Development of Dementia Neurofeedback System Using EEG Brainwave Signals

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***Abstract*—Dementia is one of the diseases where the number of cases is increasing annually in Malaysia. Although dementia cannot be cured, but the disease progress can be slowed down with proper treatment and monitoring. However, it is difficult to track the disease progress periodically. This project proposes a dementia neurofeedback system by implementing electroencephalogram (EEG) method. The main objective of this project is to implement a neurofeedback system using EEG signal to collect and analyze the EEG signal to track the progress of the patient. This project serves two purposes. Firstly, acquire the EEG signal from the dementia patient. Secondly, implement signal processing method to retrieve useful information from the complicated EEG waveform in order to ease the analyzation for research purpose. In this project, the EEG signal is acquired by using the EEG headset namely Emotiv EPOC+. The EEG signal acquisition and recording is done by using neurofeedback software whereby the software is implemented by using Microsoft Visual C#. Lastly, the signal is processed by using the EEG analyzation software which is implemented by using MATLAB. The results show that this system is able to collect the EEG brainwaves data and aid in analyze the brain condition of the patient. The performance of the developed dementia neurofeedback system shows that the system is reliable and highly useful in medical research field.**

***Index Terms*—neurofeedback system, brainwaves, dementia, EEG**

I. Introduction

According to the statistic in Malaysia, the number of dementia patient increases annually. [1] Dementia is a disease whereby brain cells are damaged. [2] This leads to the dementia patient lost certain brain function especially in cognitive functioning and controlling physical body function. Thus, usually dementia patient will have difficulties in memorizing, communication, problem solving, ability to perform daily tasks and even paying attention. These functions include physical movement, sensing, emotional expression and cognitive ability. [3]

The current technologies that used to determine the brain condition of the dementia patient in order verify the seriousness of the disease are known as Magnetic Resonance Imaging (MRI) and Computed Tomography (CT). However, both methods cannot be used frequently as it will damage the human cells during the process. [4] Thus, this project proposes a system which collect the neurofeedback data in term of brainwaves. This is due to the brainwaves collection process is not invasive and do not harm human body cells. Thus, this method is suitable to be used periodically to determine the brain condition for progress monitoring.

Few years ago, scientists and engineers have invented technologies to capture brainwaves data which is known as electroencephalogram (EEG) in scientific term [4]. In order to capture the EEG data, a headset embedded with sensors is placed over the head whereby the sensors are contacting with the scalp. This technology is a major contribution in providing a non-invasive method to obtain neurofeedback from the human brain [5]. The EEG signal is resulted from the process of neurons communicating with each other in the brain. During the communication process, electrical pulses will be produced. Thus the electromagnetic waves resulted from the electrical transmission is known as the EEG waves. [6] However, the signal power of EEG is extremely low. The signal has to be amplified once after the acquisition. The EEG data are made up of electrical waveform in various frequencies [7]. The frequencies are classified into few frequency bands which known as Alpha, Beta, Gamma, Delta and Theta. Alpha band ranges from 9Hz to 13Hz, Beta band ranges from 13Hz to 30Hz, Gamma band ranges from 30Hz to 90Hz, Delta ranges from 0.5Hz to 4Hz and Theta band ranges from 4Hz to 8Hz [8]. Research shows that different frequencies of the brainwaves will be dominant when the brain is conducting different activities [9].

The EEG signal is extremely complicated since it consists of waveform with different range of frequencies. Thus, the signal is required to process before analyzation in order to obtain informative data from the captured signal [10]. The signal processing method is used to extract useful information from the complicated signal in order to alleviate the signal analyzation for research purpose [11]. Hence, this project has two major purposes. The first objective is to design a procedure to acquire the EEG data. Another objective is to convert the high complexity EEG data into informative data in order to track the disease progress of the patient. Thus, this developed system is useful for the medical experts to collect the neurofeedback data to perform scientific research and track the disease progress of the patient. In this way, proper medication can be given to the patients to slow down their disease progress.

