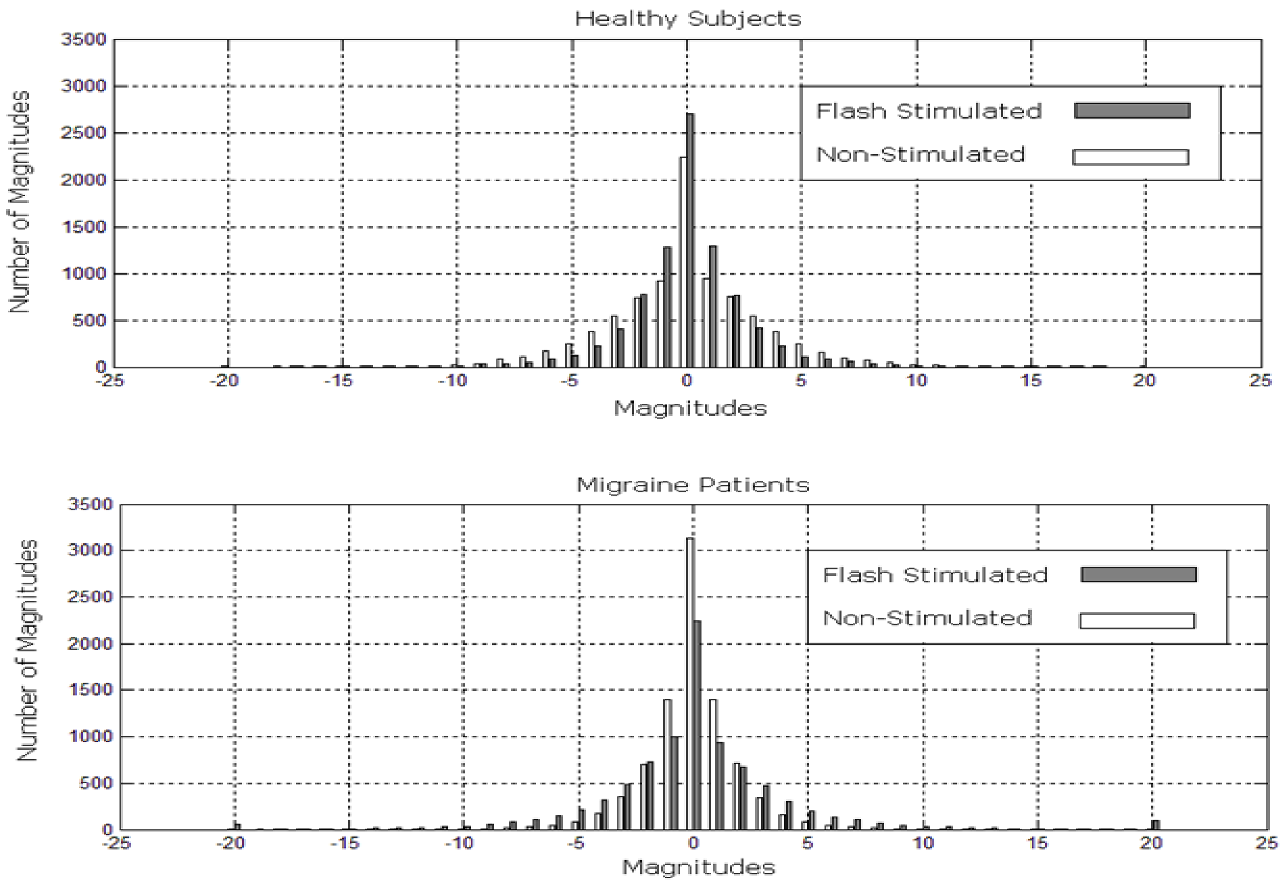

Figure 4. Average histograms.

