CHAPTER 1

INTRODUCTION

1.1 Brain Computer Interface

Brain-computer interfaces (BCIs) acquire brain signals, analyze them, and translate them into commands that are relayed to output devices that carry out desired actions. A BCI allows for direct communication between the brain and an external device, often to control its activity. BCIs read signals from the brain and use machine learning algorithms to translate the signals into an external action. A BCI is an artificial intelligence system that can recognize a certain set of patterns in brain signals following five consecutive stages: signal acquisition, pre-processing or signal enhancement, feature extraction, classification, and the control interface.

The goal of BCI research is to provide communications capabilities to severely disabled people who are totally paralyzed or ‘locked in’ by neurological neuromuscular disorders, such as amyotrophic lateral sclerosis, brain stem stroke, or spinal cord injury

1.1.1 Brain Anatomy

Before knowing about Brain Computer Interface, we have to know about Brain and how it works. Amazingly, nothing in the world can be compared with the human brain. Intelligence, creativity, emotion, and memories are a few of the many things governed by the brain. hearing. The brain constructs the received data from the different sensors and form a meaningful message. The brain controls our body movement of the arms and legs, thoughts, memory and speech. It also determines how a human respond to different situations such as stress by regulating our heart and breathing rate.

This is as shown in Fig-1, Anatomically five basic parts of the brain can be distinguished including Cerebrum, Diencephalon, Cerebellum, Mesencephalon, and Medulla oblongata

- The **cerebrum**, located directly under the skull surface, is the largest part of the brain. Its main functions are: (1) the initiation of complex movement, (2) speech and language understanding and production, (3) memory, and (4) reasoning. Brain monitoring techniques which make use of sensors placed

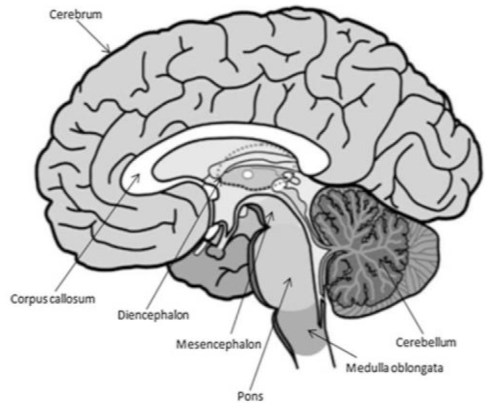

Fig-1.1 Parts of Brain

- The second part of the brain is the **Diencephalon**. One important function of the diencephalon is the forwarding of sensory information to other brain areas.
- The coordination of all kinds of movements is done in the third part which is the **cerebellum**
- The largest part of the reticular system is located in the **Mesencephalon** where it controls vigilance and the sleep-wake rhythm.
- The **Medulla Oblongata** connects the brain with the spinal cord**.**

Moreover, the cortex consists of two **Hemispheres** which are connected via a beam called corpus callosum. Each hemisphere is dominant for specific abilities. For right-handed persons, the right hemisphere is activated more during the recognition of geometric patterns, spatial orientation, the use nonverbal memory and the recognition of non-verbal noises [8]. More activity in the left hemisphere can be observed during the recognition of letters and words, the use verbal memory and auditory perception of words and language. This is as shown in Fig-2. Each hemisphere is partitioned into five anatomically well-defined regions, the so-called lobes as

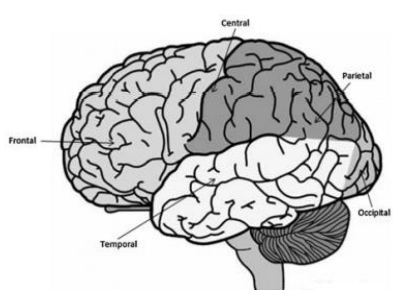

Fig-1.2: Lobes

1.1.2 Brain Signals

The **neuron** is a fundamental building block of our Central Nervous System (CNS). Neurons can be thought of as small interconnected processing units. The function of a neuron is to carry information in the form of electrical signals, i.e., action potential. Action potential gives information about a particular action that needs to be carried out. These action potentials occur due to the presence of neurotransmitters. For instance, neurotransmitter like Acetylcholine (ACH) helps to carry out voluntary actions.