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AF4	F8	F4	FC6	T8	P8	O2	O1	P7	T7	FC5	F3	F7	AF3	time
4108.718	4114.359	4091.795	4122.564	4148.718	4138.462	4184.103	4167.179	4133.846	4166.154	4132.821	4122.051	4030.256	4093.846	348.7646
4132.308	4120	4112.308	4152.308	4150.256	4135.897	4191.795	4177.436	4131.282	4080	4154.872	4131.282	4051.282	4112.821	348.7729
4103.077	4115.897	4091.282	4137.949	4141.538	4136.923	4186.667	4146.154	4131.795	4086.154	4147.692	4120.513	4027.179	4085.128	348.7813
4105.641	4119.487	4096.923	4145.641	4137.436	4141.026	4187.692	4149.744	4131.795	4215.385	4132.308	4118.974	4013.333	4082.051	348.7896
4115.385	4123.077	4102.564	4147.179	4138.974	4139.487	4188.718	4163.59	4130.256	4155.385	4134.872	4121.538	4030.769	4095.385	348.798
4127.692	4123.59	4109.231	4148.718	4140.513	4136.923	4190.769	4175.385	4136.923	4075.897	4144.103	4124.103	4065.128	4113.846	348.8063

Figure 1. Recorded EEG data in CSV format.

II. Methodology

The dementia neurofeedback system is established by combining seven major components. The system starts with EEG signal acquisition and attention test application that used to drag user's attention. Then, the data processing is performed using Hann Window technique and Fast Fourier Transform (FFT). Lastly, the results are visualized by using Frequency Band Power Generator and Data Correlation Feature.

A. *EEG Signal Acquisition*

During the process of EEG signal acquisition, user is required to wear the EEG device on the head [12], [13]. Then, the signal recording is performed by using the developed EEG signal acquisition software. The EEG device is connected to the personal computer (PC) wirelessly via Bluetooth [14]. The data acquisition software records the data in the form of comma separated values (CSV) file format. Fig. 1 shows the sample recorded EEG data in CSV format.

Each column of the table represents each channel of the EEG. EPOC+ consists of 14 channels where different channel detects different region of the brain. The unit of the acquired data are recorded in terms of micro Volt (uV).

B. *Hann Window Technique*

The complicated EEG signal is required to process in order to convert the complicated waveform into simplified waveform whereby informative data can be acquired. Thus, a EEG signal processing software is mandatory. The signal processing methods start with windowing technique. The windowing technique is implemented for reducing the spectral leakage effect. In this project, Hann Window technique is employed. [15] This technique is applied by multiplying the input value with the window value. The amplitude of the window signal will increase deliberately from zero at starting edge and decrease deliberately to zero at ending edge. The purpose of this technique is to avoid the sudden transitions in between the starting point and the ending point [15]. The Hann window technique is performed by using Equation 1 and Equation 2.

$$\omega(n) = 2\pi \frac{n-\left(\frac{N+1}{2}\right)}{(N+1)} \tag{1}$$

$$\text{win} = \frac{\sin\omega(n)^2}{\omega(n)} \tag{2}$$

C. *Fast Fourier Transform*

Fast Fourier Transform (FFT) method is implemented on the signal once the Hann Window technique is carried out. FFT method split the signal into few sine waves with several frequencies and amplitude [16]. The EEG waveform in time domain are in term of sine and cosine waves [16]. Thus, the EEG waveform signal can be streamlined into few sine waves. Once streamlined, all the major frequencies in the signal can be revealed out. Since Hann Window technique is applied before FFT, the preprocessed signal is periodic. Hence, the result of FFT provides simplified results whereby the number of period of the acquired signal is in integer form [17].

D. *Frequency Band Generator*

This frequency band generator is used to generate the bar graph representing the power spectrums of specific frequency bands. This method starts with defining the index of specific frequency bands. The algorithm continues with accumulate the value of power spectrum for the specific frequency bands by using the defined index. Lastly, the sum of the value representing the Power Spectrum of specific frequency bands is present in term of bar chart. Besides that, another useful information known as the relative power is acquired by using equation 3. Fig. 2 shows the generated power spectrum and Fig. 3 shows the generated relative power.

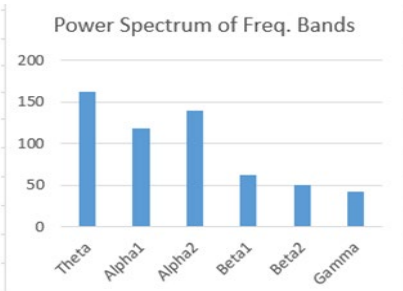


Figure 2. Power spectrum.

