Study of Brain Computer Interfacing (BCI) with Cochlear Implant as an Example

---

A Master's Project

Presented to

Department of Telecommunications

In Partial Fulfillment

of the Requirements for the

Master of Science Degree

State University of New York

Institute of Technology

By

Debsuta Roy

Aug 2016

Study of Brain Computer Interfacing (BCI) with Cochlear Implant as an Example

Declaration

I declare that this project is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references is given.

Debsuta Roy

08/18/16

SUNY POLY

DEPARTMENT OF

COMPUTER AND INFORMATION SCIENCES

Approved and recommended for acceptance as a thesis in partial fulfillment of the requirements for the degree of Master of Science in Telecommunications

9/6/2016

DATE

Dr. Larry J. Hash

Project Advisor

Executive Summary

Brain Computer interfacing (BCI) has been under constant research to improvise the pathway amongst the brain and outside subject in several characteristics. This technology is being widely appreciated as the world tends towards automation.

The mechanics of this domain include computer prone brain interfaces induced on the cortical part of the brain which helps in controlling external devices via thought. These interfaces are designed such that they will receive and transmit acoustic data and process them so that they can be recorded as a generalization thereby helping in generating signals artificially. Cochlear Implant has been demonstrated as an example of BCI where stimulation of brain takes place with the help of an external device. As this field is still being developed, there are several factors needed to be focused viz. research/study of the subject, location of electrodes, cost, complexity, performance, setup requirements and security.

BCI field is a highly vast topic and is a combination of various fields like science, technology, medicine etc. This piece of research and study focuses primarily on the neuroscience and technology part. This project is presented to showcase the depth of this field and create interest for further advancement in this field.

Chapter one deals with introduction to the technology as a whole and its related study of papers. Chapter two discusses about brain and the principle behind this technology. Chapter three helps in

understanding the technology by splitting its components. This is followed by taking an example of cochlear implant technology in chapter four. Chapter five initiates the wireless approach brought to this technology. And then chapter six is all about challenges, conclusions and ideas of enhancement.

Table of Contents

List of Figures

Chapter 1: Introduction

Brain computer interfacing is the field of emerging technology where the brain communicates with external device forming a pathway of direct communication to enhance assistance with functionalities of sensory motors. This concept basically helps the humanoid to obtain control over the device by the power of thinking. For an instance, a person can control his wheelchair directions with his thoughts; perform his daily activities say moving of objects, restore his partial hearing to normal, reach a new level in the gaming world, say advanced form of 3D gaming etc.

Control of the brain happens with the help of electrodes whose purpose deals with detection of electric signals in the brain. The main goal of this technology deals with figuring out a person's thoughts by capturing of electrical activities from the brain and analyzing the signal. This basically detects neural oscillations in the diagnosis by computing muscle movements, skin senses, eye gestures etc.

Certain examples where the technology can be effectively used are cochlear implant, bionic eye, brain gates, BCI gaming, Cyborgs etc. This implies that this field combines different areas of discipline such as neurosciences, robotics, computers etc. Among the vast utilities, Cochlear implant is taken as a focus to further demonstrate the technology. In this technology, the part of the ear that is damaged is electrically bypassed with the help of electrodes providing access to sound.

As the world of technology moves towards automation with ideology of small size lesser wiring and more output lead the way for implementing wireless in this technology. With the onset of wireless capabilities, the whole mechanization becomes easily accessible and is convenient. Such a type of technology will help contribute to the innovation world by introducing development in wireless as its advocatory, providing constant scope for future works.

1.1 Background

Man versus machine theory has been continuing from a long time. The constant growth for development of sciences evolved so much that the notion of apprehending thoughts and correctly speculating them over the machines categorizes under latest trend of man and machine. This integration has been given the name of Brain Computer Interfacing or the BCI. The other names for it are mind-machine interface or MMI, synthetic-telepathy interface or STI, direct-neural interface or DNI, brain-machine interface or BMI.

The history to the evolvement of this technology can be dated back to 19^{th} century where Deep Brain Stimulation evolved. This is a surgical procedure in order to treat various neurological disabilities like Parkinson’s, terror, stiffness etc. Here, electrodes form a wired connection to neurostimulator implanted under the skin. The principle behind this is as follows: Electrical pulses travel from the neurostimulator travel along the wire to the electrode into the brain and these pulses interfere/block electrical signals which are responsible in causing the disease symptoms.

It started off by discovery of the electrical signals on the exterior of the brain of animals. This followed experimentation on human where EEG signals were analyzed in a way to find the capacity of the human brain to withhold the signal. This was first tested on epilepsy patients. The first recording of the human brain activity with EEG took place in 1924 by a neurologist named Hans Berger. [1]

1.2 Literature Review

The purpose of this technology case study is to understand the brain computer interfacing model featuring cochlear implant as an illustration and thereby understanding the technology in a more comprehensive fashion.

1.2.1 Review 1

The paper "Brain-Computer Interface: Past, Present & Future" is written by Md. Ibrahim Arafat. This research article gives exposure to future predictions by analyzing the way the technology evolved and its progress. In this paper, the types of BCIs which are invasive, partially invasive and non-invasive are briefly defined with instances for each. The non- invasive technique which forms the most practical solution for implementation was described broadly explaining each instance's approach.

Electroencephalography, EEG which was discovered on the basis of Edelmann model had its electrodes placement on both front and back of the head which is known as 10-20 system helping to develop the standard electrode placement followed by the letter-number designation. This 10-20 system evaded the placing of eyeball by defining constant distances and utilizing 10% or 20% of that marked distance as the electrode interval. Magnetoencephalography, MEG method was based on SQUIDs i.e. superconducting quantum interface devices where the activity of the brain was mapped to the recording of the magnetic fields. Initially, only one SQUID detector was used for measurement of the field in different points of the brain but present day scenario includes 300 sensors covering almost the entire head and the array is helmet shaped. Functional magnetic resource Imaging, fMRI is categorized as a special type of MRI scan for the purpose of measuring responses related to blood flow changes for neural activity. This doesn't have exposure to radiation. Electrocorticography, ECoG is a process of electrical activity recording of the cortex. This falls under invasive type of BCI and electrode placement is on the brain's exposed surface. This also withholds a standard for defining epileptogenic zone. The research for how this technology evolved started from the year 1929 where EEG was first recorded to its future predictions until 2090 where immortality to human brain are defined.

