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Brain Computer Interface- An Eye on Electroencephalogram (EEG) Applications in Clinical Medicine

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ABSTRACT

Brain-Computer Interface (BCI) like other research areas was developed with the primary objective of helping man to solve problems that is bordering him. While other fields were seen having direct applications in unraveling societal challenges, it was not so with BCI then as many thought it was more of experimental jamboree of some few interested artificial intelligence (AI) researchers. But today the story has changed as BCI applications has enveloped all nook and crannies of humanity especially in the area of medicine. This paper evaluates the impact of brain computer interface in modern day research with special interest on its clinical applications. The discourse majors in the usage and measurement of brain activity through the process of electroencephalogram (EEG). The knowledge of EEG finds its wide applications in rehabilitation of patient after suffering stroke attack or its related locked up syndrome, restoration of coordination in someone that suffers schizophrenia, epileptic seizures, and even as a measure of therapeutic control in cases of paralysis. The research work also highlighted the technique of recording brain activity via electroencephalogram and other methods through which brain action can be ascertained.

Keywords: Electroencephalogram, Brain-Computer Interface, Neuron, Brain Signal, Artificial Intelligence, Neural Network.

INTRODUCTION

Brain-Computer Interface is actually an alliance in which a brain accepts and controls a mechanical device as a natural component of its body. Computer-brain interfaces are built to restore sensory function, transmit sensory information to the brain, or stimulate the brain through artificially generated electrical signals. Earlier before now, researchers had developed Brain Computer Interfaces that decode brain activities from animals and used such devices to reproduce movements in such objects.

The fact that the human and other animals utilize the electrochemical signals when transmitting instructions from the brain to the rest of the body formed the bedrock of BCI technology. This is because the opportunity makes it possible to design machines that can speak directly to the nerve cells. This is also in line with the law of energy which states "that energy cannot be lost but can only be transformed from one energy form to another form." (Anyakoha, 2011) So, it was the discovery that about 100 billion neurons can communicate through tiny electrochemical impulses that sparkles like fireflies that produces the movement, expression or words; marked the major breakthrough in designing computer devices that can interface with human body to produce desired action.

DIFFERENT METHODS FOR MEASURING BRAIN ACTIVITY

It is important we study at the famous techniques for measuring the brain activity. The brain sends and receives millions of signals every second both in awake or sleep state. This happens through nerve impulses, hormonal events or other substance transmission. This swapping of information among body cells causes actions like sleep, move, eat, think and others to take place.

The procedures adopted for measuring brain activity can either be structural or functional oriented. Structural methods show the anatomy of the brain while function analysis tries to measure and locate actual point of brain activity. Famous structural methods are Magnetic Resonance Imaging (MRI) and Computerized Axial Tomography (CAT). Common functional analysis methods are Positron Emission Tomography (PET), Electroencephalography (EEG), and Functional Magnetic Resonance Imaging (FMRI). (MACALESTER COLLEGE, 2014)

Magnetic Resonance Imaging (MRI): This involves passing a strong magnetic field through the head. The magnetic field should be well above 30000 times that of the earth. The main aim of MRI is to create cross sectional imaging that will depict a significant contrast between separate tissues of interest. Since MRI can detect radiation from certain molecules that are present in different concentration in assorted tissues, the fluid contrast between structures in the brain can easily be pictured. MRI offers detailed pictures of brain anatomy, which makes it suitable for diagnosing any abnormalities of the tissue in the brain and spinal cord. It can also be used to diagnose disorders of ear, joints and eyes. MRI apparatus sends its signals to a connected computer and the display screen where the images can then be pieced together.

Computerized Axial Tomography (CAT): This is a computerized assembly of several x-ray images taken from different successive angles. The patient is exposed to a small amount of radiation during the process of scanning. The tools required for CAT scan include gantry, x-ray source, computer, detection system and the display network. The detector is used to measure the amount of radiation (signal) unabsorbed as it passes through the skull and brain tissues. When appreciative number of the x-rays has been gathered, the complete picture is reformed by the computer and sent to the display network for onward evaluation and storage. CAT scan may beneficial in cases of finding tumors and other deformities in the brain, for monitoring the effect of brain surgery, or as measure of radiotherapy or chemotherapy on brain damages, and also to detect any possible blood clots after head injury.

Positron Emission Tomography (PET): This measures the emission of positrons from the brain after a small amount of tracers have been injected into the blood stream. PET provides a 3-dimensional drawing where the brain activity is represented using colors. It had contributed usefully in researches especially when it comes to how we think. Its strong point is that it shows changes that occur quickly on the order of seconds. It can deployed in cases of cardiovascular diseases, early brain diseases, ascertain the cause of mental disorder, and locating areas affected by clot or stroke.

