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A study on Analog and Digital EEG Signal Filtering for Brain Computer Interfaces (BCI)

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Abstract: Brain Computer Interface (BCI) is a robot/machine communication based on brain activity. The main purpose of BCIs are facilitate the living of disables which has hearing, vision or mobility disabilities. The first and most basic step of the implementation of this system is obtain the recordings of brain signals known as Electroencephalography (EEG). In this study, we aimed to obtain regular EEG signals which were cleaned from negative impacts for BCIs. In this context, analog and digital filter effects were focused to achieve effective and clean EEG signals. Analog and dijital low/high pass filter effects examined on EEG and suitable filter rates are identifyed for clean signals.

Keywords: Brain computer interface (BCI), electroensephalogram (EEG), analog/digital filtering

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Beyin Bilgisayar Arayüzünde Kullanmak için EEG Sinyallerinin Analog ve Dijital olarak Filtrelenmesi

Özet: Beyin bilgisayar arayüzü (BBA), beynin aktivitelerine bağlı olarak gerçekleştirilebilen bilgisayar-makine arasındaki iletişimdir. BBA'ların temel amacı, duyma, görme veya hareket etme kabiliyetinden yoksun olan engelli kişilerin yaşamlarını kolaylaştırmaktır. Bu sistemlerin ilk ve en temel aşaması Elektroensafalogram (EEG) olarak bilinen beyin sinyallerinin kaydedilmesidir. Bu çalışma ile EEG sinyallerinin BBA sistemleri için kullanılabilir bir forma dönüştürülmesi amaçlanmıştır. Düzgün bir sinyal elde edilebilmesi adına gerekli olan filtreleme oranları ve analog/dijital alçak ve yüksek geçiren filtrelerden yararlanılmıştır.

Anahtar Kelimeler: Beyin bilgisayar arayüzü (BBA), Elektroensafalogram (EEG), analog/dijital filtreleme

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1. Introduction

BCI is a communication between robot and machines. For this purpose, EEG signals are processed, desired commands determined and suitable operations carried out. An electromechanical lever or variety of electronic devices can be actuated without using the motor neuron. Any of muscle action is required for BCI.

Human brain activity is measured by invasive or non-invasive approaches. The sensing devices are placed inside the skull with invasive approaches. But, measurements are done by sensors outside of the head in non-invasive approaches and EEG signals obtained. The non-invasive approaches have been studied in the literature much more and is easier [1]. These signals are generally recorded from various parts of the skull by 8, 16 or more different electrodes and peak to peak amplitude values varies 1-400 µV [2]. EEG signals have wide frequency band (0.5-100 Hz) but clinical and physiological information is concentrated between 0.5 and 40 Hz. This frequency band is typically divided into 5 parts [3] :

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1. Delta (δ) Waves: Frequencies between 0.5 and 4 Hz and amplitudes range from 20 to 400 μV. It is encountered in very low activity of the brain as deep sleep and general anesthesia.

2. Theta (θ) Waves: Frequencies between 4 and 7 Hz and amplitudes range from 5 to 100 μV. It is observed at normal individuals in low activity of the brain as dreaming sleep, mid-depth of anesthesia and stress.

3. Alpha (α) Waves: Frequencies between 8 and 12 Hz and amplitudes range from 2 to 10 μV. It is occured in individuals of awake, full quiescent physically and mentally, no external stimulis and eyes closed.

4. Beta (β) Waves: Frequencies between 13 and 40 Hz and amplitudes range from 1 to 5 μV. It is appeared in active thinking, interested, concentrated and solving daily problems.

5. Gama(γ) Waves: Frequencies between 40 and 100 Hz and amplitudes range from 0.2 to 2 μV. It is encountered during certain motor functions of the brain.