To initiate any action, the action potential must conquer a threshold of -55mV else the response fails to start. The potential which fires the action is called as Excitatory Post Synaptic Potential (EPSP) whereas the potential which limits this action is called as Inhibitory Post Synaptic Potential (IPSP). Before any action occurs, the brain generates Bereitschafts potential (BP). This potential is used to predict the upcoming voluntary movement. BP can be BP1 and BP2. BP1 occurs 1.5 sec before the action, and BP2 400msec before the action [. A potential called readiness potential (RP) is used to relate the cerebral

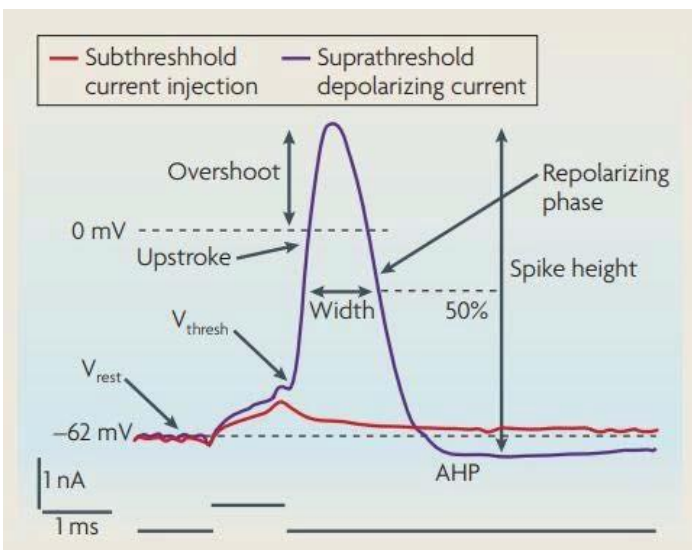

Fig-1.3: Action Potential

1.2 Types of Brain Computer Interface

Brain computer interface can be classified into three main groups, this is as shown in Fig. 2.3. Classification depends on the way that the electrical signal is obtained from neuron cells in brain

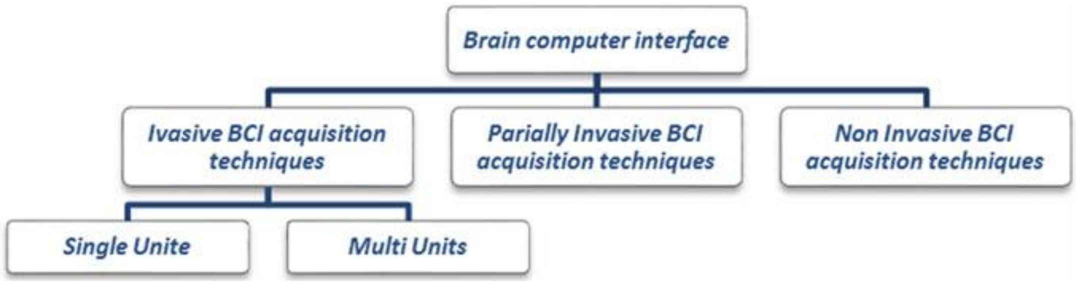

Fig-1.4: Types of BCI

Invasive BCI Acquisition Techniques

In invasive BCI techniques, special devices have to be used to capture the brain signals. Such devices are called Invasive BCI devices; devices that are based on detecting from single area of brain cells is called single unit while the detection from multiple areas is called multi-units. Invasive BCI devices are inserted directly into the human brain by a critical surgery as can be seen in Fig. 2.4. The electro-corticogram (ECoG) are the obtained signals from these inserted electrodes. These devices have the highest quality of human brain signals but have the risk of forming scar tissue.

Fig-1.5: Invasive BCI

Partially Invasive BCI Acquisition Techniques

Other devices that can capture the signal from the brain are the partially invasive BCI devices. Devices are inserted in the skull on the top of human brain as depicted in Fig. 2.5. These devices have bit weaker quality of human brain signals than invasive BCIs and have less risk of forming scar tissue

