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Electroencephalogram (Eeg): Beyond Laboratory Experiment; Clinical Persepective

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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 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 highlight 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 a collaboration in which a brain accepts and controls a mechanical device as a natural part of its representation of the 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 produces the movement; expression or words marked the major breakthrough in designing computer devices that can interface with human body to produce desired action.

The brain is the part of the body located right inside the skull responsible for the emission of electrical signal. Researchers can only dwell on the different cells that make the different parts of the brain and how they interconnected to make their inferences. The most extensively discussed part of the brain is the neuron. The knowledge of neuron brought the major breakthrough in understanding and usage of the nervous system. There are two different kinds of neurons that constitutes the central nervous system; the sensory neurons that sends signals to the brain and the motor neurons that connects the brain to the muscles, sense organs and different areas of the brain to each other. Though as stated, the two types of neurons serve different purposes, their general structures is the same. At the center of the neuron is the cell body called the **soma**. Connected to the soma is the **dendrite** that serves as input unit for the neuron and the **axon** serving as the output unit. The name dendrite is derived from the Greek word "Dendron" suggesting that the shape resembles that of a tree with branches that fork and fork again into finer and finer structure. The number of branches varies from few to hundreds of thousands. The dendrite is an input connection through which all the information is send to the neuron. The property of the dendrites worthy of notes is their ability to change over time, breaking connections with some nerve cells and form new connections with other cells. This particular property is the bedrock on which the learning process occurs. The signal produced in the dendrites and the cell body is passed out through the axon. It is a structure specialized in carrying information over distances in the nervous system. The information is usually transmitted as an electrical impulse termed **action potentials.**

DIFFERENT METHODS FOR MEASURING BRAIN ACTIVITY

Since the brain is coordinating center of the human body, it is important we look at the notable methods for measuring brain activity. The brain sends and receives millions of signals every second both day and night. This may be in form of nerve impulses, hormones actions or other chemical transmission. It is worthy to state that this swap of information among body cells causes actions like sleep, move, clap, eat, think and others to take place.

There are two major procedures adopted in measuring brain activity viz; structural analysis that analyses the anatomy of the brain and function analysis that tries to measure and locate actual point of brain activity. Structural methods include Magnetic Resonance Imaging (MRI) and Computerized Axial Tomography (CAT). Functional Analysis methods include also Positron Emission Tomography (PET), Electroencephalography (EEG), and Functional Magnetic Resonance Imaging (FMRI). (MACALESTER COLLEGE, 2014)

Magnetic Resonance Imaging (MRI): This is an imaging technique that present which involves passing a strong magnetic field through the head. The magnetic field should be well above 30000 times that of the earth. The primary aim of MRI is to produce 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 diverse 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. The effect of MRI scan on the body is minimal and harmless. The basic precaution required as a matter of safety before scanning is to remove all metal objects from the room especially iron.

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. Abnormalities like tumor, lesions will show as areas of altered density during the evaluation and analysis. 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 is known to be the first scanning method that provides useful information about the brain functions. It 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. Researches under EEG were useful in noting how long brain uses to process disparaging information and for monitoring levels of attention given to stress in the brain. 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 localizes brain activity rather than concentrating on only structure as does by MRI. It 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), it was in 1875 that the English physician Richard Caton 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.

Recording & Detection

- Several electrodes are used to collect EEG at different locations in the brain. The electrodes is a small metal discs usually made of steel, tin, gold or silver covered with silvechloride for coating.
- Prepare the skin with alcohol and wiped with a special gel that will help to increase the electrical conductivity of the electrodes.
- The number of electrodes affixed to the scalp varies from 1 -20. Though the international standard of 10 /20 system depends on the size of the head. The electrode sites are labelled with a letter and a number. The letter denotes the part of the brain. e.g. F- Frontal lobe, T- Temporal lobe, P- pariental, C- Central and O- Occipital. Even numbers denotes the right side of the head and odd numbers for the left side.
- perspiration and movements of eye, muscle and heart can affect the measurement negatively.
- At least 45 minutes are required for the electrode when fixed in the scalp for measurement.

De-Noising (Filtering)

- The EEG signals are recorded with a lot of noise generated from the environment. this is called artifacts.
- Digital filters were used in the initial stage of EEG data processing to remove power frequency from the observed signal and to reduce undesireable frequency components.
- Low-pass and high pass filters is used in removing electrical line nosie from the EEG signals.
- Artifact that occurs as a result of involuntary actions such as breathing, sweating, muscle activity, eye blink is processed and denoise separately from others.
- The standard filtering settings for EEG are 1 HZ for low frequency filter and 50-70 for high frequency filter.

Feature Extraction

- EEG signals is decomposed into different subbands according to the decomposition level, the energy of the sample in each is calculated.
- The feature of each channel varies in respect to the location of the brain where the electrode is placed on the scalp.

Classification

- Classifiers like neural networks, linear discriminator analysis , and support vector machine are used to separate different categories of EEG signals obtained after extraction.
- The accuracy rates and algorithms differs from one classifier to another.
- The algorithm is a factor of the method used in training the classifier, while accuracy is dependent on the clarity of the data, amount of the data and the type of features that used the clasifier.
- It is advisable to divide the data into three parts: the first dataset should be for training the network; the second dataset is for testing the performance of the classifier; while the third part will be used for finding and identifying the result.
- The most popular technique for signal classification is efficiency, accuracy, and applicability by researchers.

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:

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

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 ($ø_{nm}$). Since the signal is in a physical waveform, 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:

$$V(\mathrm{t}) = a_0 + \sum_{n=1}^{N} (A_{nm} \sin(2\pi \mathrm{ft} - ø \quad)$$

(ii) (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.

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

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 range 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 into 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 support 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 it is 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 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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