The most widely used criterion for optimization is the distortion criterion. Each record is assigned to a single cluster and distortion is the average squared Euclidean distance between a record and the corresponding cluster center (Zahraie and Roozbahani, 2011). Thus, this criterion minimizes the sum of the squared distances of each record from its corresponding center. In this study, K-means clustering is used to minimize the aforementioned term by partitioning the data into k non-overlapping regions identified by their centers. By using a loop, the k centroids changed their location step by step, until no more changes were done. Finally, this algorithm aims at minimizing an 'objective function', in this case a squared error function. The objective function; different steps for K-means clustering can be summarized as follows:

(a) Randomly select k-centers of clusters from existing data.
(b) Calculate the Euclidean distance of every datum from the selected centers.
(c) Classify data among clusters based on minimum Euclidean distances.
(d) Calculate new center for each cluster equal to the average of data in that cluster.
(e) Repeat steps b to d till the algorithm converges (centers of clusters do not change).

For numeric features, Euclidean distance metric is used and for symbolic features, Hamming distance is computed. Also formulation of this algorithm is given as;

$$J = \sum_{j=1}^{k}\sum_{i=1}^{n}\left\| x_i^{(j)} - c_j \right\|^2 \tag{5}$$

This algorithm aims at minimizing a J function. The $\left\| x_i^{(j)} - c_j \right\|^2$ is a chosen distance measure between a data point $x_i^{(j)}$ and the cluster centre c_j, is an indicator of the distance of the n data points from their respective cluster centers. Also k is a cluster number (MacQueen, 1967). In this study number of cluster is selected as 2. One of them is for healthy subject and another of them is for migraine patient.

Use of silhoutte values as a measure of goodness of clusters

Performance of cluster analysis or goodness of clusters is calculated and given by using silhouette values (Xu and Wunsch, 2005) which are proposed by Rousseeuw (1987). For each of the two data I and j, the distance between them is defined by d(i,j). The average distance of the i^{th} profile in cluster A to other members in the same cluster is given as:

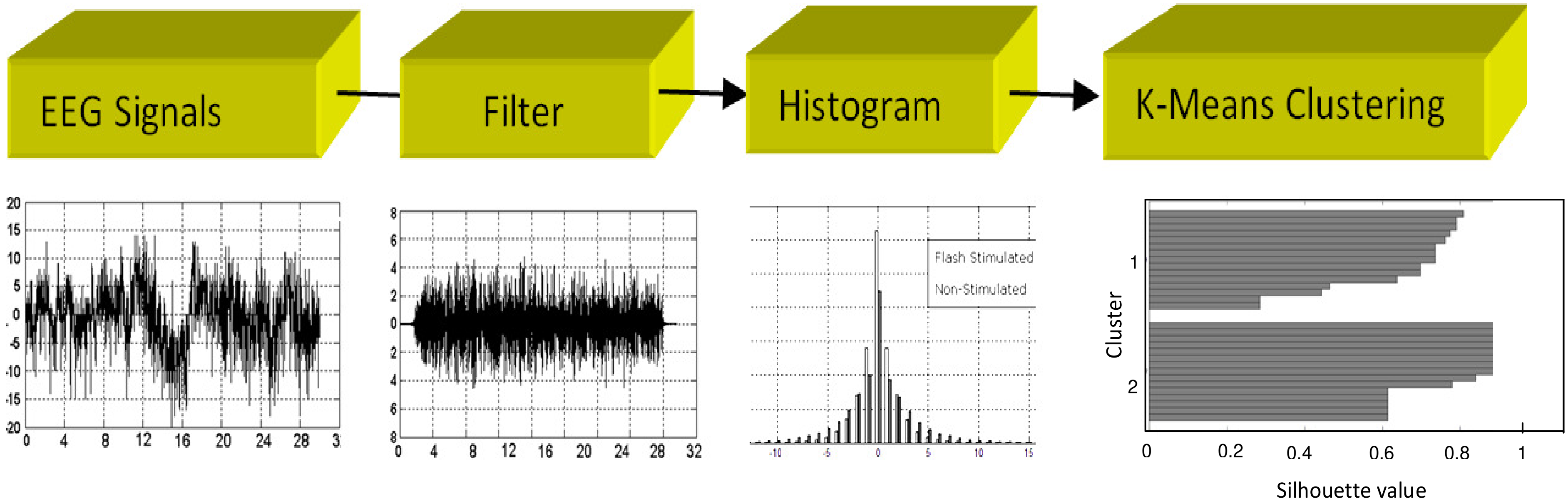

Figure 5. Block diagram of migraine clustering system.