To evaluate the consequences of such a technology one of the main parameter involved is the transfer rate for the information according to [2] which identified last decade's max transfer rate existed as 5-25bpm to present max data transfer rate is 84.7bpm. According to the paper, EEG is more preferable for BCI research. The author also predicts on the future research of BCI advocated with nanotechnology.

This paper helps the reader understand how the technology is moving forward. The author's outlines to this technology to its future predictions and also claiming it as being one of the top researches globally which as a matter of fact is proven true for some of the forecasts thus proving its solutions towards intelligence and medicine.

1.2.2 Review 2

The paper titled "What the Frog's eye tells the Frog's brain" is authored by J.Y. Lettvin et al. The behavior of frog was studied and a technique to determine the stimulus activity related to nerve fiber with corresponding responses were discussed.

Frog's visual system was analyzed as how his life depends on movements. Here, Hartline's and Barlow's concept of brightness affecting the cell's response was noted. [3] The three receptive field slots (ON, ON-OFF and OFF) were estimated based on the light intensity, area and the discharge timing. Frequencies of discharge spikes to the appearance of light were recorded. With all the findings the ideology remained as OFF interpreting diminishing of light, ON-OFF determines intensity boundaries, ON represents delay. Nerve fibers were studied to find what part of the hemisphere was detected by the stimulus detector and then match the area to the receptive field inside the fiber. This output was logarithmic which was obtained with the help of photomultiplier.

After the analysis from four operations viz. sustained contract detectors, net convexity detection, morning edge detection were performed in terms of studying graphically and importance of depth of fibers to the speed was found. This paper tells how the technology of BCI has its roots built from the early experiments.

1.2.3 Review 3

This article named Hearing Preservation in Cochlear Implant Surgery is published in International journal of Otolaryngology on 3rd September 2014 and is authored by Priscila Carvalho Miranda et al. This research article gives an insight to electrode design and compared it to standard electrodes thereby reviewing EAS or electric acoustic system and implementing surgery technique for hybrid cochlear implantation to see development of test objects inculcating guidelines. The basis of the test was for low frequency hearing and the parameter involved for this was Consonant-Nucleus-Consonant word scores. The two trials were for S and L devices which imply short and long electrodes.[4]

Low frequency hearing relies on various factors such as diameter of electrode, membrane, hair cells etc. The development of low frequency preservation for hearing involved standard electrodes but limited the length of insertion to 24mm (compared to regular 31.5mm). There existed certain guidelines with respect to initial EAS or electric acoustic Stimulation. The criteria stands as 65dB for the low frequency range from 125-500 Hz (standard cochlear implantation) which was then gradually expanded to general low frequency hearing up to 1500Hz(cochlear implantation with partial deafness.) The actual guidelines have been classified as 60dB for 125-500Hz and 70dB for 1500Hz. The patients selected for the experiment had to survive the condition for best aid hearing of CNC word scores which was segregated as 80% for the best hearing ear and in between 10% and 60% for worst case ear. The surgery technique is defined as soft surgery which was used by University of Iowa. In this method, a stitch is placed for the purpose of electrode anchoring in order to reduce spring movement when electrode placed in scalp. Round window is totally open to the facial nerves. The receiver stimulator placement is same as the way as in the normal implant process. In order to prevent blood debris and bone particles from entering the cochlea meticulous hemostasis is done. Cochleostomy is used by the US as preferred strategy whereas in Europe it is round window with neither overpowering the other in terms of preserving residual hearing. Prior to opening of endosteum, electrode and processor must be placed in position. Then two holes are drilled in tegmen tympani after which S and L electrode arrays are inserted to the nylon suture of 2-0 or 4-

0 measurement. A washer of 1.5*1.5 diameters is inserted in the facial tissue and punctured with a needle so that the electrode is sealed in scala tympani. The final stage would be to reduce the time the cochlea is opened by opening endosteum into scala tympani by a 0.2mm footplate hook. The electrode is then pushed slowly to lessen the trauma to a minimum.

There existed improvements with CNC scores from 1-2 years of activation. For hybrid L type, the improvement was 21% at an average whereas for the S type, there was 48% of the test objects showcased improvement with the scores. Tests from hearing over noisy background was also seen impressive (-9dB) when compared to SNR of long electrode patients (+3dB) but didn't match up to normal-hearing SNR(-30dB). Degree of significant identification for music was highly successful as 65% to 100% of the time there were right answers of song identification from the hybrid S/L trials which was the same as normal hearing listeners. Despite this, the detection of instruments and discrimination of melody pertained to similar results as of general cochlear implant objects.

The article emphasizes on how cochlear implant design can be improvised by advocating it with hearing aid thereby introducing hybrid behavior which provides advantage of clarity in speech and music. There could have been a little broader description on what is a CNC scores and the exact methodology followed after insertion of electrode. As the main challenge with cochlear implant lies with hearing in low-frequency and under noisy environments, this article brings out the advances in surgery techniques and focuses on the importance for design of electrodes also describing Electric acoustic Stimulation.

1.2.4 Review 4

This research paper named Cochlear Implant Programming: A global state of art is conducted by a group of researchers Bart Vaerenberg et al. globally in 2012 and published in the scientific world journal (2014). This paper gives insight to the current scenario of clinical practices. The data for this research was set up on a questionnaire basis and the results were discussed as a debate. The various electrical parameters are termed as MAP and the main objective revolves in the variation of fitting techniques and settings. The opinion statistics included number of implant processes annually, brands and fittings, MAP parameters, assessments and targets.

The switch on procedure is after 2 weeks or 28 days while the Cambridge starts with 6 weeks gap from the electrode placement. Firstly, the impedance is measured. The definition for the threshold level as a minimum is 31% and a max of 24% current level for the electrodes. The minimum level is obtained on eCAP thresholds behaviorally on a few electrodes. Maximum level is obtained by setting the minimum level to 0% or 10% of the max level. Loudness balancing is another measurement of consideration. In cases where max level derivation is independent of min level, they are reduced before the microphone is switched on. After the switch-on, certain tests such as Ling sounds, psychoacoustic tests, scaling of loudness, open words understanding etc. MAP parameters depend on threshold level with central dot indicating as median value in the frequency plot. Once the switch-on process is done along with MAP settings, next comes the follow-on procedure which occurs as 3 sessions every quarter and then 1 session annually. If there exists non auditory simulation then electrodes get deactivated. The additional MAP features for cochlear device which are modified are Auto sensitivity feature, pulse width, maxima number, channel rate. Mean time for fitting and testing after the process of switch on is six hours. This is distributed as 3.3 hours for fitting and 2 hours for testing. After the completion of the first year, median time comes down to 1.3 hours where fitting is dedicated 0.5 hours and testing is given 0.8 hours.[5]

