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A Comprehensive approach For Brain Waves Exploitation To Control A Robotic Arm

Husham Ibadi[1]
[1](*Terna College of Engineering, Mumbai University, Mumbai, India*)

Abstract: - *Brain Computer Interfacing is newly developed field of neuroscience and computer science. Brain Computer Interface (BCI) is a System that provides a non-muscular communication between men and machines. Communication with BCI is done without the use of language or without controlling the computer manually with body parts. Brain signals can be recorded in either passive of invasive manner where the invasive will required a surgical intervention. Brain signals are recoded by the means EEG are employed to control external devices (robots) for providing extra input for human functions. This study involves the methods that used in recording the brain signals as well as the methodology required to operate the brain computer interface system.*
Keywords: - *Deep learning, Brain waves, Motor imaginary (MI), Motor execution (ME), near-infrared spectroscopy (fNIRS)*

I. Introduction

Human nervous system is something much complex and its operation is still rather obscure to scientists. Nevertheless, more and more emerging techniques are helping scientists in examining the human brain in detail and making hypotheses on its operation. However, the exact functioning of the brain was unclear until the discovery of underlying electrical activity in 1924, when Hans Berger first recorded the human brain activity by means of EEG. By analyzing the traces, Beger was able to categorize a certain oscillatory activity, now commonly referred to as the 'alpha signals' (8-13 Hz). Interestingly, he correlated the abnormalities in the EEG traces to brain-related diseases. However, it was 53 years later, in 1977, when UCLA Prof. Jacques Vidal realized the potential of Electroencephalography. He demonstrated in an experiment the control of a cursor-like graphical object on a computer screen. He coined the term 'BCI' and is considered as the inventor of brain-computer interface paradigm. Soon after Vidal's work, in 1988, Bozinovski et al. reported a non-invasive EEG control of multiple start-stop-restart movements of a physical robot. From the year 2000 onwards, more focus was put on developing algorithms that had improved classification ac- curacies on EEG data.

Brain-computer interface can have a profound impact on the life of paralyzed or elderly citizens as they offer control over various devices without any necessity of movement of the body parts. This technology has come a long way and opened new dimensions in improving our life. Use of electroencephalogram (EEG wave) based control schemes can change the shape of the lives of the disabled citizens if incorporated with an electric wheelchair through a wearable device. Electric wheelchairs are nowadays commercially available which provides mobility to the disabled persons with relative ease. But most of the commercially available products are much expensive and controlled through the joystick, hand gesture, voice command, etc. which may not be viable control scheme for severely disabled or paralyzed persons [2]. Prior to record any signal from the brain, the particular region of the brain need to stimulated. Three types of stimulations found in the literature; it involves stimulating the brain with electrical signals (TES)or with magnetic field (TMS) [5]. Another stimulation may achieve under the term Event Related synchronization/de-synchronization (ERS, ERD) which involves creating such environments to trigger a particular region of brain, more likely conducting some actions alike imagination of parts movement guided by graphical object (using a screens to display the guide object) [4]. Eye movement may overlap with classification of brain waves, also some other organs in the body are indirectly distorting the classification decision, it can result due to heart beat of eye blinking.

To measure eye movement, pairs of electrodes are typically placed either above and below the eye or to the left and right of the eye. If the eye moves from center position toward one of the two electrodes, this electrode "sees" the positive side of the retina and the opposite electrode "sees" the negative side of the retina. Consequently, a potential difference occurs between the electrodes. Assuming that the resting potential is constant, the recorded potential is a measure of the eye's position. In this study, a constructing of Brain Computer Interface (BCI) is established. To do this, we use EOG patterns and make artificial neural networks "learn" to identify them. In order to obtain reasonable EOG signal, a wavelet transform is used for providing input neural network and to distinguish EMG artefacts from EOG signals [6].

