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BRAIN-COMPUTER-INTERFACE: VARIOUS SIGNAL ACQUISITION APPROACHES

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ABSTRACT

This article addresses to the fundamental approaches for signal acquisition in Brain-Computer-Interface technology. Signal acquisition approaches are broadly classified into three major categories as Invasive-Approach, Semi-Invasive-Approach and Non-Invasive-Approach. In this context first of all we discussed the invasive approach in which electrical signals to be extracted from gray matter of the brain by neurosurgery, than semi invasive approach discussed in which electrical signals to be extracted from outside the gray matter by using electrocorticography technique. After that we discussed non invasive approach in detail including various techniques as EEG, MEG, EMG, MRI, TMS, PET, CT, NIRS, EROS, fNIRS, and fMRI.

Keywords: *Neurosurgery, Craniotomy, SQUID, Radioactive Tracer, Multivariate Calibration.*

I. INTRODUCTION

In the world of brain research the philosophy of Brain Computer Interface initiated from the Hans Berger's discovery of electroencephalography. Hans Berger recorded human brain activity by using electroencephalography in 1924, first in the world, and he known as inventor of electroencephalography. He identifies oscillatory activity of the brain, such as the alpha wave by analyzing electroencephalography traces, and this alpha wave become popular by his name as Berger's-Wave. However Berger's primary recording device was much unsophisticated as he used silver wires under the scalps of object, and later replaced by silver foils attached to the object's head by rubber bandages for tracing electrical activities. Berger connected his device to a Lippmann capillary electrometer, which produce unexpected results. However from that time to till today various technologies emerged with their variance. Nowadays some popular techniques used for signal acquisition are MRI, PET, EMG, MEG etc. [1]

The overall signal acquisition approaches may be invasive, semi-invasive, and non-invasive. As shown in the fig.-1, the first approach is invasive technique in which signal acquisition device can be directly implanted within the gray matter by neurosurgical procedure, second approach is semi-invasive technique in which signal acquisition device can be placed on the cortex surfaces under the scalp by using technique, and the third approach is non invasive technique in which no need of any kind of surgical procedure means signal acquisition devices are in the form of cap wearable on the head. These approaches can be used alternatively as per there procedural variance. [2]

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II. VARIOUS APPROACHES

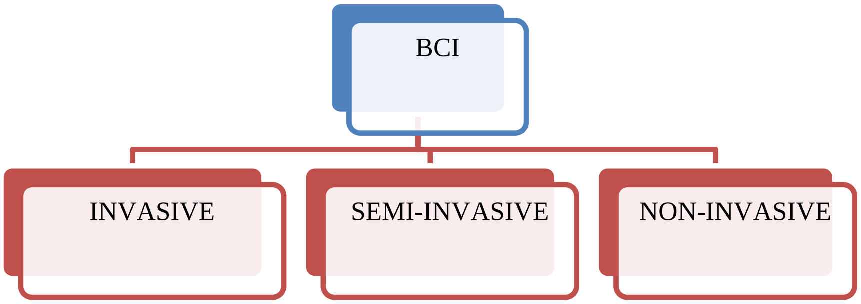

Figure-1 Hierarchy of Approaches

III. INVASIVE-APPROACH

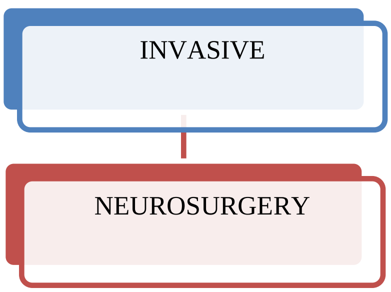

Fig.2 Hierarchy of Invasive Approaches

Neurosurgery: Neurosurgery is the medical operation which is most probably applicable in invasive signal acquisition approach in brain computer interface technology. As shown in the fig.-2, signal acquisition device or sensor can be implanted within the gray matter during neurosurgery in invasive approach. In the signal acquisition process signal acquisition device is array of electrodes which is actually implanted. Because they lie within the grey matter, invasive devices produce the highest quality signals but are prone to scar-tissue, causing the signal to become weaker. [3]

IV. SEMI-INVASIVE-APPROACH

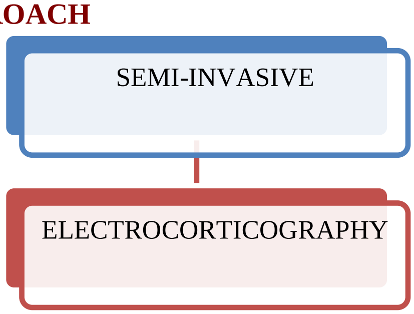

Fig.3 Hierarchy of Semi-Invasive Approaches

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Electrocorticography [ECoG]: ECoG is a semi-surgical operation which is applicable in semi-invasive signal acquisition approach. As shown in the fig.-3, signal acquisition device means array of electrodes can be implanted on the cerebral cortical surface by craniotomy process, removing a part of the skull to expose the cortical surface of the brain unlike within the gray matter in invasive approach. Signal acquisition device may either be placed in epidural region or in the subdural region. Signal recording is performed from array of electrodes implanted on these cortical regions. [4]