The two main observations include how the brands of the cochlear implants expanded to 3 contrasting to only one from the past years and how common practices evolved in spite of the variabilities across different centers. The results were based on subjective and objective features. The subjective measures included overall comfort, auditory and non-auditory assessments. The percentage sums up for these are 93% for overall comfort and the assessments include 83% each. Psychoacoustic outcomes were also considered which defines the number of centers having definitive targets which are well defined. The objective measures included electrode impedances, thresholds etc. basically to set up the MAP profile. The data from cross-sectional perspective included speech audiometry, loudness scaling, ling sound detection etc. The paper also contains histograms depicting frequencies. The multicochlear implants has been present around for more than 25 years according to this paper. The art of fitting is requires good theory of clinical practices which is still an improving graph due to individuality of the clinical centers. It also assumes that the field is dominated by European habits due to higher individual clinicians. These were based on 2013 analysis.

Questionnaire, interview and snapshots were the main criteria to perform analysis. There is no hard evidence but the validation is done through cross-sectional sample. This paper also tells its readers that the data is not 100% accurate but forms an indicative to give better idea.

1.3 Statement

An in depth study of brain computer interfacing advocated by cochlear implant technology as an epitome in order to draw attention to this emerging research, belonging to the field of human computer interaction; understanding the problems and necessities thereby exploring wireless feasibility allowing user to interact with brain powers without any physical wired connection.

1.4 Audience Definition

This project is oriented towards upper level undergraduates and graduate students in Telecommunications or related field. Brain functions, Electrophysiological sensor technology, EEG, neural networks, cognitive and biomedical states assessment, adaptive filtering, machine learning algorithms, linear vectors, logarithms and virtualization are the terms requiring minimum background.

Chapter2: Model and working principle of BCI

2.1 Definition

BCI or brain computer interfacing refers to a technology wherein the brain analyzes the control from an external device and restores the function by transmitting signals and stimulating sensory information thus building a channel amongst the body and brain. This happens in a one way format of input or output where the signals are either sent from the computer to the brain or vice versa at a particular time.

It is fairly different from neuroprosthetics which deals with connection of the nervous system (central and peripheral) to the device. On the contrast, BCI mainly deals with connecting the central nervous system to the computer. Thus BCI is like a subset to neuroprosthetics. Both the areas include common methodologies, surgical process and experiment techniques with their major aim being to restore activities physically and mentally thus creating a better environment and a healthy life.

2.2 Input and Output

For a normal BCI process, the input of BCI refers to capturing of thought information electrically. This can be done via different sensor placements in different areas of the brain and can be defined as signal from the brain to the computer. The output of BCI refers to converting the information taken from the brain and manipulating by machine learning so that the user is able to control the object. This process of converting the thought to action is done by different signal trials evaluation in the computer and the state of the brain is thus measured which are categorized as below. Since each brain behaves different, measuring the reactions of the below three states are of importance. Based on the thought computing requirement this is then fed from the computer to the brain. There have also been evidences of trials for Reverse BCI where the scientists try sending signals in a rat and the experiments are termed as RATBOT.

Tonic: This pertains to degree of relaxation which reflects slower change in brain processes. It indirectly refers to how much cognitive load the brain can handle. Example – remembering, thinking etc.

Phasic: This pertains to switching attention implying fast changes. Example – listening to music and choreographing a dance move. This results in shifting attention back and forth and helps the brain to adapt to new situations.

Event related: This is the brain's state based on a particular event. Example – Given a situation, how does the brain react (happy/unhappy, surprised/not surprised etc.)

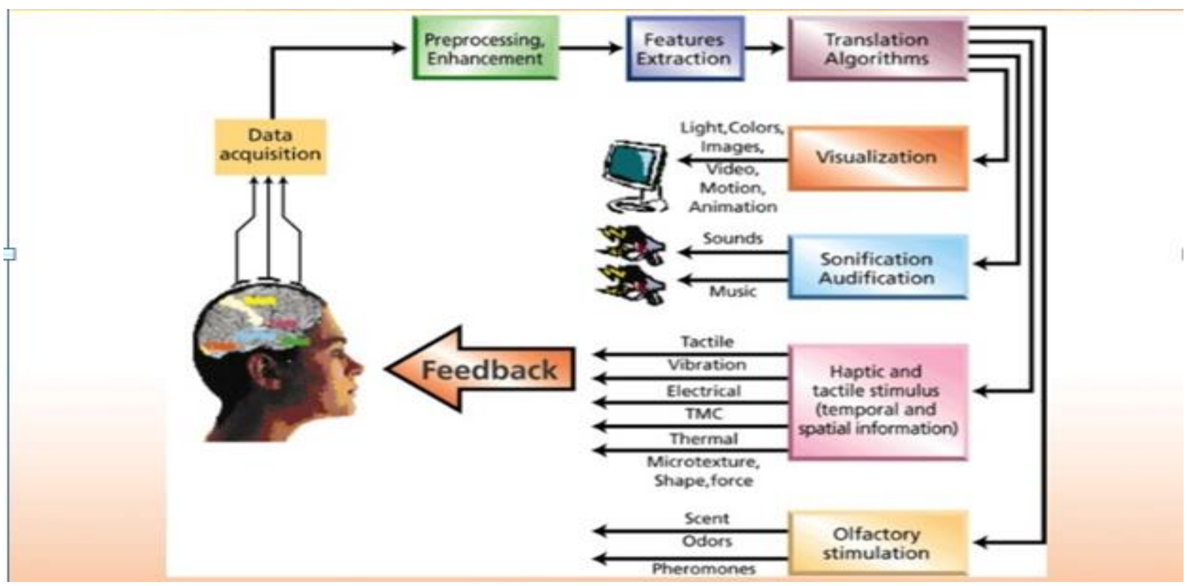


Figure 1: An example of a BCI system with the building blocks to help provide desired function via different feedbacks.

http://www.brain.riken.jp/bsi-news/bsinews34/no34/research1e.html

This figure showcases multiple neurofeedback's which helps the machine to recognize complex brain wave patterns to make the brain function accurately. The process involves collecting of data from the brain (data acquisition), process this data (preprocessing enhancement, features extraction), analyze the data (translation algorithms) and then send it to the brain via a feedback. This whole process helps to gain control of the brain by recognizing patterns of activities from the brain.