Generally, the most dependable approaches to detect brain activity can be EEG which used to identify the thoughts of human alike imagination and it involves five sub bands Delta (>=3 HZ), Theta (3.5-7.5 HZ), Alpha (7.5-13 HZ), Beta (>14 HZ), Gamma (25-100 HZ). EOG is another technique to define the eye blinking or eye direction, EMG is more likely to detect the muscular activity and can be initiated with placing electrodes on the body muscles itself. At [7], EEG data was collected from 20 healthy subjects for performing four different motor imagery tasks. Motor Imagery (MI) Task 1 is imagining left hand movement, task 2 is imagining right hand movement, task 3 is imagining left hand movement with finger and elbow movement and finally task 4 is right hand movements with fingers and elbow. Signal is recorded by Emotiv SDK with two devices (EPOC+ (14- channel) and INSIGHT (5-channel)).

Studies reveals that recording the brain signals may exists with several sessions, however, signals due to motor imaginary can be seen with five sessions, whereas those resulted from motor execution is granted after single session [9]. Near-Infrared Spectroscopy (fNIRS) is another technology that depends on optical sensing of blood flow in brain veins. It can work side by side with EEG to detect the motor activity [16]. In other word, brain signal can be either recorded with above technologies or obtained indirectly from online resources as made by many studies like [15]. In this paper, the required methodology to implement a BCI system is provided with technical concept of entire BCI chain. In next section, we are going to nominate the term 'MW' for motor waves which reflect the motor activity due to motor imagination (MI) or motor execution (ME).

II. Motor stimulation

Brain can be stimulated by electrical of magnetic felids or even by video stimulators; that can activate the brain to perform specific task which can be recorded and studied. In the regard of video stimulation; Arrow Video is based on imagination of motoric activity. This video shows the right and left arrow that appears alternately. Participant may be asked to imagine right/left hand movement based on the direction of the arrow. Palm video is based on observation of motoric activity, but it gives a different observation with the imagination that is instructed. This video shows a palm that appear alternately on the left or right side of the screen, and the participant is told to imagine their hand movement based on the palm location on the screen. Self-video is alike recoding a video for a person when he is performing a particular action, the actor in the video is the participant himself. Transcranial Magnetic Stimulation (TMS) is used to grant the signals from the brain and defined as: stimulating the brain motor area responsible of the left hand movements with a magnetic field, and measuring the evoked brain waves with a couple of electrodes implanted at C1-C2 vertebra levels. In the early 80s, first raise of brain stimulation is witnessed by stimulating the brain through an electric field. This stimulation technique is called Transcranial Electrical Stimulation (TES). Unfortunately, it has been found that TES is quite uncomfortable to the patient, because only a small fraction of the applied current flows through the resistance of the skull and scalp in to the brain, while the rest travels between the electrodes on the surface, causing local pain and contraction of scalp muscles. TMS is painless and lacking in harmful effects to the human nervous system. The first magnetic stimulators were very heavy and they could reach low stimulation frequencies. Recently, novel stimulators with lower weight and smaller size have been designed. The stimulator used in the experiments of [5] is 'Magstim 200R', the stimulation level is variated in range of 20 % to 53 % with 3 % increment in each step. The data is collected after recording the stimulation from patients with spine problem.

III. MW recording

There are several techniques to uncover the brain neuron activities such as MEG, EOG, EEG. In order to record the brain signal, once the area of action should be identified and then, the stimulator must be applied on that region. Eye movement may be involved as well as the top-shoulder neurons are important to detect the hand movement alongside with EEG results. Some studies have been refereed the publicly accessed database for brain waves information without recording any. The international 10-20 EEG system is set the locations of EEG electrodes to be as in Fig 1. In order to record the MW, researchers have used ready-made headset which provide electrodes placed according to 10-20 system. Selecting a suitable device i.e. headset; may depend on the number of channels researcher aims to record. The more channels the more efficient classification, also more features can be extracted to provide extra commands for the arm machine (robot). Cost of deploying such devices may vary in (200-2000) depending on channels availability, usually people are using two channels as seen in [7]. Fig 2 is demonstrating some verities from available recording devices.