V. NON-INVASIVE-APPROACH

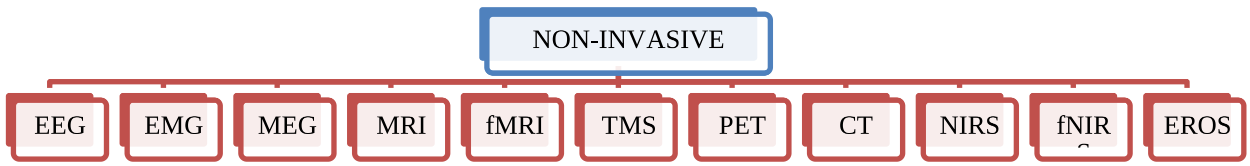

Fig.4 Hierarchy of Non-Invasive Approaches

Electroencephalography [EEG]: EEG is a non-surgical operation which is applicable in non invasive signal acquisition approach. An EEG is a process to examine the electrical activity in the brain. Brain cells communicate with each other through electrical impulses. An EEG can be used to detect potential problems associated with this activity. An EEG measures the electrical impulses in brain by using several electrodes that are attached to scalp. An electrode is a conductor device through which an electric signal enters or leaves. The electrodes transfer information from brain to a device that measures and records the data. The electrical impulses in an EEG recording look like wavy lines with peaks and valleys. These lines allow to quickly assessing whether there are abnormal patterns. Any irregularities may be a sign of seizures or other brain disorders. EEG is used to detect problems in the electrical activity of the brain that may be associated with some brain disorders. The measurements generated by an EEG are used to confirm various conditions, including: seizure disorders like epilepsy, a head injury, an inflammation of the brain, a brain tumor, encephalopathy, memory problems, sleep disorders, stroke, and dementia. [5]

Electromyography [EMG]: EMG is a non invasive diagnostic approach that evaluates the health condition of muscles and the nerve cells that control them. These nerve cells are treated as motor neurons, they transmit electrical signals that cause muscles to contract and relax. EMG translates these signals into visual graphs, for making diagnosis. Abnormal result of EMG diagnosis usually indicates nerve or muscle damage. EMG results can help to diagnose muscle disorders, nerve disorders, and disorders on connection between nerves and muscles. EMG procedure has two categories: first is nerve conduction examination and the second is needle EMG. A nerve conduction examination evaluates the nerves that control on muscle movement by placing small sensors that is surface electrodes on the skin to assess the ability of the motor neurons to send electrical signals. The needle EMG assesses nerve activity within the muscles by using sensors to evaluate electrical signals, and they are directly inserted into muscle tissue to evaluate muscle activity when at rest and when contracted. In each procedure one electrode releases a very sensitive signal and the other electrodes measure how long it takes for the signal to reach them. An abnormal speed often represents muscle or nerve disorder in specific region of brain. [6]

Magnetoencephalography [MEG]: MEG a non-invasive signal acquisition approach that measures the magnetic fields generated by neural activity of the brain. The distributions of the magnetic fields are analyzed to determine the sources of the neural activity within the brain, and the locations of the sources are represented, to provide the structural and functional information of the brain. Since the neuronal activity is detected by sensors over the head, it is possible to identify where the information is produced with reasonable accuracy. Synaptic input to a neuron results in a small post synaptic signal that involve a very small magnetic field. When a large amount of neurons receives synaptic inputs within a short time scale, the dendrites' signals will sum up, for producing a field which can

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be detected outside the head. MEG is based on Superconducting Quantum Interference Device (SQUID) technology, which is a sensitive detector of magnetic flux. Today's MEG systems contain a large number of SQUIDs connected to sensor coils in a configuration as the curvature of the head. Since the external magnetic noise level is higher than the neuromagnetic signals, the MEG system required a magnetic shielded room. However the magnetic field measured by MEG is directly produced by neural activity, it is an advantage to detect signals from the brain on a millisecond time scale. [7]