2.3 Neuron Interfacing

2.3.1 Brain and its parts

Brain comprises of different cells and is responsible for controlling different senses say taste, hear etc. and movements of a body. It is the hub for consciousness and emotions. The approximate weight of the brain is 3 pounds which is classified in two hemispheres separated by four different lobes namely:

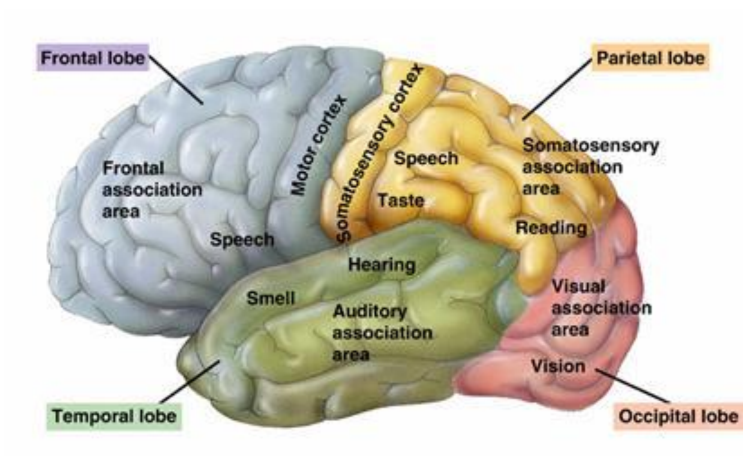


Figure 2: The Brain and its sectors

http://biomed.brown.edu/Courses/BI108/BI108_2005_Groups/03/physio.html

Frontal: Responsible for speech and movement

Parietal: Responsible for stimuli related to touch

Temporal: Responsible for stimuli related to hearing and memory

Occipital: Responsible for vision

Segregation of the lobes is by fissures. Signal is generated at the outer layer cortex which is the Grey Matter. Parietal and temporal lobes fill in as the most important lobe for BCI. Nervous system is divided into two categories such as the Central nervous system which comprises of brain and spinal cord and the Peripheral nervous system which comprises of the sensory nerves along with the motor which resides outside of central nervous system. The main difference between the nervous systems is while the central nervous system plays its role as the command center controlling all the senses and movements by understanding different signals and analyzing the outputs the peripheral nervous system delivers it to different zones in the body connecting carrying it over the right veins.

2.3.2 Neuron

Neurons are divided into two parts- dendrites and axons. They are contradictory to each other; while dendrites are primarily responsible for bringing information to the body of the cell (reception of chemical messages), axons take away the information from the cell body (transmitting electrical signal).

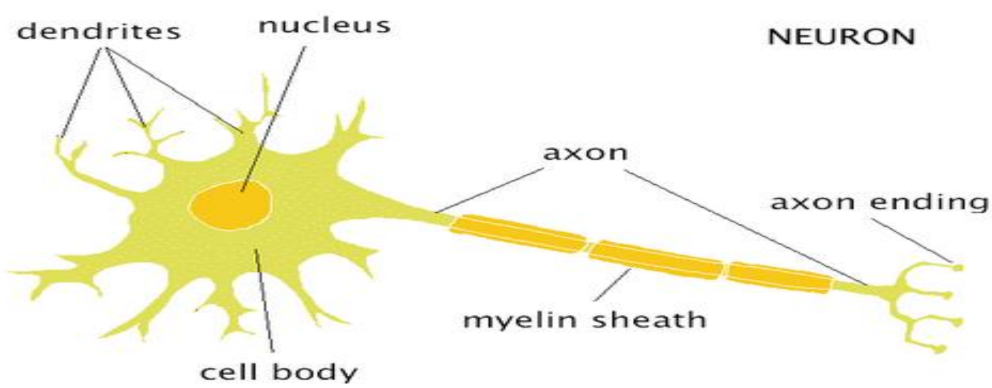


Figure 3: Neuron

http://webspace.ship.edu/cgboer/theneuron.html

The neurons are enclosed within a fatty substance known as Myelin which serves as insulator. Hence, neurons, myelin sheath and ions providing a scope for electrical wire through which the electrical impulses travel to different groups of neurons. Scientists have figured ways where artificial neuron acts similar to natural neuron using diffusion as the tool of science. [9]

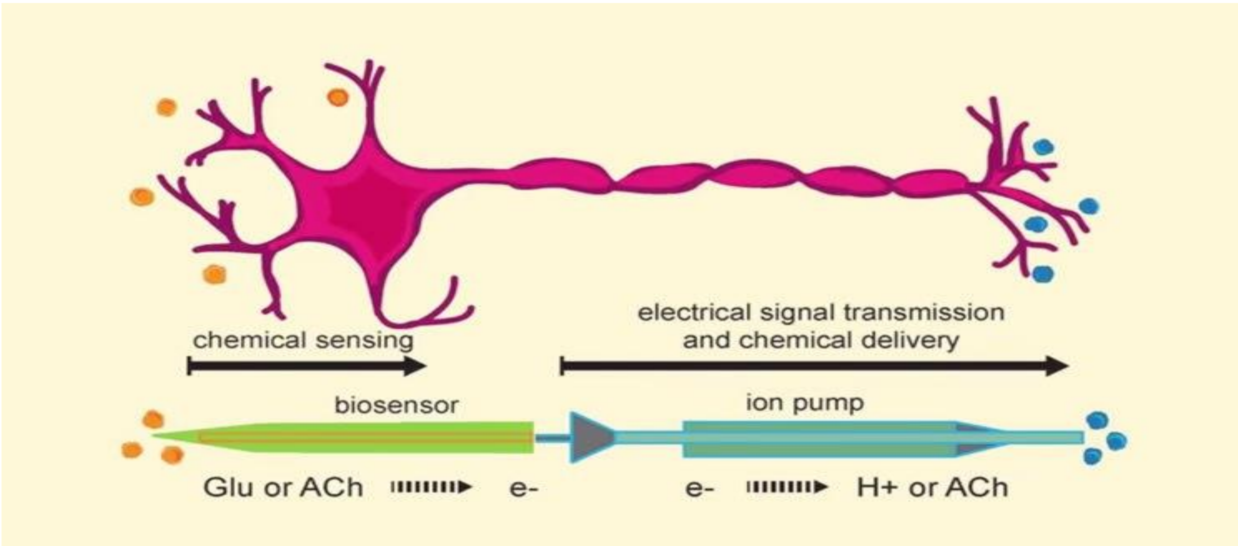


Figure 4: Artificial Neuron

http://neurosciencenews.com/bioelectronic-artificial-neuron-2157/

If there is electrical stimulus being applied to the axon it conducts the current all the way to the bottom of the axon itself which is the axon potential. When a neuron is fired, it sends the signal to the electrode. A neuron gets fired when it is sufficiently stimulated to conduct the action potential. When the neurons are stimulated by sensory input, they transmit signals which are picked up by the dendrites activating the action potential. The neuron can be communicate to the electrode in ways like electrical, magnetic field etc. which forms the basis for classification of implant and is discussed in chapter 3.