Electroencephalography (EEG): This is a simple and accurate way of measuring brainwave activity from the outer part of the brain. It involves attaching sensitive electrodes to the head where the signals are amplified to give a graph of electrical potential versus time. This measure and compare different spots on the head simultaneously. The brain signals are recorded for a special stimulus, and the experiment repeated severally to obtain desired result. It presents a 2-dimensional activity map of the cerebral cortex. It is useful in diagnosis of brain seizure, tumors, head injuries and brain death. The major advantages are its low price compare to other methods and portability. The signal generated can be transmitted via a radio link before recording. Thus, it encouraged the brain activity measurement for an individual performing a task in a real time. The time is measured in milliseconds. EEG can only measure brain activity within the cerebral cortex.

Functional Magnetic Resonance Imaging (FMRI): This technique produces images of activated brain regions by observing the indirect effects of neural activity on local blood volume, flow and oxygen saturation. The FMRI equipment is connected to the computer which spontaneously generates 2- dimensional images. This technique examines the oxygen usage of distinct parts of the brain. It does not require any form of injection of substance on the subject before experiment.

TRENDS IN EEG DEVELOPMENT

According to (Al-kadi, Reaz, & Ali, 2013), the English physician, Richard Caton 1875 discovered the presence of electrical current in the brain when he observed a continuous and spontaneous electrical activity from the brain surfaces of rabbit and monkeys. Also in 1912, Russian physiologist Vlamdir Vladimirovich Pradich through his publication informed his discovering and detection of first brain signals and evoked potentials in mammals (dog). The first human brain signal was recorded by German neurologist Hans Berger in 1924. According to (MACALESTER COLLEGE, 2014), "a German psychiatrist named Hans Berger was measuring the brain waves of his daughter when she was doing mental arithmetic. He found the activity increased when trying to multiply difficult numbers. From this evidence, he deduced that the frequency of the wave pattern from the recording reflected the amount of wave activity in his daughter's brain." Ordinary radio equipment was then used to amplify the electrical activity for recording in graph paper. The device was named "EEG". It was observed that the rhythmic brain waves varied with the state of consciousness of the subject. Franklin Offner developed EEG equipment alongside the concentric needle electrodes to help in measurement of the brain signals. Different methods were developed by researchers in late 1940's for detection, purification, and classification of brain signals that allowed them to diagnose abnormal signals. Shortly after this, English physician Willian Grey Walter developed EEG topography, which allowed for the mapping of electrical activity across the exterior of the brain. These maps were used in diagnoses and treatment of mental illness before 1980s. Techniques were developed in 1990s for processing EEG signals like Blind Source Separation (BSS) and Independent Component Analysis (ICA). Artificial Neural Network (ANN) detection system was designed to help in brain signal classification.

EEG SIGNAL PROCESSING TECHNIQUES

EEG signal analysis undergoes four stages as follows: recording and detection stage, de-noising stage, feature extraction stage and signal classification stage (Al-kadi, Reaz, & Ali, 2013). At each stage certain operations need to be carried out before proceeding to the next stage. These stages are illustrated using figure 1 below.