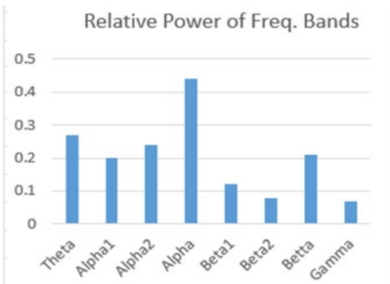


Figure 3. Relative power.

$$P_{relative} = \frac{P_{specific\ spectrum}}{P_{total}} \quad (3)$$

E. Data Correlation Technique

The EEG analyzation software is equipped with data correlation technique to compare the results of two different group of samples. This feature allows the user to correlate and find out the major difference between two sets of EEG data in term of power spectrum. Thus, this system provides the feature for correlating the relative power of respective frequency bands of various groups, for eg. Patient group and normal person group. The software also display how many groups are saved and will be compared. The result of comparison is also presented in term of bar chart.

F. Neurofeedback Algorithm

The neurofeedback algorithm is developed to process the captured data and determine their brain condition. Research found that different major frequencies found in the EEG signal indicates different condition of the brain [17], [18]. The research found that the relative Alpha band power is significant during resting state [19]-[21]. The Alpha band power correlates to how attentive the person is [22]. Thus, it is concluded that alpha power indicates the resting state. Resting state means that the person is relaxing without giving any attention. The power of alpha band is calculated using Equation 4.

$$P_x(f) = X(f)X^*(f) \quad (4)$$

where $X(f)$ is the frequency domain representation of the signal $x(t)$, while $X^*(f)$ is the complex conjugate part of $X(f)$. Then, the value is generated by using scaling term as shown in Equation 5.

$$\text{scaling term} = \frac{1}{\text{length of signal} \times \text{transform length of FFT}} \quad (5)$$

The relative power of alpha frequency is used to indicate how relax the person are and not focus on anything. The value is generated by using the Equation 6.

$$P_{alpha\ relative} = \frac{P_{alpha}}{P_{theta}+P_{alpha}+P_{beta}+P_{gamma}} \quad (6)$$

G. Procedure on Neurofeedback Acquisition

There are two kinds of feedback data collected for the study. One is the EEG data in resting state and another in attentive state. The procedure of the EEG data acquisition is shown in Fig. 4.

During the starting of the EEG data acquisition process, the patient is asked to sit and rest for three minutes. The EEG data is collected for these three minutes and used to analyze in term of Alpha power. Then, the attentive memory game application is started and the patient is required to play the memory game for three minutes. During the three minutes, the EEG data is collected and is used to analyze in term of Beta power. Fig. 5 shows the developed memory game to keep the patient focus and attentive.

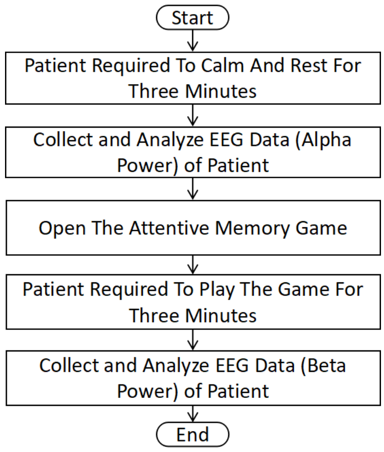


Figure 4. Procedure of EEG data acquisition.

Figure 5. Developed attentive memory game.

Alpha power is indicating the person is relaxing and not focusing. Thus, the higher the power of alpha frequency band, the calmer the dementia patient is during resting state. The relationship is shown in the Table I.

TABLE I. RELATION BETWEEN RELATIVE ALPHA BAND POWER AND CALMING LEVEL

Relative Alpha Band Power (%)	**Calmness**
70 and above	High
Between 50 and 70	Medium
Between 30 and 50	Low

Beta power indicates attention level while playing the memory game. Thus, the higher the power of beta frequency band, the higher attention level the dementia patient has achieved during resting state. The relationship is shown in the Table II.