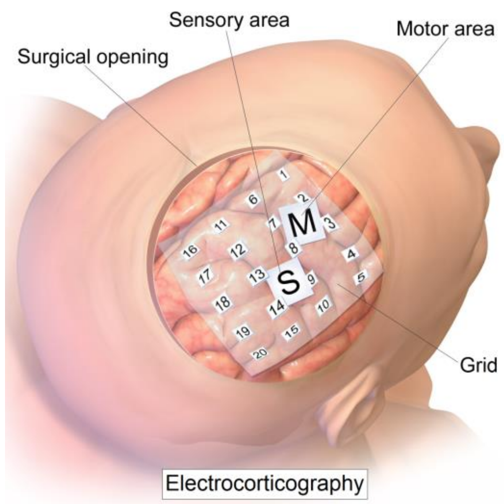

Fig-1.6: Partially invasive BCI

Non-Invasive BCI Acquisition Techniques

Non-Invasive BCI devices are considered the safest type and low-cost type of devices. However, these devices have weaker human brain signals than other BCI devices due to the skull. The detection of signals is done by some electrodes placed on the scalp as given in Fig. 2.6. At the same time, placing such electrodes is easy as well as portable. Most non-invasive techniques are constructed by recording Electroencephalographs (EEG) from the scalp. Recent EEG Non-Invasive BCI devices have better temporal resolution due to use up to 256 electrodes on the whole area of the human scalp.

Fig-1.7: Non-Invasive BCI

1.3 Electroencephalogram (EEG)

Electroencephalography is an electrophysiological monitoring method to record electrical activity of the brain. EEG measures the current that flows during synaptic excitation of dendrites of many pyramidal neurons in cerebral cortex. This device comprised of electrodes, conductive gel, amplifiers and Analog to Digital converter. The electrodes or leads are used to conduct electrical activity from the scalp of the brain. Different types of electrodes are used in general for EEG analysis. One type of electrode is reusable disk. These electrodes placed on the scalp with small amount of conductive gel (Ag-Cl) applied under the disk

1.3.1 Brain Waves

The BCI revolves around different forms of EEG patterns; especially α waves, β waves, γ waves, θ waves and δ waves These EEG patterns are associated with different frequency, different amplitude, and different state of mind. Most of the BCI applications use β wave because it is produced only when the subject has an active state of mind. These waves are measured using EEG electrodes. The EEG signals are highly random, non-linear, non-correlated and non-Gaussian

Delta Signal- It is captured within the frequency range of 0.5–3.5 Hz. It tends to be the highest in amplitude and the slowest waves. It is seen normally in adults in slow wave sleep as well as in babies. A sample from the Delta signals is shown in Fig. 2.7.

Theta- The frequency of this signal's ranges from 3.5 to 7.5 Hz. Theta is linked to inefficiency and daydreaming. In fact, the very lowest waves of theta represent the fine line between being awake or in a sleep.

Alpha-As shown in Fig. 2.9, this signal frequency ranges from 7.5 to 12 Hz. Hans Berger named the first rhythmic EEG activity he saw, the "alpha wave". It is brought out by closing the eyes and by relaxation.

Beta- Beta is another brain signal in which its frequency ranges from 12 Hz to about 30 Hz. It is seen usually on both sides in a symmetrical distribution and it is most evident frontally. Beta waves are often divided into β1 and β2 to get more specific range. The waves are small and fast when resisting or suppressing movement, or solving a math task.

Gamma- It is a signal with frequency range of 31 Hz and up. It reflects the mechanism of consciousness.

Brain wave types	**Frequency (hz)**	**Amplitude (mv)**	**State of Mind**
Delta	0-3 Hz	20-200	Deep sleep
Theta	3-8 Hz	<20	Meditation
Alpha	8-12 Hz	30-50	Relaxing
Beta	12-38 Hz	5-30	Active
gamma	38-42 Hz	>5	Highly active

Table-1.1: Summary of Various EEG signals

1.3.2 Monitoring Brain Activity Using EEG

Several techniques have been used to monitor brain activities such as Electroencephalography (EEG), Magnetoencephalography (MEG), Functional Magnetic Resonance Imaging (fMR), However, for several reasons the potential differences which can be measured between two points of the scalp are very different from those could be measured when electrodes were implanted directly in the brain.

Therefore, the positions for EEG electrodes should be chosen in a way, which all cortex regions are covered. For most applications, this is usually the whole cortex. An internationally accepted standard for electrode placements is the 10–20 system (electrodes are placed at distances of 10 or 20 % of the length of several connections between some reference points) introduced in 1957 by the International EEG Federation. Electrodes were placed according to the 10–20 system. Three anatomical reference points must be determined before the 10–20 system electrode positions which are:

- **Nasion**: the onset of the nose on the skull, below the forehead.
- **Inion**: the bony protuberance which marks the transition between skull and neck.
- **pre-auricular reference point**: located before the cartilaginous protrusion of the acoustic meatus (the auditory canal).