Magnetic Resonance Imaging [MRI]: MRI a non invasive approach, to perform an examination; the patient is laid down within a MRI scanner which generates a strong magnetic field around the patient. During examination, hydrogen atoms are used in tissues to create a signal for imaging, which is processed to form an image. First of all, energy from an oscillating magnetic field is temporarily applied to the patient at the required resonance frequency. However MRI requires a magnetic field that is both strong and uniform. The hydrogen atoms emit a radio signal which is further measured by a receiving coil. The radio signal can be made to encode positional information by changing the main magnetic field using gradient coils. The contrast between various tissues is determined by the rate at which excited atoms return to the equilibrium state. These coils are rapidly switched on and off they produce the repetitive noise of a MRI scan. MRI is the diagnosis for neurological cancers, as it provides better resolution and better visualization of the posterior fossa. The contrast provided between grey and white matter makes it the best choice for many situation of the nervous system, including cerebrovascular disease, demyelinating diseases, infectious diseases, dementia, and epilepsy. It shows how the brain responds to different stimuli temporally; both the functional and structural brain abnormalities in psychological disorders can be examined. MRI is also used typically mriguided stereotactic surgery and radio surgery for treatment of intracranial tumors using the N-localizer. [8]

Functional Magnetic Resonance Imaging [fMRI]: fMRI a non invasive approach, a variation of MRI approach. fMRI assess how a normal, diseased or injured brain is functioning. fMRI identify regions of brain linked to critical functions such as planning, speaking, moving, and sensing. fMRI is very useful to planning for surgery and radiation therapy of the specified brain structures. fMRI also can be used to map the brain anatomically and detect the tumors, stroke, head and brain injury, or diseases. Tumors and lesions can affect the blood flow in ways not related to neural activity, masking the neural high dynamic range. Drugs can also affect high dynamic range such as caffeine. fMRI has been specially used to map functional areas, and note the presence of disorders like depression in brain. fMRI can also be used to check the neural correlates of a seizure, test how drug or behavioral therapy works, study how the brain recovers partially from a stroke, and check hemispherical asymmetry in language and memory regions. This is of particular importance in detecting and removing brain tumors. Pharmacological fMRI, determined brain activity after drugs are administered, can be used to check how much a drug penetrates the blood brain barrier and dose effect information of the medication. [9]

Transcranial Magnetic Stimulation [TMS]: TMS a noninvasive approach that uses magnetic fields for stimulation of neurons in the brain. TMS cause depolarization or hyper polarization in the neurons of the brain. TMS used to diagnose symptoms of chronic disease such as depression, dementia, schizophrenia, and stroke. TMS uses electromagnetic induction to arise weak electric currents using a rapidly varying magnetic field this can cause activity in specific region of the brain painlessly, permitted the functioning of the brain to be studied. During a TMS process, an electromagnetic coil is placed on patient's scalp near forehead. The electromagnet delivers a magnetic pulse that stimulates neurons in the specific region of brain involved in mood control and depression. And it may activate those regions of the brain that have decreased activity in patients with depression. Treatment involves delivering repetitive magnetic signals, so it's called repetitive TMS or rTMS. rTMS has been tested as a treatment tool for different neurological disorders such as migraines, strokes, Parkinson's disease, depression and auditory hallucinations. The stimulation shows to affect how this part of the brain is working, which in turn seems to ease depression symptoms and improve mood. The use of magnets instead of electric current reduced the discomfort of the process and used to mapping the cerebral cortex and its connections. [10]

Positron Emission Tomography [PET]: PET brain imaging test allows seeing how brain is functioning. The scan captures images of the activity of the brain after radioactive tracers have been absorbed into the blood stream.

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Tracers are attached to compounds like glucose that is the main fuel for brain functioning. Glucose utilized by the active areas of the brain at a higher rate than inactive areas. PET scanning allows seeing how the brain is working and helps them examine abnormalities. PET accurately details the size, shape, and function of the brain. However PET examination allows detecting the structure as well as the functioning of brain. This also allows diagnosing cancer, dementias, Alzheimer's disease, Parkinson's disease and epilepsy surgery. During examination an examiner will insert an intravenous catheter into patient arm. A special dye with radioactive tracers will be injected into patient veins through this intravenous catheter. Patient's body needs some time to absorb the tracers as blood flows through the brain, so it will wait about an hour before the scan begins. The scans record brain activity as video or as still images. The tracers are concentrated in areas of increased blood flow. The images of brain PET scans appear as multicolored images of the brain, ranging from dark blue to deep red. Areas of active brain appear in dark colors, such as yellow and red. Examiner will look at these results and check abnormalities, such as a brain tumor will show up as darker spots on the PET scan. [11]