$$a_i = \frac{1}{N_A - 1} \sum_{j \in A, j \neq i} d(i, j) \tag{6}$$

Here, N_A is the number of the members in cluster A. At the same time, the average distance of i to members in clusters different from A is denoted by L which is defined as:

$$d(i, L) = \frac{1}{N_L} \sum_{j \in L} d(i, j) \tag{7}$$

Where N_L is the total number of members in L and the average distance to the members of the closest cluster is given as follows;

$$b_i = \min_{L \in A} \{d(i, L)\} \tag{8}$$

As a result, the silhouette value s(i) of the i^{th} profile is written as;

$$s(i) = \frac{b_i - a_i}{\max\{a_i, b_i\}} \tag{9}$$

The silhouette value s(i) for each data i lies between -1 to 1. If s(i)>0, then the data is said to be well classified, and if s(i)<0 then data is poorly classified (Xu and Wunsch, 2005). Thus, the average silhouette value for a cluster is used as a measure of its goodness. (Horimoto and Toh, 2001)

RESULTS

In this research, the beta band of each flash stimulated and non-stimulated EEG data for both migraine patients and healthy subjects are filtered by employing the FIR filter. If Figures 7 and 8 are compared with Figures 1 and 2, it can be seen that, the beta band of EEG signals has lower amplitudes. Then for all filtered EEG data, the time domain based preprocessing technique, namely histogram is applied. Histogram values of all data are calculated. From Figure 4, one can see some differences between flash stimulated and non-stimulated EEG signals. If Figure 4 is examined, it can be seen that at lower magnitudes (between magnitudes -2 to 2) frequency of flash stimulated EEG is higher than non-stimulated. On the other hand, higher magnitudes frequency of non-stimulated EEG is higher than flash stimulated. These values are oppositely changed when Figure 4 is examined for the data from the migraine patients.

This result shows the effect of flash stimulation

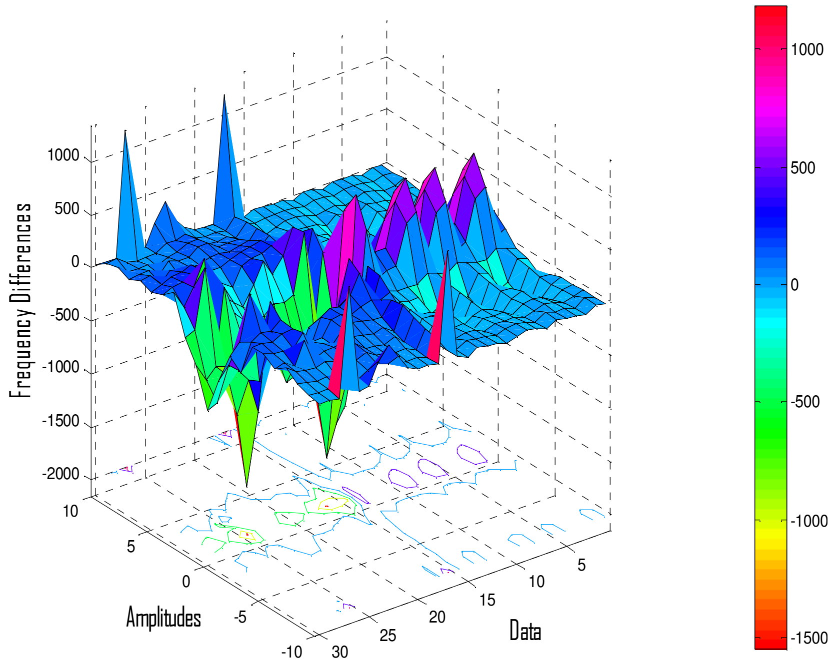

Figure 6. Frequency differences between flash stimulated and non-stimulated EEG signals: Data is organized as 1 to 15 healthy subjects and 16 to 30 migraine patients.