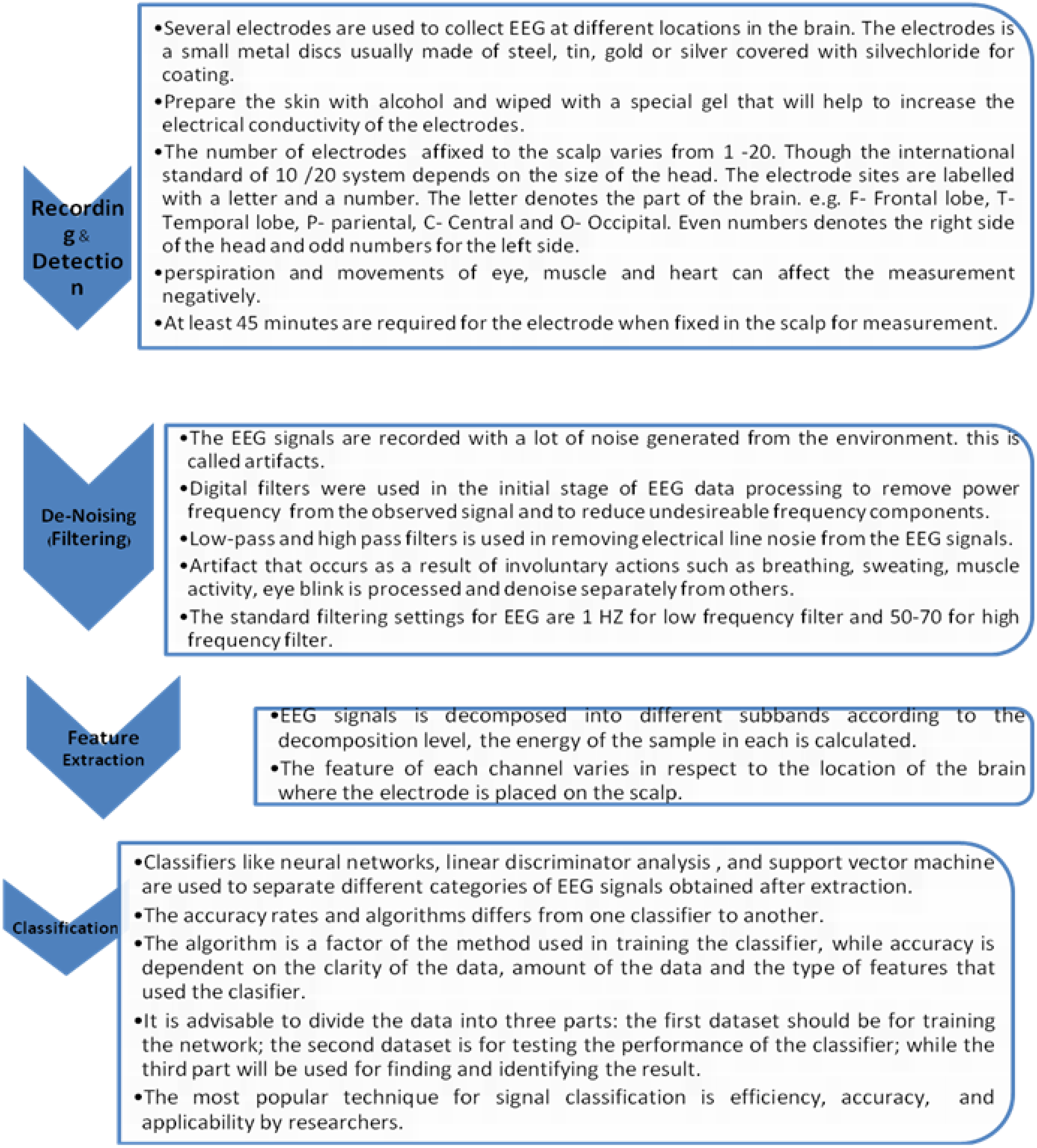

Figure 1: EEG Signal Processing Stages

MATHEMATICAL REPRESENTATION OF EEG SIGNAL

The brain signals are accumulated through the electrodes fixed on EEG cap wear by the subject. This is represented mathematical as shown in the equation (i) below:

$$Y(t) = [Y1(t), Y2(t), \dots, Ym(t)]T \qquad \text{(i)}$$

Y(t) denotes the recorded EEG signal, T is the transposition and m represent the total number of channels used for the recording. Each row of the matrix corresponds to EEG signals recorded at different electrodes, and the columns denote the variations in the signals at different time points. Note that before the data obtain is stored, the signals must have undergone the process of filtering (de-noising) of low and high frequency noises and other interferences. The user will only utilize the amplitude of the bio-signals, hence the importance of eliminating the artifacts that will taint signals and subsequently lead to inaccurate results and deductions.

Voltage traces of EEG signals recorded from electrode pair oscillate with mixtures of component waveforms. Each comprises of amplitude (A_{nm}), frequency (f_{nm}) and phase ($ø_{nm}$). The Fourier series can be used to represent as a sum of the different frequencies, amplitudes and phases. The EEG voltage V_M (t) recorded from any electrode pair m is then expressed generally as a sum over of all the parameter components as shown in equation (ii) below:

$$V(t) = a_0 + \sum_{n=1}^{N} (A_{nm} \sin(2\pi f t - ø \quad) \qquad \text{(ii)} \qquad \text{(Nunez \& Ramesh, 2007)}$$

Let's consider the third equation where the total signal Z (t) generated is polluted with artifact at stipulated time (t); varying source signal is denoted by X (t), and the concatenated matrix is marked B; the external noise is represented with N (t). Thus the equation (iii) will illustrates the model of the signal distorted signal.