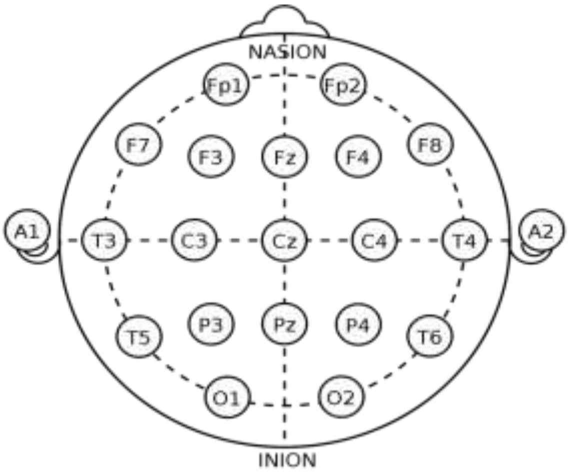

Figure 1: International 10-20 EEG system electrodes locations.

EMOTIV EPOC+ 14 Channel Mobile EEG

EMOTIV Insight 5 Channel Mobile EEG

GTECH active dry-wet EEG cap 8, 16, 32 channels

Figure 2: EEG recorders with brand name.

Another technical aspect is most important while recoding any signal which is proper setting of sampling frequency. It seen in most of studies that two types of MW granting were done which are: invasive and passive methods. Invasive may use with those who are severely paralyzed and involve implantation of electrodes under the mote cortex whereas passive method is on the cortex scalp and mostly used technique. Coming to the point, sampling frequency is important as any recorder is expected to produce arrays of data reflecting each channel. However, passive EEG recorder are working with lower sampling rate as compared with invasive recorders. Table 1 is demonstrating what we observed while reviewing the previous studies of same context.

Table 1: Sampling frequency for brain wave signals recorder.

Reference	Method	Sampling frequency Hz
[5]	*Under cortex (invasive)*	*5000*
[9]	*Over the scalp (passive)*	*250*
[10]	*Over the scalp (passive)*	*1000*
[14]	*Over the scalp (passive)*	*256*
[15]	*Invasive*	*1000*
[16]	*Over the scalp (passive)*	*128*
[20]	*Over the scalp (passive)*	*128*

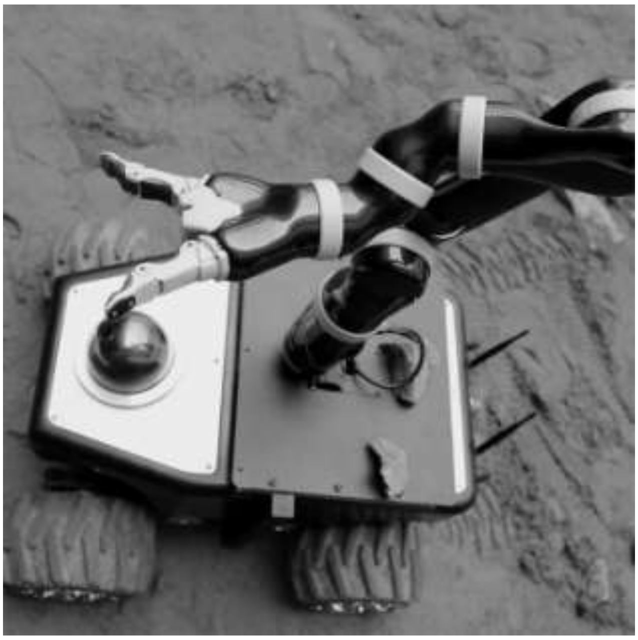

Figure 3: Robotic arm that performs several tasks to be controlled by brain signals.

In this paper, we are more interested to create a concrete features extraction and MW classification methodology more than designing the robot for executing the commands of signal processing stage. However, attractive robots are ready-made available for similar agenda depending on the functionality more likely, two fingers, three or five fingers robotic hand as in Fig 3.

Commenting on electrodes positioning, as stated in pervious sections 10-20 electrodes system is the most dependable for similar purpose. However, at some points, a particular region of motor cortex is preferred more than any other for availing known features. In coming sub-section, we are going to demonstrate some important regions of motor area.