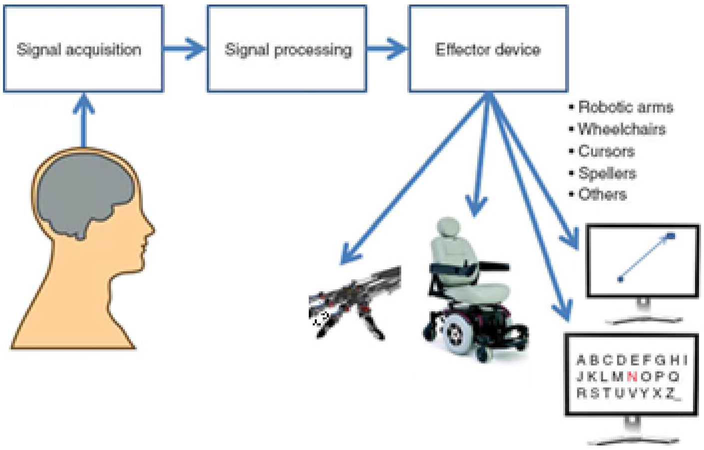

Figure-1 The General Structure of BCI Systems

As shown in the figure, the first part of the BCI systems is signal acquisition that EEG signals are obtained. It is one of the most important parts. In EEG recordings, the signals can be accurately obtained after passing through various difficulties. Signals any errors made while acquiring a fundamental effect on all the BCI system makes it difficult to reach firm conclusions. While acquiring signals, made of any errors effects all the BCI system and difficult to reach clear conclusions. Therefore, to obtain clear signals play an important role for BCI system [4]. When EEG signals assessing, the most important factors are artifacts. The existed artifacts in EEG recording (eye movements, movement and muscle artifact, electrode drift, sweating, etc.) is the result of various mechanical-electrical potential[5]. Before the evaluation process, EEG signals must be removed from the artifact.

In this study, before starting EEG signal assessment, analog and digital filtering techniques are emphasized to obtain clean and properly EEG signal acquisition.

2. Construction of the System

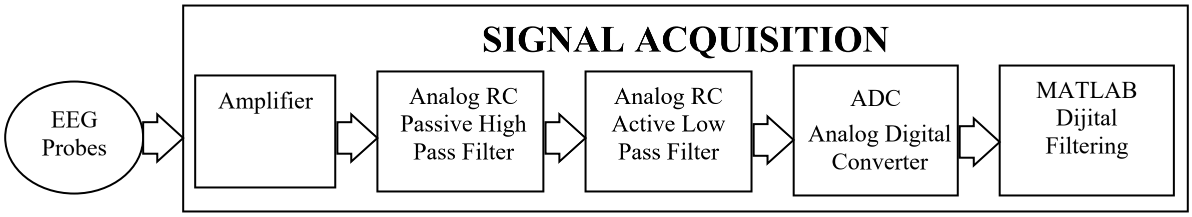

Figure-2 Block Diagram of The System

The block diagram shown in our own system, EEG signals from the skull surface with the probes are amplified, filtered and converted to digital and transmitted to a computer as with all the EEG measurement system.

2.1. Electrodes and Possitions on the Surface of the Skull

EEG electrodes are positioned within a standard coordinate system on the skull. This system known as 10/20 coordinate system [6, 7]. EEG electrode placement slots in caps are made in accordance with this system and they electrode names consist of a letter and a number. The letters represent of brain parts (lobes) which located on and the numbers rank of them. In addition, the combination of two letters shows the seperation of the parts.