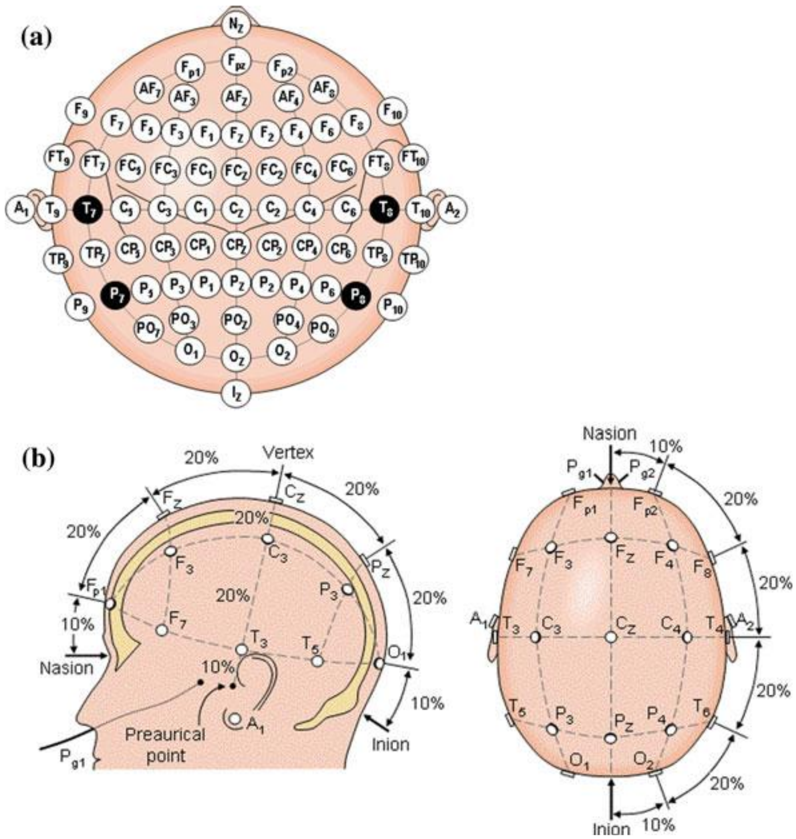

Fig-1.8: Electrode position. a) Brain electrodes. b) top view of the brain and electrodes positions

Figure 2.12 shows the electrode positions of the 10–20 system in their projection on the cortex. The name for a particular electrode position reflects the anatomical region of the cortex above which it is located. Fp stands for frontopolar, F stands for frontal, T stands for temporal, C stands for central, P stands for parietal, O stands for occipital and A stands for auricular while G denotes the ground electrode. Even Numbers denote the right part of the head; odd numbers refer the left part.

CHAPTER 2

LITERATURE SURVEY

EEG signal analysis and Classification for BCI: A review

An overview of BCI system's EEG classification for voluntary actions which can be used for various applications. This paper initially gives detail information about the neuron, on how it works and generates a signal, which can then be acquired by BCI system to carry out required application. This paper also focuses on methodology of EEG signal analysis. It also tells how the signals are extracted, pre-processed, and classified based on different features.

A review on analysis of EEG signals

Electroencephalography (EEG) enlighten about the state of the brain i.e., about the electrical bustle going on in the brain. The electrical activity measured as voltage at different points of brain act as basis of EEG. These signals are generally time-varying and non-stationary in nature. These signals can be scrutinized using various signal processing techniques. In this paper, few statistical approaches to analyze EEG data are conversed.

Basics of brain computer interfaces

An introduction to the main concepts behind the BCI is given, the concepts of the brain anatomy is explained, the BCI different signals are stated, Monitoring Brain Activity Using EEG is explained and the entire BCI system is elaborated. In addition, the used hardware and software for the BCI are elaborated.

A Quick Review of Machine Learning Algorithms

The author intends to highlight the merits and demerits of the machine learning algorithms from their application perspective to aid in an informed decision making towards selecting the appropriate learning algorithm to meet the specific requirement of the application. In this paper an attempt was made to review most frequently used machine learning algorithms to solve classification, regression and clustering problems, Types of machine learning techniques namely supervised learning, unsupervised learning, semi supervised learning, have been discussed.