3.1 Motor Cortex

The primary motor area (PMA), or M1, is one of the principal brain areas involved in motor function. M1 is located in the frontal lobe of the brain, along a bump called the precentral gyrus Fig 4. The role of the primary motor cortex is to generate neural impulses that control the execution of movement. Signals from M1 cross the body’s midline to activate skeletal muscles on the opposite side of the body, meaning that the left hemisphere of the brain controls the right side of the body, and the right hemisphere controls the left side of the body. Every part of the body is represented in the primary motor cortex, and these representations are arranged somatotopy the foot is next to the leg which is next to the trunk which is next to the arm and the hand. The supplementary motor area (SMA) is a part of the primate cerebral cortex that contributes to the control of movement. It is located on the midline surface of the hemisphere just in front of (anterior to) the primary motor cortex leg representation. Positions involving the primary motor area are (C3 and C4) and the supplementary motor area are (FCz) according to 10-20 positions Fig 1.

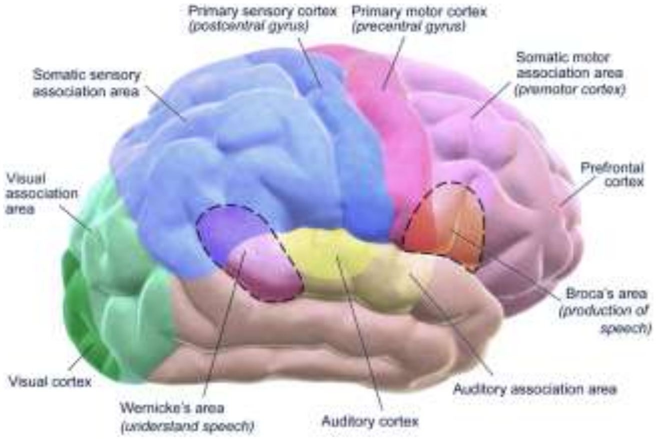

Figure 4: The brain related region that is functioning in BCI systems.

IV. Preprocessing

Involves removing the DC offset and artifacts from the original signal, DC offset amplitude is resulting while recording the EEG signal and increase the amplitude of the recoding to a new value which does not reflect the actual rhythm amplitude. In order to remove the DC offset, most of studies are obtaining the mean value Eq. (1) of EEG row signal and the minus the same from all samples amplitude.

$$M = \frac{1}{N}\sum Xi \qquad (1)$$

Heart rate, muscular movement, eye blinks, eye movements, etc. are the critical contamination or artifacts of the recorded EEG signal. For EEG signal analysis and classification, these artifacts are vital issue. There are some simple ways to remove eye movement and eye blink artifacts from the recorded EEG signal is by Simply rejecting the EEG epochs which are contaminated and considerable loss of the collected signal.

Usually, regression is a method used on electro oculographic (EOG) and EEG signal recordings simultaneously, to measure all the EOG artifacts in the EEG signals. The regressing method simply uses a subtraction mechanism of EOG signal from the EEG signal, because the brain signals are also included in the EOG recorded signal. So, a subtraction is required for each recording to regress out a portion of EOG signal from the relevant EEG signal. Muscular noise, electrode noise, heart rate noise and line noise are the different type of noises, and generally, these are not happening in the particular channel (reference channel). So, the regressing out method is not capable of removing these types of noise. A preferable alternative is ICA (Independent Component Analysis). ICA method is capable of removing different kinds of noises or artifacts (previously mention) from the raw EEG signals without losing the core information of the signal.

V. Features extraction

MW feature can be obtained by de constructing the waves, there are two kind of techniques which are done in two domains, time and frequency domains. In time domain, four features are more interested which are the mean, variance, standard division and median as per the following equations.

$$\sigma = \sqrt{\frac{1}{N}\sum (Xi - X')^{2\cdot}} \qquad (2)$$

$$Med\ even = \frac{\left(\frac{n}{2}\right) + \left(\frac{n}{2}+1\right)}{2} \qquad (3)$$

$$Med\ odd = \frac{(n+1)}{2} \qquad (4)$$

Where, σ is standard deviation and Med is the median, x represents each value of the dataset of a particular window. X’ is the arithmetic mean of the window data and N indicates the total number of data points in the window. Finally, n represent the total sample points in the specific window. In frequency domain, more analysis is applicable such as power spectrum calculations.

$$P(wi) = \frac{1}{N}|X(wi)|^2 \qquad (5)$$

$$Pi = \frac{P(wi)}{\sum P(wi)} \qquad (6)$$

$$PSE = -\sum Pi \ln Pi \qquad (7)$$

Where, P(w) is power spectrum density (PSD) and Pi is the normalized PSD and ultimately the PSE stands for entropy.