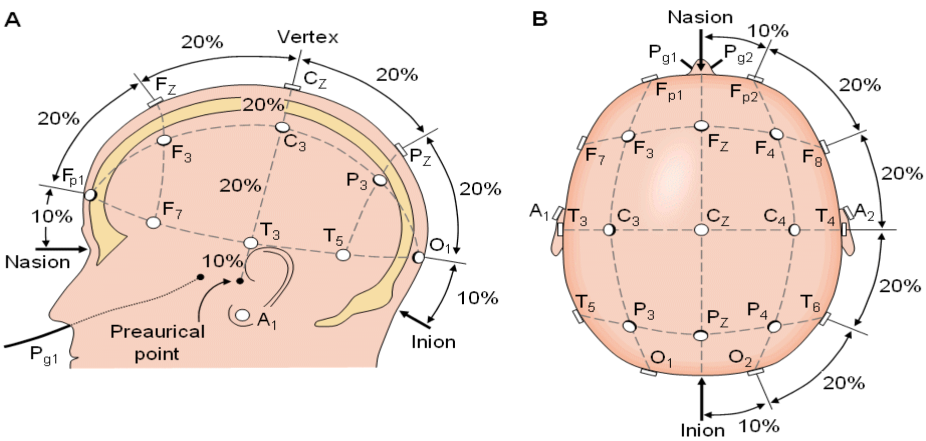

Figure-3 International 10/20 Coordinate System

Also, the electrodes on the right side of the head named with odd numbers, on the left side even numbers and on the center of the head represented with “z” [8, 9].

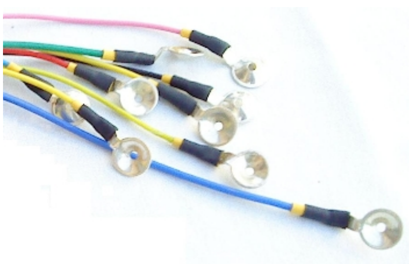

Figure-4 Metal disc electrodes

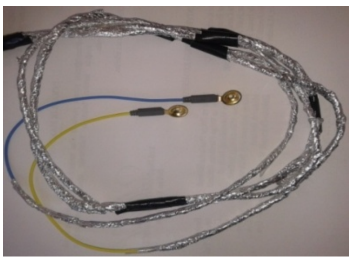

Figure-5 Isolated electrodes

Metal disc electrodes are generally used in EEG measurement systems. The metal plate is flat or part of a cylindrical surface. They are made typically nickel-silver and nickel-gold alloy. As shown in Figure 2.3, different color is used for the insulation of each wire to easily identify of the electrodes. In addition, the electrode jel is used to obtain higher quality of human instrumentation system measurements and minimize to skin resistance of electrode contact surface [10]. With the created EEG measurement system, all necessary standards are implemented and electrodes were placed 10-20 system with the help of gel. Further, EEG mesurement with insolated cable was showed that the signal variation is less than unisolated cable and negative impacts are less effective. Therefore, all the EEG measurement cables were isolated with DIY (Do-It-Yourself) methods as shown in the Figure 2.4 [11].

2.2. Amplifier

Signals amplified from µV ranges to mV within amplifiying part for analyze detail. This section contains a integrated circuit AD620 known as medical instrumentation amplifier designed by Analog Devices Company [12]. Schematic representation of the circuit is shown as below.

This integrated circuit has low power consumption and its most important characteristic is the range of amplifiying from 1 to 10000. Besides low noise level, it provides in the range of ±2.3V to ±18V supply voltage. Its amplifiyng range is calculated with a resistance (R_G) between 1 and 8 pins as formulated below.

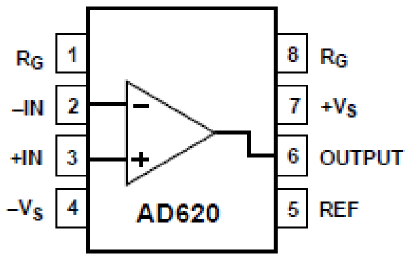

Figure-6 AD620 Pinout

$$G = \frac{49.4k\Omega}{R_G} + 1 \qquad \text{and} \qquad R_G = \frac{49.4k\Omega}{G-1} \tag{1}$$

The letter 'G' is gain and 49.4kΩ is feedback resistance value of the amplifier. In the study 10Ω is selected for Rg, so the gain of the circuit G is 4941.