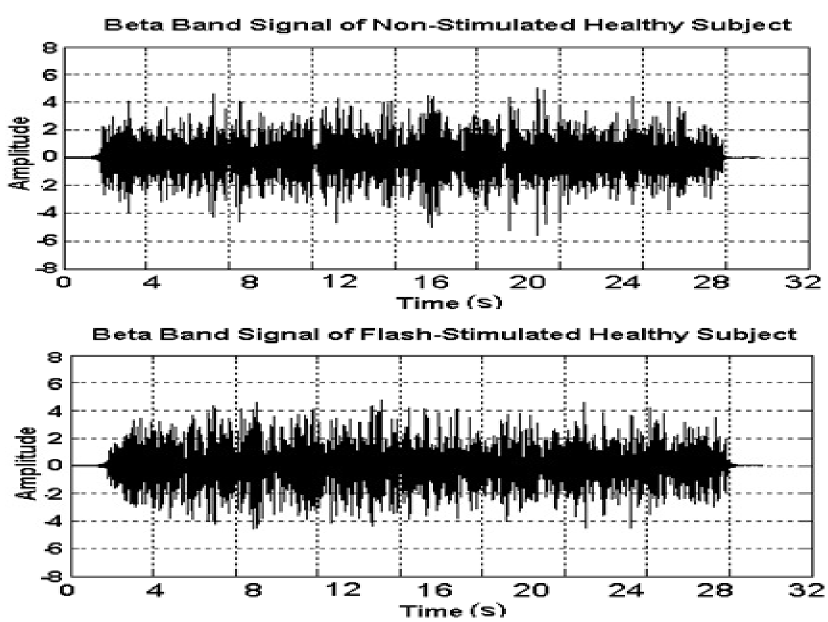

Figure 7. Flash stimulated and non-stimulated EEG signals of healthy subject.

on the beta band of EEG data of healthy and migraineur subjects. Figure 6 demonstrates histograms of all the data for both migraine patients and healthy subjects. In this figure, data was organized as 1 to 15 healthy subjects (group 1) and 16 to 30 migraine patients (group 2). From Figure 5, frequency differences between flash

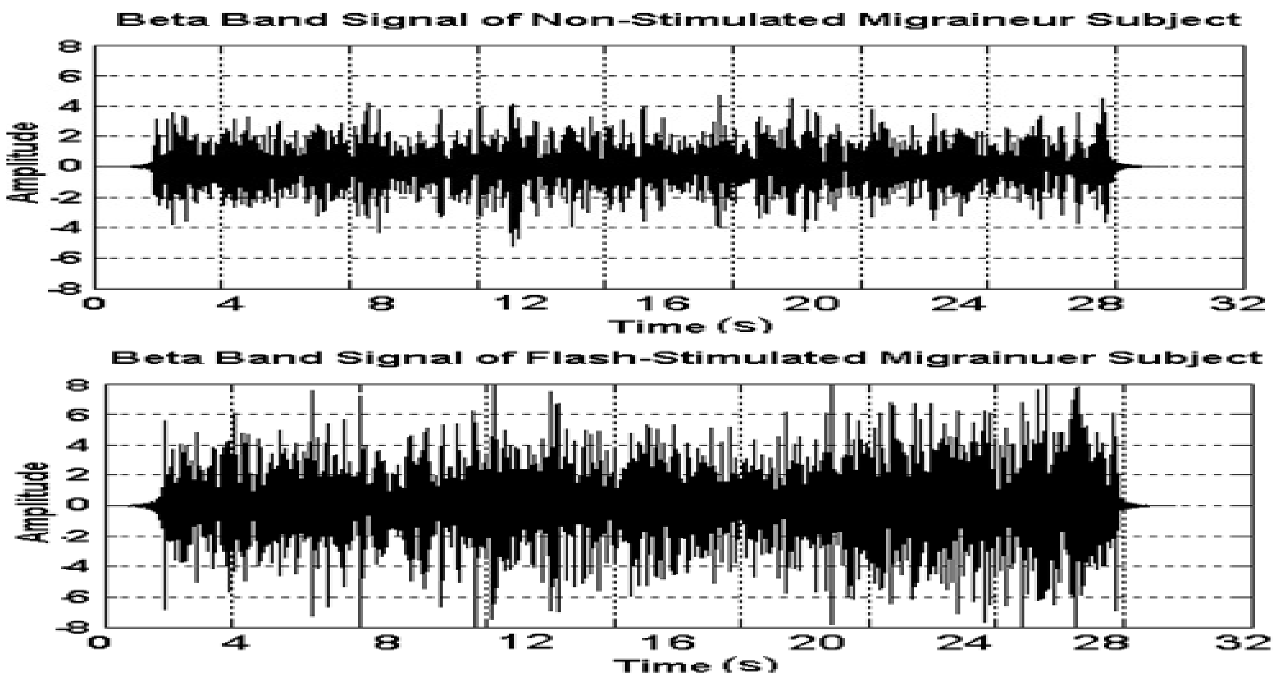

Figure 8. Flash stimulated and non-stimulated EEG signals of migraine patient.