2.3.3 Synapse

The concept of Synapse helps to identify response signals of the brain. Synapse can be briefly described as a junction where neurotransmitters are released in a spacious center i.e. a small space amid axon and dendrite of the cell. Synapse comprises of the following parts:

Presynaptic end: consisting cell organelles, neurotransmitters etc.

Synaptic cleft: space between pre and post synaptic ends

Postsynaptic end: consisting receptors for the neurotransmitters

In order to establish communication among neurons, the electrical impulse must be mobile from the axon to the synaptic terminal. The electric signal which helps the thought to process travels with a rate of 250 mph. The speed impulses are dependent on the type of stimuli.

At the terminal, there is migration of vesicles which is caused due to the trigger of electrical impulse. The vesicles consist of neurotransmitters which move towards presynaptic membrane. Now, both the membranes (from vesicle and presynaptic) gets combined thereby releasing the neurotransmitters to the cleft. In the past, Dale's Law was trailed which summarizes that only one type of neurotransmitter can be formed and unconfined. But there have been advancement of handling more than one neurotransmitter.

2.3.4 Example of neuron interfacing

When the neuro transmitters diffuse themselves to fit in receipting sites of neuron causes chemical action to take place which can either increase or decrease the membrane potential present in the neuron. The membrane potential of the resting state of neuron is -70mV. If the membrane potential increases (adding positive charge) then it causes excitation and if there is decrease in membrane potential (negative charge) then it restricts the neuron. The process of current flow is explained in 3.1.2.

The electric signals do not transfer completely. Some of the signal spurts. These signals lately have been detected by scientists and their meanings are inferred. They are then directed to a device of certain kind. The analyses of researches are found by studying the signals in the brain which are transferred through the optic nerve. For example, a camera can be introduced which directs the signals to a person's brain and it would allow someone who is blind to see whenever the camera saw red.

When a neuron is activated, there's a change in voltage approximately around 100mv over the cell. This can be read among different devices. Electrode arrays play a key part for neurons to communicate with the electrode. In order to understand the approaches for electrode to work right, electrode to tissue interaction was studied which is described in section 3.1.3. During the course of a forced action, frontal lobe generates commands. The characteristics of magnitude and frequency are obtained from the signals which are located on the brain's surface. These signals can be analyzed by monitoring in different phases and understanding the functionality.

During course of imagination, the brain keeps producing signals collected from different areas. The signals though measurable are not enough to travel across the spine for initiating the action. Generation of impulse is done by neuron depolarizing which causes changes in electric field and are weighed as 0 or 1 on the characteristic basis. 0 indicates no impulse generated and 1 indicates the generation of an impulse.

After analyzing these signals, they can be artificially generated and sent to respective body part via simulation thus controlling the thought process via electrode implant. The sensing of neural activity depends on the type of implant which is described in section 3.1.5.

2.4 Working Principle

Human brain is unique and has a lot of power to coordinate and control different tasks. The purposes of BCI is not just thinking of a word and make it appear on the screen but to control the thought process like where characters are visually displayed and if the brain recognizes certain character it wants the brain wave changes. The positive energy in the brain triggers a spike in the signals which gets detected by the BCI system.

The three main steps involve

1) Sensing of the signal
2) Transmission

3) Analyzing

A small sensor implanted in the cortex picks up the signal and sends out via transmitter which is then interpreted by the software followed by the translation of the signal to control objects.

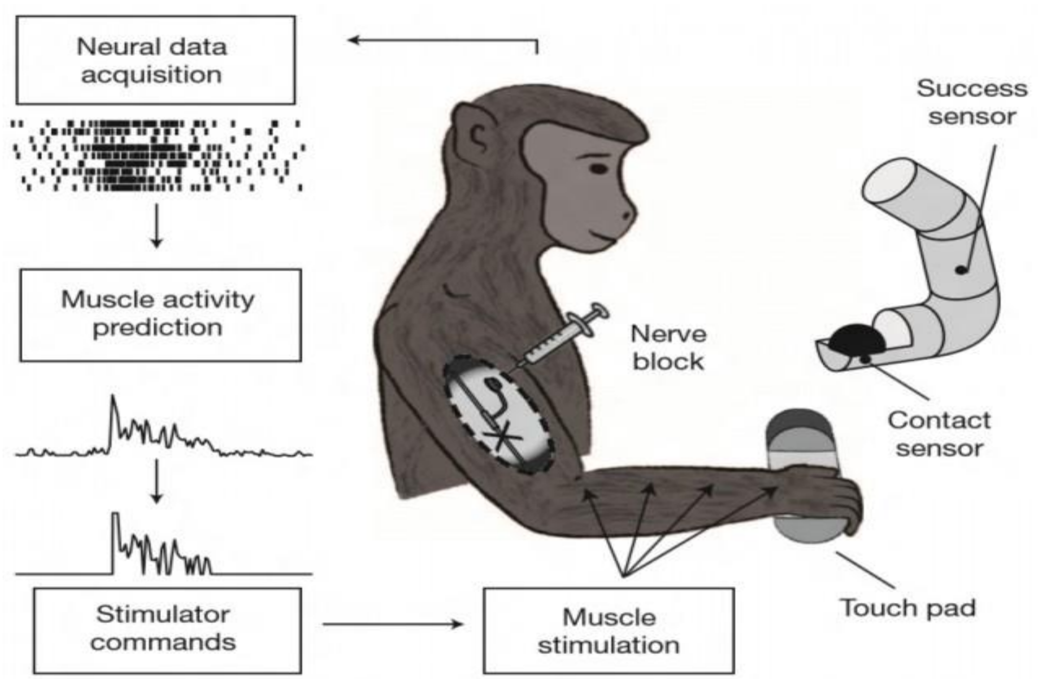


Figure 5: Steps in BCI

http://oc1dean.blogspot.com/2012/05/researchers-create-brain-computer.html

The zeal of learning new things influence rapid connectivity among neurons and thus helps reduce neurological disorders in the old ages. During, an injury the other parts of the brain take control for the damaged portion.