Computer Tomography [CT]: CT brain scanning is a non invasive brain imaging approach, the basic principle behind a CT scan relies on the reconstruction of a 3D image of brain, using computer. During a CT scan, the patient is moved along the scanning system, because during scanning images of the organs being examined from different angles. These images are obtained by passing beams of X-rays through the specified region. Sophisticated computer algorithms combine these images to create a view of the brain organ, which is available soon after the scan is complete. CT scan used to examine brain tumors, intracranial bleeding, structural anomalies, and infections, brain functioning or other injuries. CT scan may also be used to detect clots in the brain that may be responsible for strokes, and provide guidance for brain surgery or biopsies of brain tissue. CT scan uses computers and rotating X-ray machines to produce cross-sectional images of the brain. These images provide more detailed specified information than normal X-ray images. They can show the blood vessels, soft tissues and bones in various parts of the brain. A CT scan provides detail of soft tissues and bone structures. [12]

Near Infrared Spectroscopy [NIRS]: NIRS a non invasive and portable brain imaging approach and it uses nonionizing light. NIRS imaging uses the concept of combination vibrations and molecular overtone. The molecular overtone and combination bands seen in the near infrared are typically much broad, leading to complex spectrums of molecules; it can be difficult to assign specific features to respective chemical components. Multivariate calibration approach such as, artificial neural networks, partial least squares, and principal components analysis are often employed to assess the desired chemical information. There is a source, a detector, and a dispersive element such as a prism, to allow the intensity at different wavelengths to be recorded. Light emitting diodes or quartz halogen bulbs are used as broadband sources of near-infrared radiation for analytical uses. Charge coupled devices of silicon are suitable for the shorter end of the NIR range, but are not enough sensitive over most of the range. Instruments for chemical imaging in the near infrared may use a 2D array detector with an acousto-optic tunable filter an electro optical device. Researchers are using NIRS for treatment of seizures such as Alzheimer's disease, schizophrenia, and stroke rehabilitation. [13]

Functional Near Infrared Spectroscopy [fNIRS]: fNIRS a non invasive signal acquisition approach which is the use of near infrared spectroscopy for the purpose of functional neuroimaging. Using fNIRS, brain activity is measured through blood flow response associated with neuronal activities. fNIRS is having the quantification of chromophore concentration resolved from the measurement of near infrared light attenuation, temporal or spatial changes. NIRS spectrum light takes advantage of the optical window in which tissue, bone, and skin are mostly transparent to NIRS light in the spectrum of 700-900 nm, while hemoglobin and deoxyhemoglobin are stronger absorbers of light. Differences in the absorption spectra of deoxyhemoglobin and oxyhemoglobin allows the measurement of relative changes in hemoglobin concentration through the use of light attenuation at multiple wavelengths. Multiple wavelengths are selected, with one wavelength above and one below the isosbestic point of 810 nm at which deoxyhemoglobin and oxyhemoglobin has identical absorption coefficients. Using the modified Beer Lambert law, relative concentration can be calculated as a function of total photon path length. Typically the light emitter and detector are placed same side on the subjects skull so recorded measurements are due to back reflected light following elliptical pathways. Through neurovascular coupling or blood flow response technique, neuronal activity is linked to related changes in localized cerebral blood flow. [14]

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Event Related Optical Signal [EROS]: EROS a non invasive signal acquisition approach that uses infrared light through optical fibers to measure changes in optical properties of active areas of the brain. It was developed at the University of Illinois in the Cognitive Neuroimaging Laboratory. Techniques such as diffuse optical imaging and near infrared spectroscopy measure optical absorption of hemoglobin, and thus are based on blood flow, EROS takes advantage of the scattering properties of the neurons themselves, and provide a much more direct measure of neuronal activity. EROS can detect activity in the cerebral cortex spatially within millimeters and temporally within milliseconds. Its biggest limitation is the inability to detect activity more than a few centimeters deep, which limits this fast optical imaging to the brain. EROS is a new, relatively inexpensive technique. [15]

VI. CONCLUSION

In early time for the purpose of signal acquisition from neural system invasive procedures was used which was very risky and uncomfortable from the implantation point of view. Sometime later non invasive approach was in existence for signal acquisition which was something simpler and less risky rather than non invasive approach. But now days on the basis of signal quality with respect to visual and auditory signal accuracy is necessary parameter for selecting brain scanning device. Spatial and temporal resolution is the emphasis for which alternative approaches can be used for signal acquisition. However in futuristic point of view non invasive approaches are more growing. Studies shows that, the most popular BCI signal acquisition approach is non-invasive signal acquisition technique EEG. In modern era various biomedical industries manufacture mobile Bluetooth enabled EEG based signal acquisition headset such as Mind-Wave headset manufactured by Neurosky Inc., EMOTIV Epoc manufactured by Emotive Inc. etc.

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