CHAPTER 3

PROPOSED METHODOLOGY

3.1 BCI 2000 System

BCI 2000 was the first system implemented for e measurements. it particularly consisted of 4 modules, i.e., a source module, a signal processing module, user application, and the operator interface. it was implemented using the c++ programming language because it is a highest-level language that had satisfied all the system requirements.

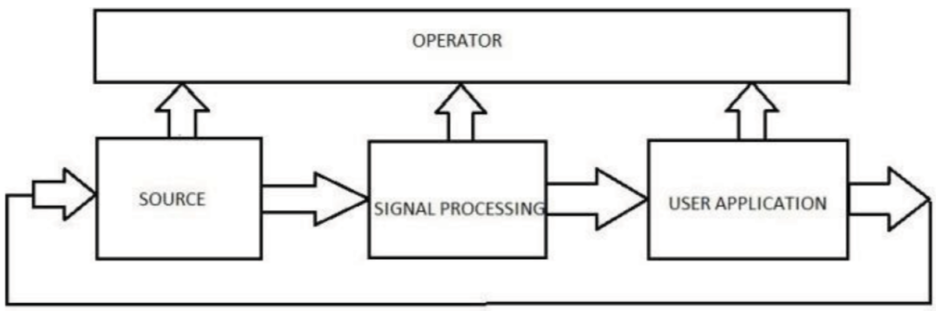

Fig-3.1: BCI 2000

1) Source Module: The source module digitizes and stores brain signals and passes them on without any further pre-processing to signal processing. It consists of a data acquisition and a data storage component.

2)Signal Processing Module: The signal processing module converts signals from the brain into signals that control an output device. This conversion has two stages: feature extraction and feature translation. In the first stage, the digitized signal received from the source module is subjected to procedures that extract signal features. In the second stage, a translation algorithm translates these signal features into control signals that are sent to the user application module.

3) User Application Module: The user application module receives control signals from signal processing and uses them to drive an application. In most present-day BCIs, the user application is presented visually on a computer screen and consists of the selection of targets, letters, or icons.

4) Operator Module: The operator module defines the system parameters (e.g., the trial length in a specific application or a specific signal processing variable) and the onset and offset of operation. The system model does not specify how these definitions are made they could come from an automated algorithm and/or from the investigator.

3.2 Modern BCI System

Modern BCI systems mostly use any development environment like MATLAB and any programming language. Forming a BCI system requires following four main steps as shown in Fig.

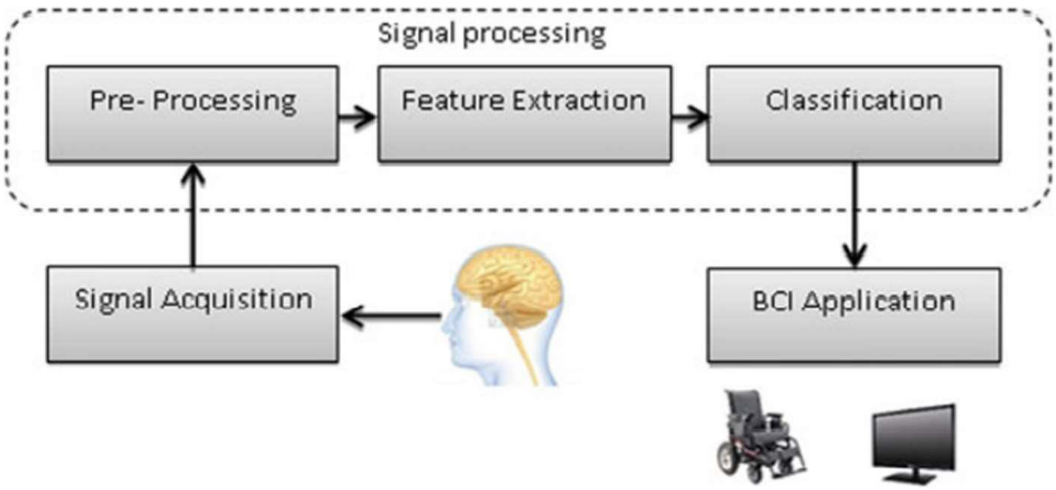

Fig-3.2: Proposed methodology flow diagram

3.2.1 Data acquisition

Data acquisition is a process of accepting EEG based data for the brain surface. Data acquisition can be achieved in two ways by invasive and non-invasive. Usually, for data acquisition, different neural analysis techniques are used they are EEG, Electrocorticography (ECOG), Magnetoencephalography (MEG), Positron Emission Tomography (PET) and Functional Magnetic Resonance Imaging (fMRI). Most often, EEG is used for neural analysis. because of less risk factor and portability.