Scientists have found a process where the BCI combines a number of neurons, say 100 inside the cortex of the individual with wiring involved and the functional device is inserted into the muscle of the arm. So, during movement of the arm, those particular groups of neurons get activated and the data stream is studied on the basis of different analysis by the device for the direction. Then the required amount of force necessary for the action to be completed is passed on to stimulation system which prompts for the accurate muscle parts desired for the activity.

The above explanation indicates that this can be used to trigger the activity from outer sources bypassing the damaged portion. A good example for such a situation is the Cochlear Implant which is discussed in Chapter 4.

Chapter 3: Components of BCI

There are three main components for a regular BCI system which are shown in the below figure. They are Signal acquisition, Signal Processing, Device Output.

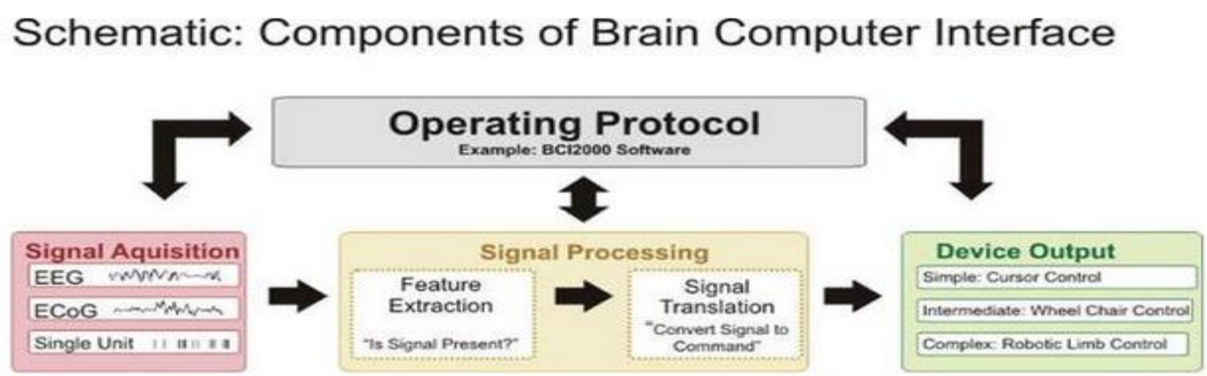


Figure 6: Components of BCI

https://kin450-neurophysiology.wikispaces.com/Brain-Computer+Interface

3.1 Signal Acquisition

This process is based on electrode sensing activity. A key part is the placement of electrode which determines the type of BCI implant to capture the signal. There are three forms in which this can be achieved viz. Invasive, Semi-Invasive and Non-Invasive techniques. These are explained in detail in section 3.1.4 and 3.1.5.

When the electric signal gets transmitted via dendrite, charges get separated on the membranes of the cell. This separated charge acts similar to battery (Current leaving – positive polarity, current gaining – negative polarity). This battery otherwise known as primary current focus on determining activity of nearby neurons. Brain tissue forms a conductive medium for the primary current. Another current known as secondary current is induced through the skull. They are responsible for calculation of EEG by creating voltage differences. This is done using electric field. Both these currents (primary and secondary) generate magnetic fields and they can be measured as a sum with the help of coils by MEG. Hence, it's observed that some electrodes utilize electric field and some utilize magnetic field for the electrodes to pick up signals during neural activity.

3.1.1 Electrode

Electrodes represent sensors which determine activity of the brain. The device containing microelectrodes array is responsible for recording of action potential from a single neuron or group of neurons. These signals are then represented as a whole with the help of rate code.

Recording of bio electric signals involves different electrodes per necessity. This plays a very important role after the choosing of the correct electrode as there is constant progress being made in the field of recording electrodes which have been sustainable for few weeks/months.

They are classified as:

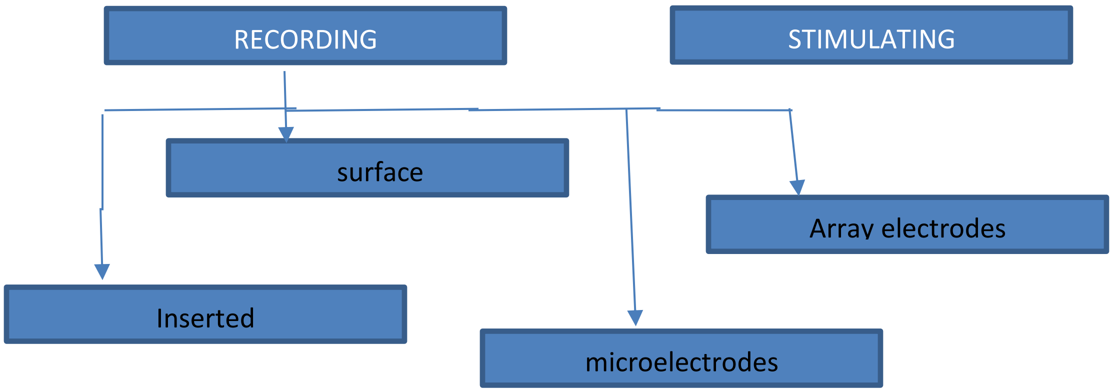


Figure 7: Types of electrodes

Both recording and stimulating electrodes are vulnerable on the same response tissue but the latter can be negotiated with increased strength of signal. The recording electrodes depend on the signals during implant. Example of stimulating electrodes can be seen in Deep Brain Stimulation, Cochlear Implant and recording electrodes in Speech or Motor Center's activity in the brain.

The different shapes of electrodes include uniform micro wires, probes having wider base and thinner tip, plane shanks and the sharpness consist of 150deg for blunt, 90deg for medium 5deg for sharp. Insertion speed levels include 0.125mm/s, 0.5mm/s, 2mm/s. The thickness of the brain area roughly estimates to 500micrometer where the electrodes get inserted.