2.3. Analog RC Highpass and Lowpass Filters

2.3.1. Analog RC Passive Highpass Filter

Analog RC High-pass Filter is simple as seen on the figure and it is created with a resistor and a capacitor. It is used to destroy high levels of undesirable components in the signal frequency near 0 (the DC component) [13].

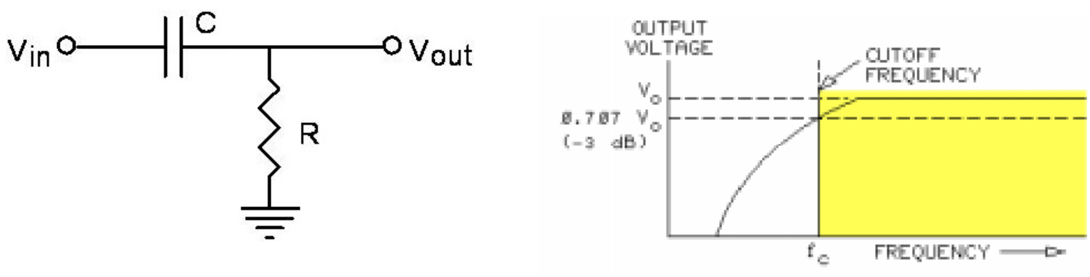

Figure-7 Analog RC Passive Highpass Filter and Its Frequency Response

Corner frequency of the filter is calculated by the Formula:

$$f_c = {}^{1}/_{(2\pi RC)} \tag{2}$$

In the study, R=400kΩ and C=1uF were chosen to obtain 0,4Hz cut-off frequency.

2.3.2. Analog RC Active Lowpass Filter

Low pass filter part is constructed with LF412 [14] integrated circuit which has quick response features and R and C circuit elements as an active filter. This active filter designed as 5th order to suppress high frequency components better. The cut-off frequency is adjusted to 40Hz because of the clinical EEG data is between 0 and 40Hz and eliminate the source disturbances. So, 5th order 40Hz active low -pass Butterworth filter was created.

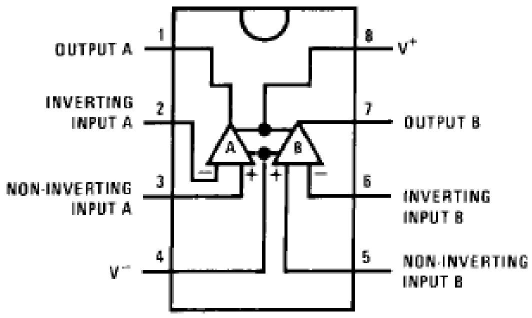

Figure-8 LF412 Pinout

Butterworth filter is an IIR (Infinite Impulse Response) filter type that the amplitude response is as flat as possible. It provides a frequency response without ripple and passband is the most smooth [15]. Frequency response curve is shown below for a variety of different elements in different degrees.

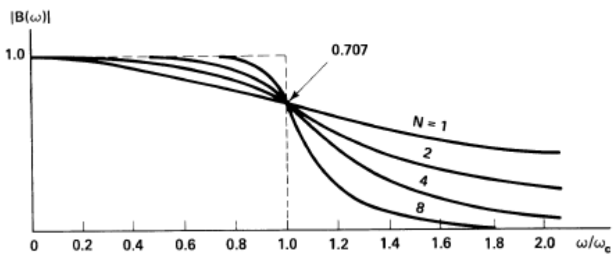

Figure-9 Butterworth Filter Frequency Response

The transfer function of the fitler is,

$$|B(jw)|^2 = \frac{1}{1+(jw/jw_c)^{2N}} \tag{3}$$

This type of filters has two characteristic parameters that are cutoff frequency (fc) and the filter degree (N) [16].