Technique	Risk factor	Portability	Signal measured
EEG	Non invasive	portable	Electrical
ECOG	Semi invasive	portable	Electrical
PET	Non invasive	portable	Metabolic
MEG	Non invasive	portable	Magnetic
FMRI	Non invasive	portable	Metabolic

Table-3.1: Data acquisition techniques

3.2.2 Pre-processing

Once the data acquisition phase is completed, the data needs to be converted into noiseless form by using some spatial filters like High Pass Filter (HPF). Also filtering devices like notch filters and low pass filters can be used to achieve this. Pre-processing involves signal filtering, signal cutting, and amplitude scaling.

Sl. No	Method	Advantages	Disadvantages
1	Common Average Referencing (CAR)	1. Outperforms all the reference methods 2. Yields improved SNR	Finite sample density and incomplete head coverage cause problems in calculating averages
2	Surface Laplacian (SL)	1. Robust against the artefacts generated at regions that are not covered by electrode cap. 2. It solves electrode reference problem	1. Sensitive to artefacts 2. Sensitive to spline patterns
3	Common Spatial Patterns (CSP)	Doesn't require a prior selection of sub specific bands and knowledge of these bands	1. Requires use of many electrodes 2. Change in position of electrode may affect classification accuracies.
4	Adaptive Filtering	1. Ability to modify the signal features according to signals being analysed 2. Works well for the signals and artefacts with overlapping spectra nature	

Table 3.2: Types of signal pre-processing techniques

3.2.3 Feature extraction

Feature extraction methods are used to obtain specific features from the pre-processed signal. Feature extraction decreases the dimensions of the data and reduces time complexity. Some feature extraction methods are Principal Component Analysis (PCA), Independent Component Analysis (ICA), CSP (Common Spatial Pattern), DWT (Discrete Wavelet Transform) and Continues Wavelet Transform (CWT).

The features that are extracted using these methods are:

1. The average power of the wavelet coefficient.
2. Mean of the absolute value of the coefficient in each sideband.
3. Deviation of the coefficient of the sub-band.
4. The ratio of absolute mean values of sidebands adjacent to each other.

PCA represents the n-dimensional data to a lower dimension. This results in a reduction of the degree of freedom. This method is primarily used for signal segmenting from multiple sources. Segmenting basically means to divide signals into epoch within which signal can be considered stationary. PCA works in the following manner.

ALGORITHM OF PCA

1. Input vectors = $x_t(t = 1, \ldots, l$ and $\sum x_{t=0})$.
   For m dimension, $x_t = (x_t(1), x_t(2), \ldots, x_t(m))^T$ and m < l
2. Calculate covariance matrix $C = \frac{1}{l}\sum_t^l x_t x_t^T$.
3. Calculate eigenvalue and eigenvector $\lambda_i u_i = C u_i$ where $i = 1, \ldots, m$ and sort the eigenvectors in descending order of eigenvalue.
4. Estimate u_i components of s_t, calculate orthogonal transformation of x_t,
   $s_t = u_i^T x_t$ where $i = 1, \ldots, m$
5. Linearly transform the each vector x_t into new s_t by
   $$s_t = U^T x_t$$

Fig-3.3: Pca Algorithm

CSP is a feature extraction method. CSP projects multiple-channel EEG signals into a subspace. So that differences between the signals can be easily identified.

CWT is a technique which is used to draw out valuable features from the signals. It is mostly used to determine the patterns in the mixed signals. The wavelet transform is very useful in the transient signal analysis where the signal varies continuously with time

ICA is a feature extraction method that converts multivariate signals to a signal having all its components independent. These independent components are extracted from the mixed signals. The component contains information which cannot interfere with other components. ICA works in the following manner.

ALGORITHM OF ICA

1. Initialize w_i.
2. Compute Newton phase
$$w_i^+ = E\left(\acute{\emptyset}(w_i^T X)\right) w_i - E\left(x\emptyset(w_i^T X)\right)$$
3. Calculate Normalization $w_i = \frac{w_i^+}{\|w_i^+\|}$
4. For i=1, go to step 7 or else continue with step 5.
5. Perform decorrelation $w_i^+ = w_i - \sum_{j=1}^{i-1} w_i^T w_j w_j$
6. Compute $w_i = \frac{w_i^+}{\|w_i^+\|}$ once again,
7. Go back to step 2 if not converged or else go to step 1 with i=i+1 until all components are extracted.