The various elements used for the electrode build are Platinum, Ceramic, Silicon, Iridium etc. In general, the common electrode used for the technology is AgCl (Silver Chloride) for the wet process. The dry process involves titanium, polyurethane. For coating purpose, titanium Nitride is chosen as it's more stable. Gold can be an alternative for this. Characteristics for the electrodes are preferred as follows:

	Ti/TiN	PU/TiN	Au	Ag/AgCl
effective pin diameter (mm)	1.5	1.5	0.5	n.a.
effective pin height (mm)	2.5	6	3	n.a.
pin number	1	24	15	n.a.
approx. electrode contact surface (mm2)	3.5	85.1	6	42.5
approx. electrode weight (g)	0.05	0.73	2.21	0.61

Figure 8: Electrode Characteristics

https://www.tuilmenau.de/fileadmin/media/bmti/ieee_2014/Fiedler_Acta_IMEKO_2014_dry_electrodes.pdf

3.1.2 Electrolyte Interface and Current Flow

Electrolytes refer to minerals present in blood which carries electric charge. Electrolyte Interface can be defined as a medium where the chemical compound disintegrates into solution (molten form) of ions. Electrode has a strong relationship with the electrolyte interface. If the process involves oxidation, which means there are loss in electrons the current flow is from electrode to electrolyte. If the process involves reduction, which means there are gain of electrons the current flow is from electrolyte to electrode.

3.1.3 Tissue Responses

The neural network relies on food and nutrients which are provided by blood vessels and glial cells. These cells are present in more number than the neurons and are responsible to help neuron function properly. This is done by wrapping around the neuron and providing insulation support. When the electrode is inserted the response is mainly affected by glia in astro or micro forms. One of the main reasons to prevent the failure of the technology is to generate proper responses of the tissue to the electrode which can fail in a condition of glial scar. [12] The other reasons include lack of positioning standards, no constant electrode materials etc.

The response time is calculated along the lines of stressed insertion of the electrode and tenacity of the electrode's presence in the neural tissue. Strain and deformations, fluid displacement were calculated from the images of electrodes in order to check on the cell deaths. Faster insertion along with sharp ness level of 5deg. was found to work better on comparing different combinations.

When the microglia engages its presence, it clutches everywhere near the foreign body and participates in degrading enzymes. Though the electrodes are built to a resistance to this condition, phagocytosis takes place which leads release of dead tissues concluding with the death of the cell surrounding the electrode hence the failure of recording.

Due to the astrocyte form of glia, the electrode gets sheathed hailing from the neurons nearby and thus causes obstruction in the diffusion or increase in impedance thereby resulting in a larger distance between the electrode and the neuron target, causing inhibitory potentials leading to farther move or regeneration of the active neurons from the recording environment. This further leads to electrode insulation since to achieve the signal from the electrode it must comply to the limit of 100micrometer range. To get past these limitations, protein functionalization, electrode design, biological coating, fluid delivery are the areas being researched upon.

3.1.4 Electrode Placement

Each brain consists of different cluster of nerve cells which makes it hard for researchers/ neuroscientists to generalize a position for placing of the electrode. Based on the electrode positioning BCI can be classified as Invasive, Semi Invasive Non-Invasive.

Invasive: In this process the electrodes are placed inside the grey matter of the brain.

Semi Invasive: In this process the electrodes are still placed inside the brain but on the surface of the brain.

Non Invasive: In this process the electrodes are placed on the scalp and thus considered the safest approach.

EEG or electroencephalography which is a method for non-invasive follows a 10-20 system for electrode placement. This indicates the electrode pair which is adjacent should be either 10% or 20% of the scalp diameter's distance. The other techniques (Fig.10) involve intense clinical trials to identify placement location for desired activity.

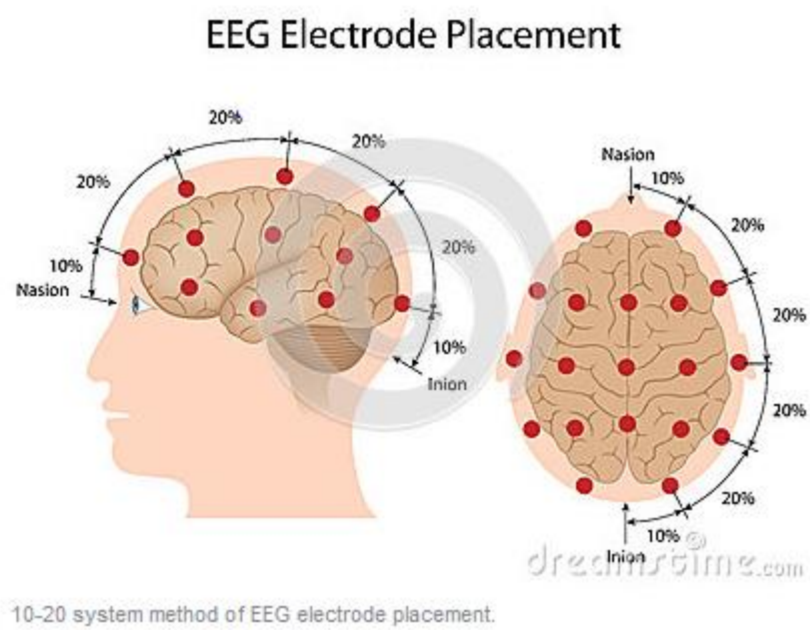
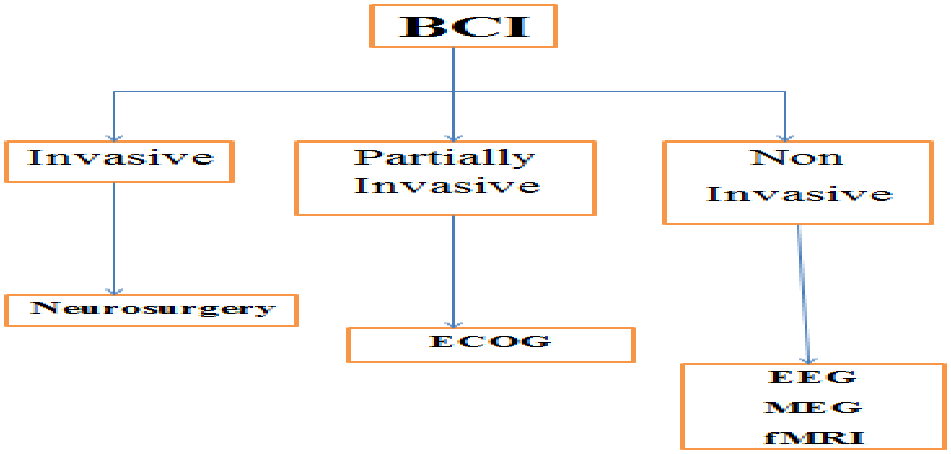


Figure 9: 10-20 system of electrode placement for EEG

http://www.dreamstime.com/stock-photos-eeg-electrode-placement-image29444803

3.1.5 Classification of Implants

Based on the electrode placement the implants are classified and the procedure for each type is discussed below.