This circuit is created with active LF412 integrated amplifier in addition to R anc C passive components. The 5th order filter circuit is obtained with the combination of two 2nd order cascade connected active filter and a 1st order RC filter. The filter cut-off frequency is calculated by R1, R2, C1 and C2.

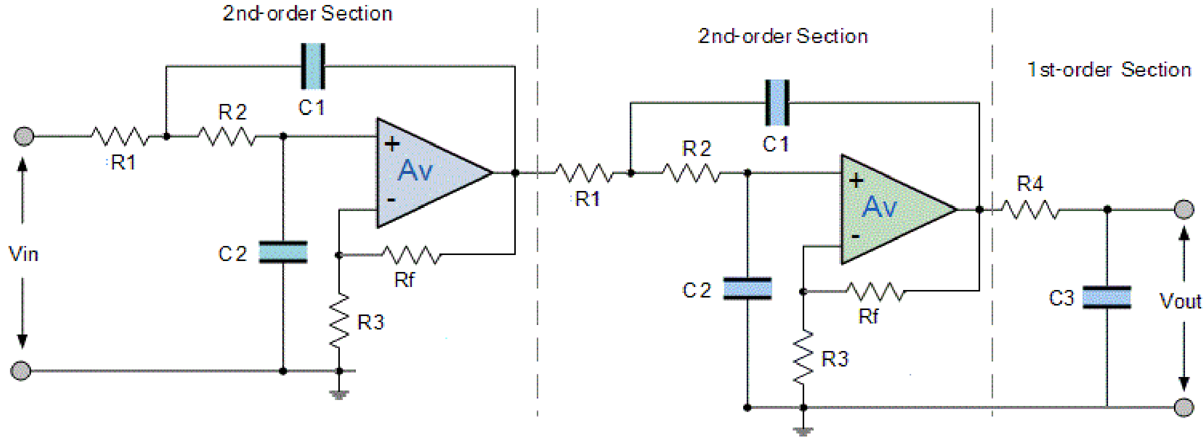

Figure-10 5th Order Active Lowpass Butterworth Filter

Cut-off frequency is calculated by the formula:

$$f_c = {}^{1}/_{(2\pi RC)} \tag{4}$$

R1= R2 are 840kΩ and C1 = C2 are 4,7nF and fc = 40Hz. Additionally, amplifier used in the filter circuit is noninverting and amplifiying. This ratio is:

$$K = 1 + \left({}^{R_f}/_{R_3}\right) \tag{5}$$

Rf = R1 are 1kΩ. So, K is equal 2 for each lap.

Measured signal amplified about 494 with AD620, approximately 2 times with each filter lap. It has amplified totally 1976 (494*2*2) times at last.

2.4. Analog Digital Converter (ADC)

The clean EEG signal is converted to digital data from analog form and transfered to computer in this part of the study. 8-bit programmable Atmega 328P [17] microcontroller made by Atmel is used for digitazed. This chip has 10-bit resolution, 6 different analog input channels and operates up to 20MHz. It uses 1ms sampling rate in the study to digitize. To perform these operationsm microcontroller is programmed by C language. Digital data is transmitted via USB port to computer because of the data has to assign an output port in Atmel microcontroller.

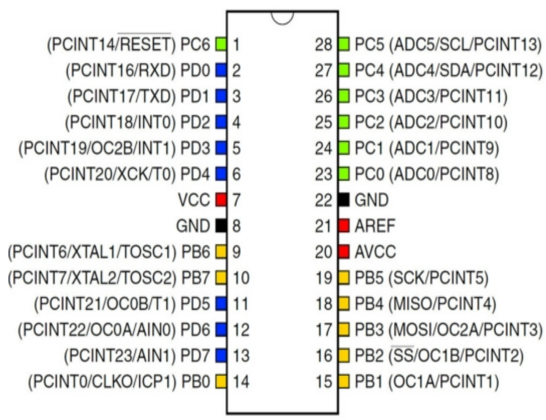

Figure-11 Atmel Atmega-328P

3. Digital Filtering, Dc Component Wipe And Normalization

EED data was recorded with electrodes placed on the frontal lobes (F3, F4) and a visual interface was created with Microsoft Visual Studio [18] to evaluate the operation of the system as shown below.