Fig-3.4: Ica Algorithm

Wavelet is a rapidly decaying wave-like oscillation that has a mean of 0. Wavelet only exists for the finite duration of time. DWT basically works on two important properties, namely scaling and shifting. DWT helps in determining slow varying potentials. Selection of required wave and its range of level of decomposition are important in the analysis of signals by DWT. The number of levels of decomposition depends basically on the dominant frequency component of the signal.

Type	**Extraction Accuracy**	**Comments**
PCA	76.34%	It assumes components with maximum variance having the most information
ICA	90%	It separates components from mixed signals
CSP	85%	It helps in differentiating multiple channel signals
DWT	72%	Helps in determining slow varying potentials.
CWT	<72%	Helps in extracting valuable features from the mixed signal.

Table- 3.3: A Summary of Feature extraction methods

3.2.4 Feature classification

Once the required feature is extracted, these features need to be classified into meaningful groups. There are different classification methods specifically Support Vector Machine (SVM), K Nearest Neighbour, Multilayer Perceptron Neural Network (MLPNN), Probabilistic Neural Network (PNN), Multiclass Support Vector Machine (MSVM), and LDA (Linear Discriminant Analysis)

Support vector machine is an algorithm that differentiates two classes by drawing a hyper plane. these two classes lay on either side of the plane. Since hyper plane is dividing these two classes, it is also called a support vector.SVM can be linear and non-linear, usually non-linear SVM is used to classify the extracted feature. Once the SVM algorithm is trained it can also classify a new set of data when given.

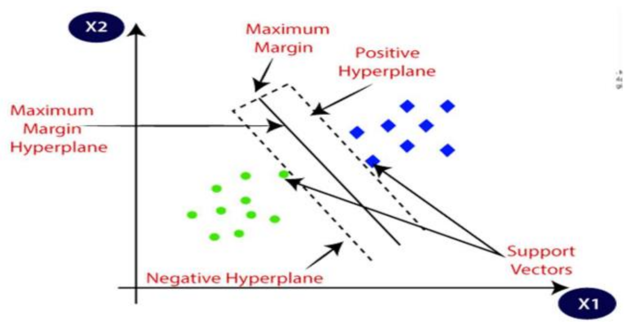

Fig-3.5: Support Vector Machine

MSVM is similar to the SVM, but it helps in differentiating multiple classes. The support vector here is usually nonlinear since the feature points are scattered everywhere in the space. This algorithm is used when SVM is failed to classify the features

KNN is an unsupervised nearest neighbour classifier in which the feature vector is assigned to the nearest class among k neighbour. These features are assigned based on the Euclidian distance. The performance of this algorithm is greatly determined by two factors. If the value of the neighbour is large then the big classes will overwhelm the small classes. If the value of k is too small then the advantage of KNN is not exhibited

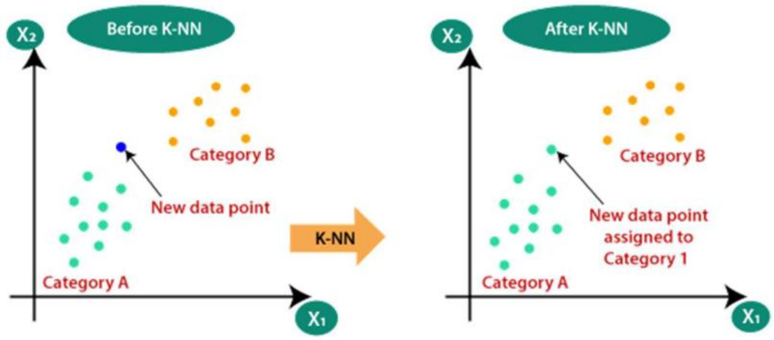

Fig-3.6: K-Nearest Neighbour

MLPNN are the most commonly used neural network classification algorithm. MLPPN works well with smaller training data set and has the ability to learn and generalize. MLPPN is very easy to implement and has a faster operation. Like SVM MLPPN can also classify the nonlinear data set. It consists of 3 layers, namely the input layer, hidden layer, and the output layer. In the input layer n data points are taken then in the hidden layer various computations take place, and at last two distinct outputs are produced.