$$Z\ (t) = \ BSM\ (t) + \ nm(t) \qquad \text{(iii)}$$

CHARACTERISTICS OF EEG WAVE BANDS

The EEG signal is categorized into five spectral frequency bands based on their rhythms. They include Delta (δ), Theta (θ), Alpha (α), Beta (β) and Gamma (γ). According to (The McGill

Physiology Virtual Lab, 2015), "The frequencies of the human EEG waves are Delta, Theta, Alpha and Beta". The features of each category of the EEG wave band are discussed below:

Delta: This frequency range is generated from the thalamus part of the brain. It has a frequency range of below 3.5 Hz. Delta produces the highest amplitude of between 20μV to 200μV and is the slowest in terms of speed. It is observed in the deep stage of sleeping; in stage 3 and 4 of sleep. It is mostly prominent in the frontal part of brain in adults and posterior part in children. It is normal in infant within one year of age. Delta frequency of 1 or 2 Hz is dominates during someone in coma or under anesthesia.

Theta: This frequency is generated from the hippocampus and neo-cortex part of the brain. The range of frequency is between 3.5 Hz to 7.5 Hz. The amplitude range is from 20μV to 100μV. It is classified to have slow activity and always associated with drowsiness, childhood, and adolescence. It is perfectly ordinary in children and sleep but known to abnormal in adult awake.

Alpha: This band is known as Berger's wave. It is also generated by the thalamus. Its ranges cover 7.5 Hz to 13 Hz with amplitude of 20μV to 60μV. It is the major rhythm observed in relaxed adults. Present throughout life especially after 13 years. The intensity increases when closing the eyes and are relaxing but disappears when opening the eyes or alerting by action like thinking or computing. In short, it indicates the alert state of consciousness.

Beta: Cortex part of the brain generate signal band of this nature. The frequency range is from 13 Hz to 30 Hz, and the amplitude of 2μV to 20μV. It is regarded as fast activity wave and normal rhythm. It is generally dominant in subject who is alert, anxious or have eyes open.

Gamma: The frequencies ranging from 30 Hz to 70 Hz. The amplitude is as low as from 3μV to 5μV. Many researchers argue that this band is of the group of beta waves since the exhibit the same characteristics.

APPLICATIONS OF EEG MEASUREMENT IN MEDICINE

Contrary to the earlier assertions suggesting that the goal of BCI will not only be achieved but will only serve for experimental purposes, scientists in the area has proved all the doubting Thomas wrong. The societal benefits of research in this field of study have surpassed imagination. With specific interest in EEG signal emission, medicine has a discipline is obviously the major beneficiary. The measurement of the brain signal through EEG recording has been used in diagnosis, rehabilitation and treatment of different kind of diseases. Below are the highlights of several contributions of EEG recording from medical perspective.

1. EEG is used to monitor the **state of consciousness** of patients in clinical work.
2. EEG measurement helps also to know the **depth of anesthesia** on patient undergoing medical surgery or other medication.
3. Recording of EEG will help to determine the level of **epileptic seizures** in the brain.
4. By monitoring the EEG signals, medical practitioners will ascertain the **distinct stages of sleep** of someone suffering from a sleep related diseases like narcolepsy.
5. EEG signal also serves as a base for **monitoring and rehabilitation** of someone having brain attack (stroke).
6. EEG is used in **evaluation of brain disorders** like Alzheimer.
7. EEG signal can be used to **detect lesions in the brain** that can lead to brain tumor.
8. EEG is also used to **monitor blood flow in the brain** during surgical procedures. (Johns Hopkins Medicine RSS, 2015)
9. EEG monitoring can help in **detecting the extreme fatigue conditions and warning of it vital circumstances** such as long way driving and monotonous exercise. (Zoshk & Azamoosh, 2010)
10. EEG measurement will help in **rehabilitation process for patient** with locked up syndrome.

CONCLUSION

The obtainable facts or information are supporting the view that EEG is applied in so many areas for clinical purposes. We have tried in this work to expose the concepts of electroencephalogram (EEG). We also through our evaluation established that the essence of using EEG is not only for experimental research but more concern in medical applications. It is either used for diagnosis, treatment or prognosis. It is therefore worthwhile to advocate for its adoption in hospital especially in developing countries. In spite of its cost advantage, it provides both structural and functional analysis of the brain. I recommend that the manufacturers of this EEG equipment should think of how to make it hand held device that doctors can easily deploy for monitoring, treatment, rehabilitation, diagnosis or as the case may be prognosis of an illness.

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