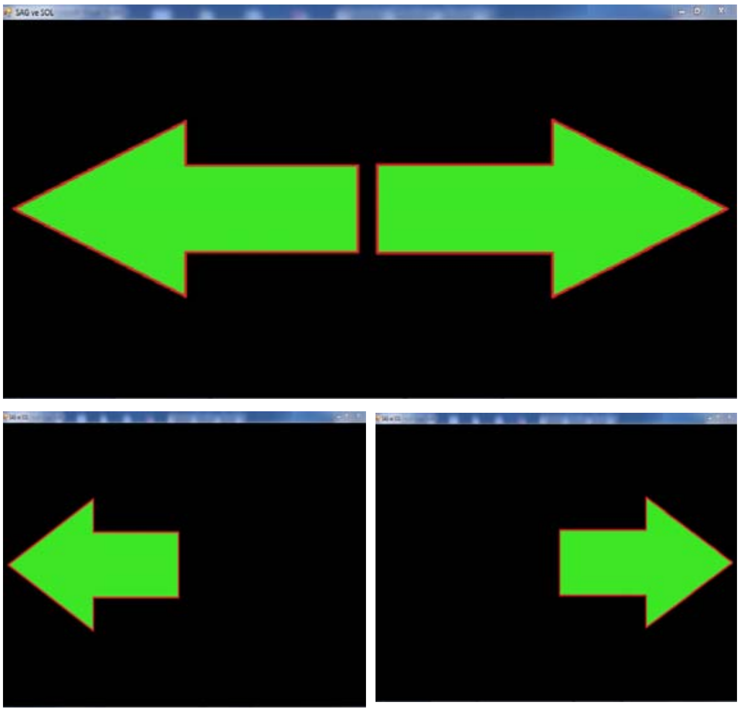

Figure-12 Visual Interface by Microsoft Visual Studio

Visual interface has two arrows that right and left as seen on the figure. Fisrtly, right arrow flashes 100 millisecond intervals along 5 seconds and then left arrow flashes systematically. This event continues for 30 seconds. During this time dijital data are transfered to computer via the USB port.

EEG signal processing made by Matlab signal processing tools [19] with the help of computer. The raw data graph was obtained as follows.

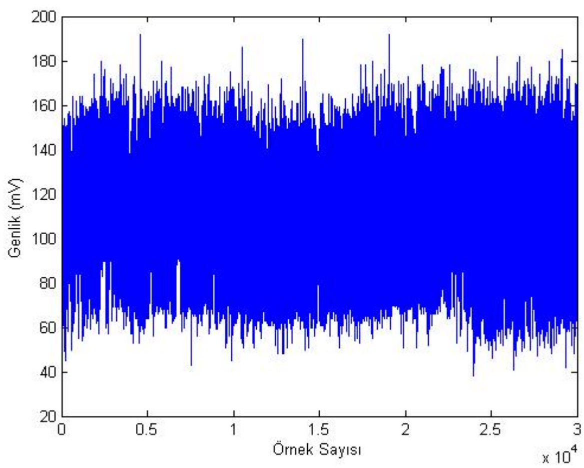

Figure-13 The Raw EEG on Matlab

When analyze the raw data graph, it is seen that high component distortions reduced greatly and the data has a reasonable range. This effect is the result of analog low and high pass filters which are established in the system.

3.1. Digital Filtering, DC Component Wipe and Normalization

40Hz low-pass Butterworth filter was applied the raw data dijitally on Matlab to eliminate all the undesirable effects to obtain pure signal. Hamming windowing technique [20] was used and filter order is maintained as high as possible. So, the elimination of artifacts and a better filtering performance has been achieved.