5.1 Master slave features

The BP is the electrophysiological sign of planning, preparation and initiation of volitional acts. It is pre-motor potential or readiness potential. Which is an activity measure in the motor cortex and supplementary motor area of the brain which generate the voluntary muscle movement. The BP is a manifestation of cortical contribution to the pre-motor planning of volitional movement. BP consists of a slow decrease in EEG amplitude starting approximately 1500 ms prior to the onset of the movement, and it can be considered as a cortical representation of motor preparation Fig 5.

For finger and hand movements, BP feature is more obvious at the lateral scalp positions where C3 and C4 electrodes are located based in the international 10-20 system. C3 corresponds to the left motor cortex, while C4 corresponds to the right motor cortex.

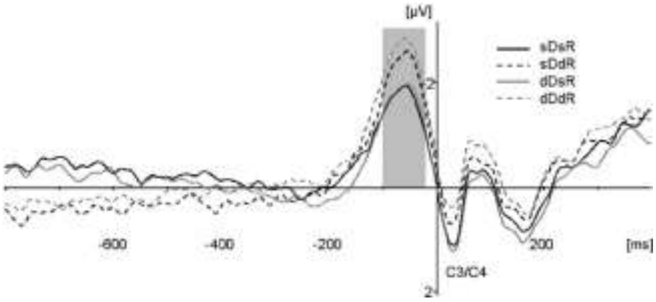

Figure 5: The readiness potential of the brain.

The group data of C3and C4 channels can be analysed In time domain and frequency domain for calculating the mean of peak PSD and variance respectively. Applying FFT to the EEG signal in C3 and C4 can yield the following:

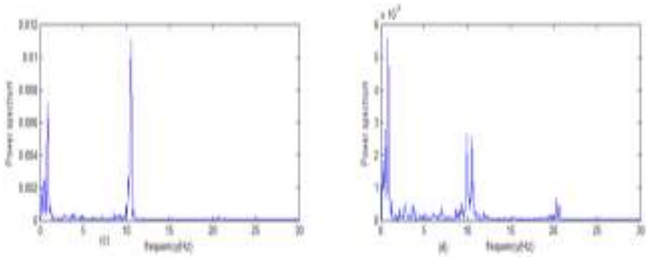

Figure 6: The BP signal as appears in frequency domain.

Where it is known that BP frequency can be visible in 0-4 Hz band, the same coefficients are updated in Low Pass Filter to obtain the BP portion only; on then, the following is gained:

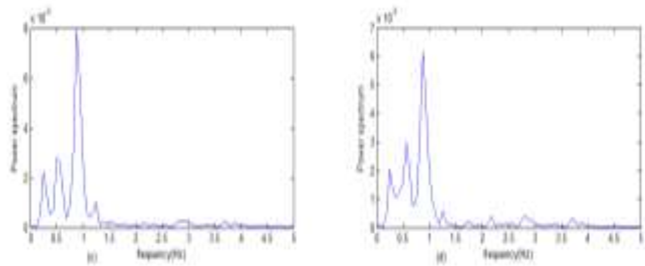

Figure 7: The DC offset removed BP signal in frequency domain.