stimulated and non-stimulated EEG signals for both migraine patients and healthy subjects were used as features for the clustering stage of the analysis. Finally, k-means clustering method is used to see clustering achievements of healthy subjects and migraine patients, by using histogram frequency differences of the flash stimulated and non-stimulated EEG data. Result of this clustering method is shown in Figure 8 by a silhouette graph.

In Figure 8, clustering accuracy is given by silhouette values (belonging degree) of each subject that are demonstrated as 0 to 1 interval in vertical axis. As shown from Figure 8, 15 healthy subjects and 15 migraine patients were accurately clustered to two clusters. For both migraineurs and healthy subject's belonging degrees to their own cluster is quite adequate. Result ofthis research braces the result of former researches related to migraine detection (Gozke et al., 2004; Akben et al., 2011a; Akben et al., 2011b). Since, in this former research, for the migraine patients, increased amplitude has been observed at the beta band of T5-T3 channel flash stimulated EEG signals, as compared to non-stimulated ones. But the former research was based on power spectrum density (PSD) comparison by using Burg-AR algorithm. This study is based on basic time domain based mathematical histogram computation which has a less mathematical complexity. The obtained result of this research can be used in migraine detection according to accuracy rate of our research.

DISCUSSION

Different migraine detection methods have beenproposed in former researches. But these former researches are generally based on frequency domain analysis of EEG data. Due to frequency domain transformation of EEG data, complex mathematical algorithm is needed; these frequency domain transformation based former researches are as practically and computationally difficult and needed long computation time period. In this study, a time domain based histogram technique was used as a pre-processing technique to extract features, to cluster healthy subjects and migraine patients from flash stimulated and non-stimulated EEG signals. It is observed from Figure 9 that, the amplitude frequency histograms (Cluster 2) clustered very well with silhouette values greater than or equal to 0.63 for migraine patients. Also, the similar achievements are obtained for healthy subjects. For all the data correct clustering accuracy can be calculated as 86.6% by using the information from Figure 10.

Since the silhouette values(i) for each data i lies between -1 to 1, if s(i)>0, then the data is said to be well classified, and if s(i)<0 then data is poorly classified (Xu and Wunsch, 2005). Thus, the obtained average silhouette values for this clustering gave acceptable accuracies ($0.6 \leq s(i) \leq 0.94$) which can be used as a measure of its goodness. Correct Clustering achievement