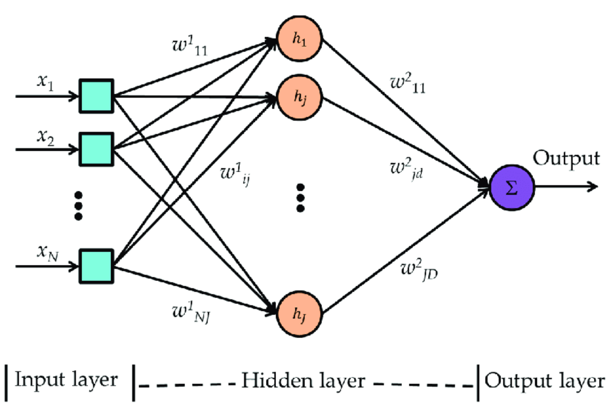

Fig-3.7: multi-Layer Perceptron

The **PNN** is composed of many interconnected neurons, also called as processing units which are arranged in a successive layer. The input layer does not perform any computation; it only helps in the distribution of the data. The hidden pattern layer segregates different patterns in the dataset, these patterns are added up to the summation layer, and finally in the decision layer single output in terms of probability is formed. The number of neuron layers can be increased to compensate for accuracy of the result formed.

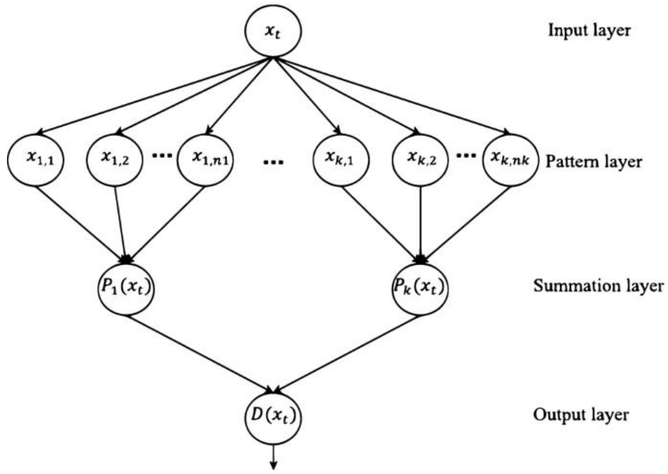

Fig-3.8: Perceptron Neural Network

LDA is a very common technique used for supervised classification problems. LDA creates the new variable, which is a combination of the original predictor. This is achieved by maximizing the difference between the predefined groups with respect to the new variable. Then the discriminator score is analysed.

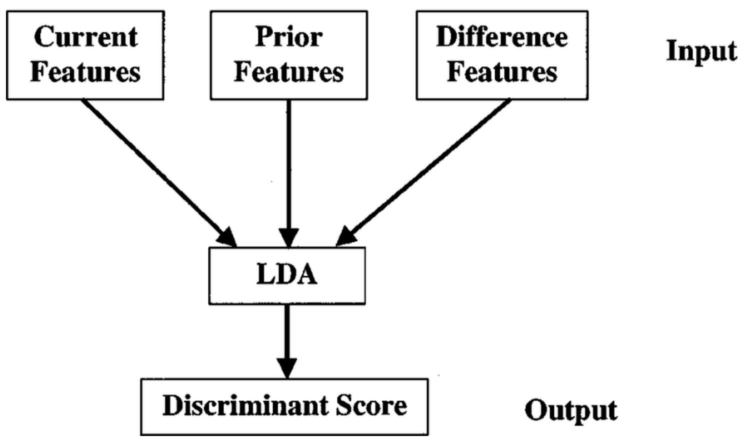

Fig-3.9: Linear discriminant analysis

3.3 BCI APPLICATIONS

Brain computer interfaces have contributed in various fields of research. As briefed in Fig-18, they are involved in medical, neuroergonomics and smart environment, neuromarketing and advertisement, educational and self-regulation, games and entertainment, and Security and authentication fields.

The development of BCI technology was initially focused on helping paralyzed people control assistive devices using their thoughts. But new use cases are being identified all the time. For example, BCIs can now be used as a neurofeedback training tool to improve cognitive performance.

Fig-3.10: BCI Applications