In time domain, the EEGs are separated into 9 segments of period 1s. The variances of each segment for C3 and C4 are computed as shown in Fig 8. The average value of the peak amplitude can be obtained from the following:

$$P= P_{max\ c3} + P_{max\ c4} / 2 \qquad (8)$$

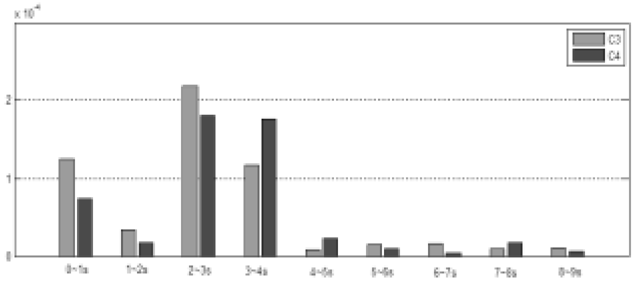

Figure 8: Resulted time domain analysis of BP signal.

In Fig 8, it can be observed that the maximal variance appears in 2-4s, just before the intentional control is performed, which furtherly reflects the BP feature in motor imagery EEGs. Then the BP feature parameters in time-domain are extracted by averaging the variances of C3 and C4 (V3 and V4) as in following:

$$V=V3+V4/2 \qquad (9)$$

P and V reflect the BP feature in frequency and time domain respectively. Therefore, the BP feature vector is composed by P and V which is served as the master feature to identify the IC states or NC states. When the IC states are detected, next step is to classify the mental tasks.

5.2 ERS and ERD

When people actually act or prepare unilateral limb movements (such as the left-hand movement), the amplitudes of μ and β rhythms of EEGs in contralateral sensorimotor cortex will be significantly reduced, while increased in the ipsilateral primary sensorimotor cortex which are named as ERD/ERS phenomena as showed in Fig 9:

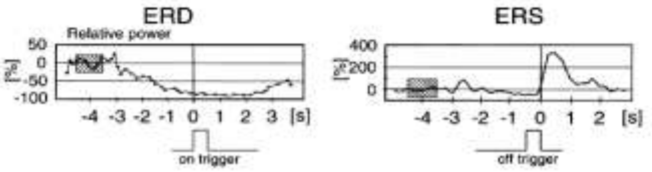

Figure 9: Event related synchronization and desynchronization signals.

After determining of master feature; slave feature is on board. However, the rhythms of alpha and beta are undergone a wavelet transform for determining the energy in the channels C3 and C4. Based on the principle of ERD/ERS, when left-hand movement imagery is performing, the energy in μ and β rhythms of C4 channels will decrease, while that of C3 channel will increase. As the result, the energy ratio will be greater than that of right-hand movement imagery and vice versa.

VI. Conclusion

Brain electrical activities can reflect organs activates in human body; however, the focal of this study was made on how brain electrical activities is acting on muscular functioning. Brain can be stimulated by electrical of magnetic felids or even by video stimulators; that can activate the brain to perform specific task which can be recorded and studied. On brain wave recording, we observed three technologies EEG, EOG and EMG. The Electroencephalography (EEG) can reflect the thoughts of the brain, EOG is reflecting the eye potential and EMG is reflecting muscles activities. Another approach is proposed by some studies is to monitor the blood flow in the vessels of brain on the task functioning, this approach is called Functional near-infrared spectroscopy (FNIRS), this depends on optical sensors alongside with EEG electrodes and can be placed on motor scalp. Upon recoding of EEG signals, other inferred components are also coming to the image it called artifacts and DC offset, it should be disposed prior to any signal processing, Most of studies are employing ICA method to remove the artifacts and DC offset. Usually, features are detected for the brain signals in time and frequency domains such as mean, standard deviation and median. Classification is the final stage in Brain Computer Interface system where various signal processing pipelines are utilized in experiments found in the literature, but the main stages are roughly the same. Artificial Neural Networks are found the best classifiers in not of previous studies as they have the ability to learn any complex phenomenon in relatively short time.

Another point is seen while studying the brain signals is that different channels can be useful in analysing the signals, there is no fixed budget for that as most of the researches have used the international positioning 10/20 for placing the electrodes in scalp and the useful channels are varied depending on the application, however, a difficulty in achieving high detection results is that the classification decisions are made between classes with different population size. The events of interest only occupy a small percentage of the total time of the recording. Down sampling is used to shirk the recoded information for reducing the computational budget. For controlling the machines or robots with brain signals, it seems like creating a global model which instantly fits any subject is a much more difficult task.

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