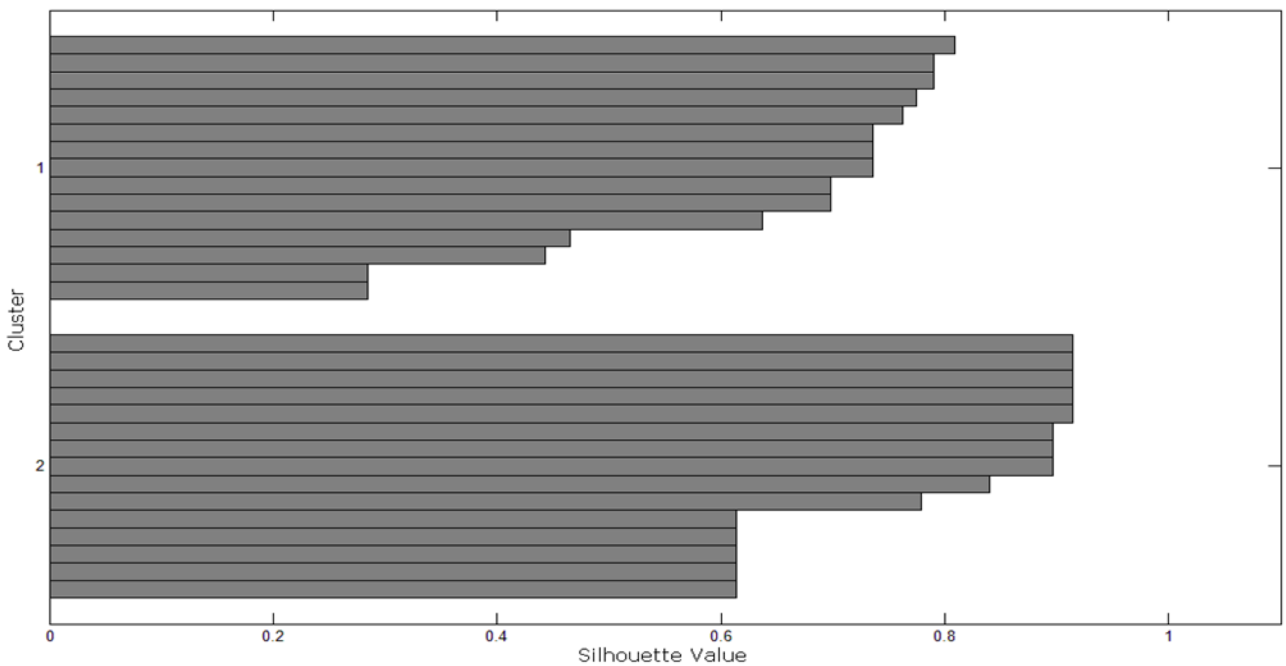

Figure 9. Silhouette values of clustering.

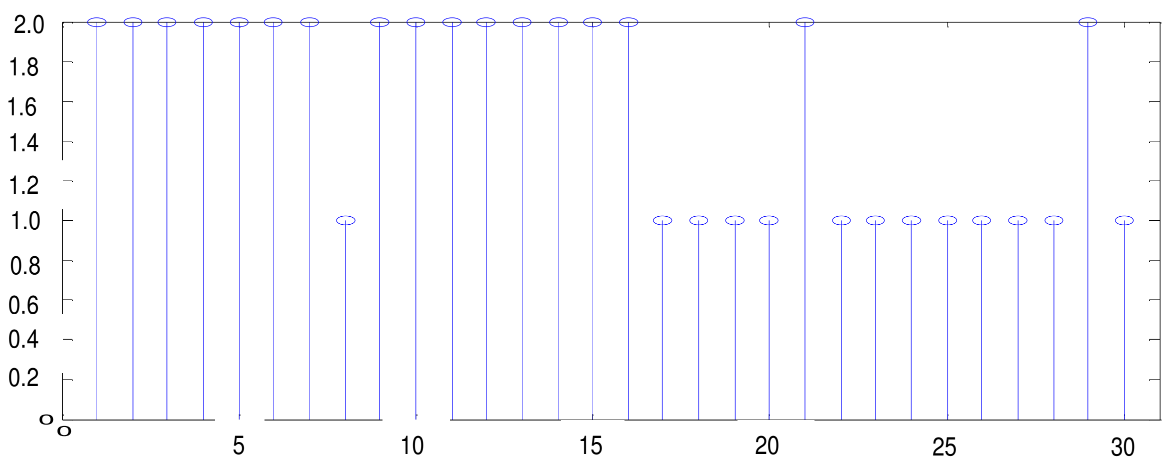

Figure 10. Clustering results: under flash-stimulated and non-stimulated EEG signals of healthy (group 1) and migraine patients (group 2).

results can be seen in Figure 10 under flash-stimulated and non-stimulated EEG signals of healthy (group 1) and migraine patients (group 2) that can be calculated as 86.6%. Therefore, putting into practice of our proposed new method is easier and more practical than the proposed method of the former research (Akben, 2011) related to migraine detection. Also, this new clustering algorithm can compute the result in a short time period as compared to methods of former researches for migraine detection because of the used methods. The average calculation time for pre-processing (Burg algorithm) in previous study (Akben et al., 2011) was about 7.2 ms but in this study, the average elapsed time for pre-processing (histogram calculation) is about 1.3 ms.

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