TABLE II. RELATION BETWEEN RELATIVE BETA BAND POWER AND ATTENTION LEVEL

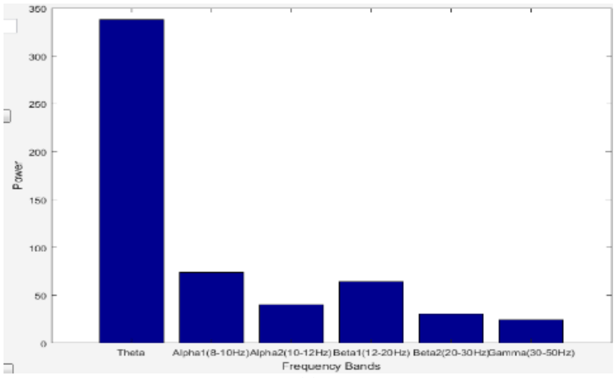
Relative Beta Band Power (%)	**Attention level**
70 and above	High
Between 50 and 70	Medium
Between 30 and 50	Low

III. RESULTS AND DISCUSSION

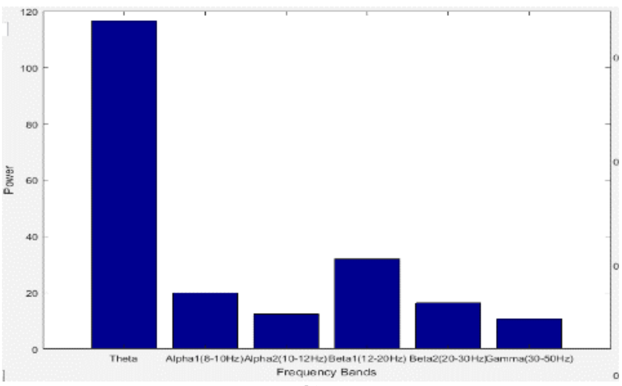
Different frequency bands dominant in the EEG signal indicates different brain activities [23]. Thus, this project analyzes the EEG data in term of power spectrum for two sample groups in order to find major difference between the groups. In this project, the EEG data of the resting group is compared with the group of playing game (both normal person group), Beta frequency power band for two different group (normal person and patient) and the frequency Alpha power band for two different group (normal person and patient). The results are used to prove the reliability of the developed neurofeedback system. The experiment is carried out with twenty samples: ten patients and ten normal people. Since the results showing the same features, the results are presented in term of only two subjects where one from patient sample and one from normal person sample.

A. Beta Frequency Band Power of Dementia Patient vs Normal Person

Beta brainwaves is significant when the person is focusing and paying attention [20], [24]. Thus, playing game requires level of attention and hence increase the band power of Beta frequency. The results show that dementia patient will have higher beta power when playing the memory game compared to the normal person. Fig. 6 shows the results of frequency band power of a dementia patient and a normal person.



(a)



(b)

Figure 6. Frequency band of: (a) dementia patient (b) normal person.

B. Alpha Frequency Band Power of Dementia Patient vs Normal Person

Alpha Amplitude increases when the individual is in resting state [20], [25]. During the experiment, the brainwave of the normal persons and dementia patients are captured and analyzed. The results show that the alpha relative power is lower for the dementia patients. The result is tabulated in Table III.

TABLE III. RELATIVE POWER OF FREQUENCY BANDS OF DIFFERENT GROUPS

Frequency Band	Dementia Patient relative power (%)	Normal Person relative power (%)
Alpha1	18.3	29.1
Alpha2	18.6	17.6
Beta1	10.6	11.8
Beta2	17.7	8.0
Gamma	4.3	6.6

Thus, the results show that the relative power of Beta2 frequency band is higher for the case of dementia patient. Besides, the relative power of Alpha1 frequency band is higher for normal persons compared to dementia patients. The results are tally with the expected results provided by the research. Thus, the performance of the EEG acquisition and acquisition software are well proven.

IV. CONCLUSION

As result, the dementia neurofeedback system which consists of EEG acquisition software, EEG analyzation software, memory game application is successfully developed. The results show that relative power of Alpha band is lower for dementia patient in resting state. The relative power of Beta band is higher for dementia patient in attentive state. Thus, the performance and reliability of the developed dementia neurofeedback system are well proven. In future, the implemented system is capable to aid the medical experts to track the patient disease progress in a scientific way, and eventually benefit the patient when suitable medication is given according to their progress.

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