High value of the DC component in the digital environment was eliminated on Matlab by the method of quality average value which thesame with anlaog RC high-pass filter to achieve better quality signal. In this method, the average of all the data was subtracted from each data value. Furthermore, the data was normalized on Matlab to examine in terms of scale with graph. In this way, it was realized that its range and absolute sizes.

Accordingly, the signal graph on Matlab with digital filtering, DC component wipe and normalization as shown below.

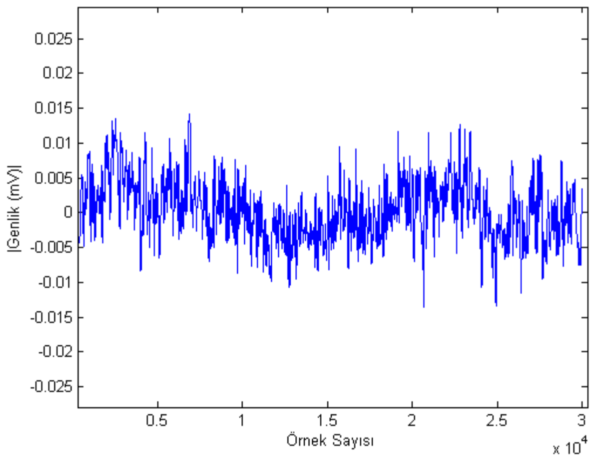

Figure-14 Digital Filtering, DC Component Wipe and Normalization on Matlab

The 30000 samples signal was separated 6 parts each of 5000 samples and drawn separately on Matlab while visual interface was viewing (right and left arrows was flashing systematically) as shown below.

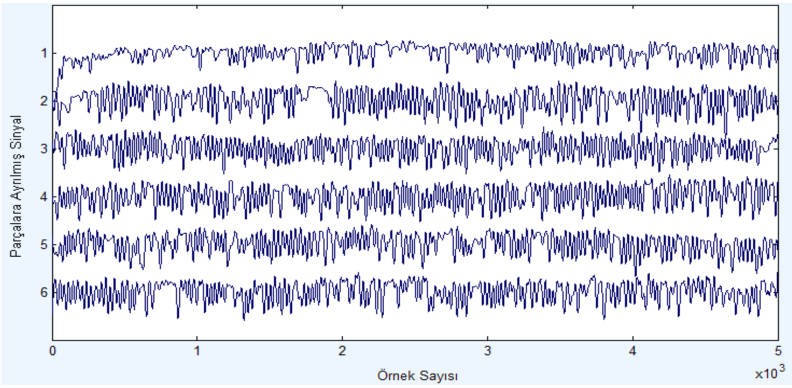

Figure-15 Partitioned EEG Data

In this way, the total signal was partitioned and achieved more visual form.So, its proximity to the standard EEG signals were revealed.

4. Results

In this study, a simplified prototype EEG measurement system was developed to collect EEG signals from the skull surface. Analog and dijital filtering techniques were enphasized to clean EEG signal from various parazites and obtain it properly at signal acquisition section one of the main part of the BCI systems. EEG probe cables were isolated to reduce signal distortion at minimum. Also, microvolt signal values were amplified up to milivolts with the help of amplifier and get healtier form. High DC component in the signal was eliminated by analog RC high pass passive filter with 0,4Hz cutoff frequency. In addition, the clinical information was selected with the cut-off frequency of 40Hz 5th order analog low-pass RC active filter. The graph of raw digital signal has proved the whole systems successful. Also, digital filtering techniques demonstrated the obtained signal is similiar to real EEG. Visual interface contributed better understanding of the signal differences during the collect of the it. As a result, amplifier part, analog filter parts, digital conversation and dijital filtering parts at the signal acquisition part one of the basis of BCI, fulfilled tasks adequately. Besides, the established system will constitute a resource for later works.

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