ECoG: Electrocorticography

EEG: Electroencephalography

MEG: Magnetoencephalography

fMRI: Functional Magnetic Resource Imaging

Figure 10: Implant Classification Types

Invasive: Neurosurgery is the technique to have the electrode implanted inside the brain. The surgical process can take up to 8 hours. Here, the electrode is directly inserted into the grey matter. This technique allows recording of individual neuron. Since the electrode is closest to the neuron compared to other techniques, highest signal quality is achieved. But this tends to fall off getting weaker due to building of scar tissues due to reaction of foreign objects in the brain.

Semi-invasive*:* This process is similar to non-invasive EEG except that the electrodes placement is below the Dura matter (outermost connective tissue to scalp comprising of fat) and above the cortex in a thin layer of padded plastic. So, this implies the brain's activity is recorded from below the skull.

Method: ECoG (Electrocorticography)

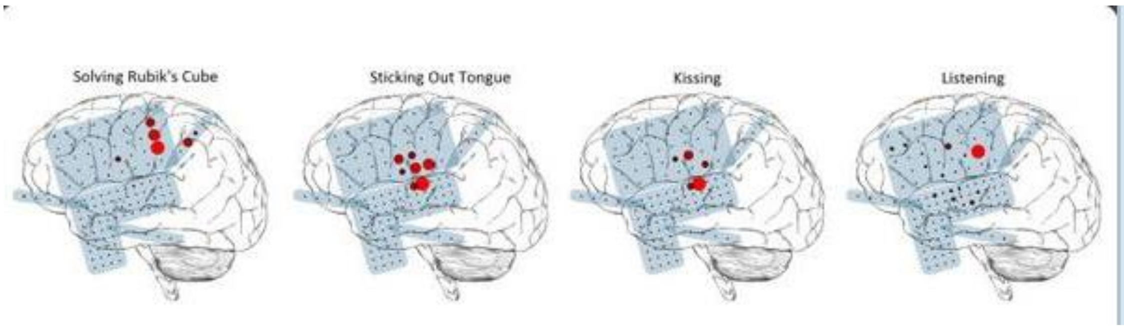


Figure 11: ECoG measuring different activities

http://www.gtec.at/Products/Complete-Solutions/cortiQ-Specs-Features

In this technique, an electrode grid i.e. 8*8 array or strip of platinum electrodes around 1.2 to 2.3mm diameter which are separated by 3mm to 1cm is placed in the brain through surgical incision. There exists several thousands of neurons below each electrode. The brain signals are recorded in the form of current shift per min. Then a graph of log power to frequency is plotted. Decrease in power in low frequency component implies rest period and an increase implies movement of the limb.

Non Invasive: This type is in more common. Here recording activity of the brain is from the scalp. Some of the techniques for this include EEG (electroencephalography), MEG (magnetoencephalography) and fMRI (Functional Magnetic Resource Imaging). Below is a representation of the non-invasive type of electrode placements.

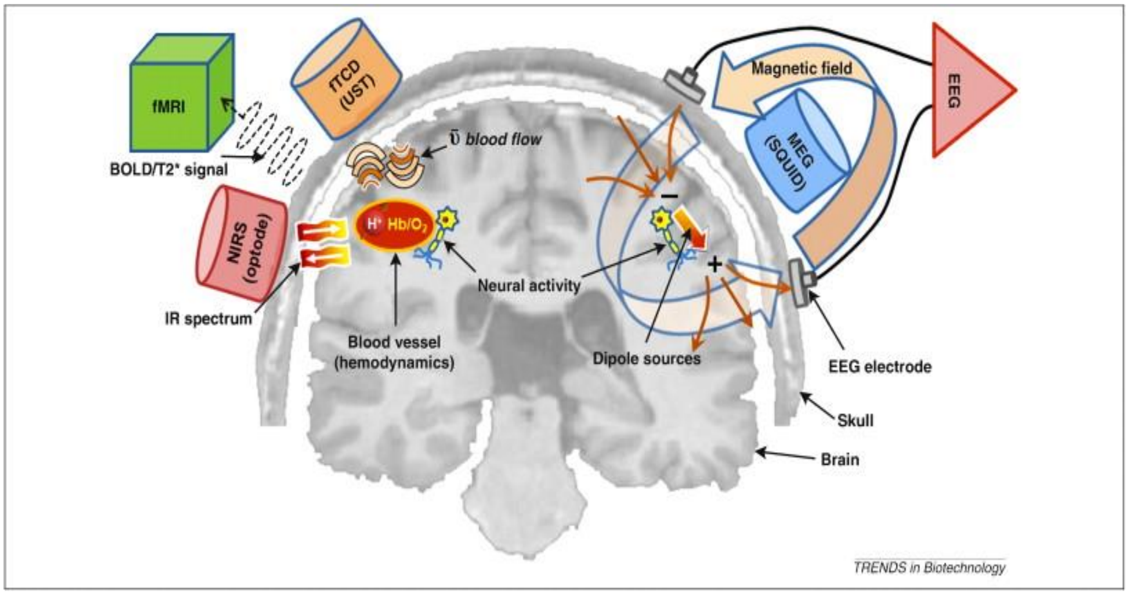


Figure 12: Non Invasive Implant Examples

http://www.cell.com/trends/biotechnology/fulltext/S0167-7799%2810%2900138-1

This figure conveys how the neural activity is being recorded for each technique. Out of the various techniques shown, 3 main techniques (EEG, MEG, fMRI) are described below. The dipole sources are shown to indicate current flow amidst the blood vessels and flow of blood.

Method: EEG (Electroencephalography)

Most non-invasive techniques use EEG since its setup cost is low and is simple. The procedure for this includes electrodes placed on the scalp; thus indicating a comfortable process. The setup is attached to the scalp by conductive gel which needs to be washed on completion. The gel is specially maintained for acceptable SNR.

Here, single neuron's activity details can't be obtained. The drawback for this is when there are recordings outside shielded rooms, it produces noise. Also, amplitude characterization is by few volts which is small. They can be classified into evoked and spontaneous types. First voltage gain is calculated after which filtering and amplification takes place. Then the analog signal is converted to digital. The gain in voltage is then measured and used to calculate SNR with caution to decrease the noise. After this, the signal gets processed undergoing time-division type of multiplexing and finally broken into samples. The EEG signal is measurable in microvolts within millisecond range.

Evoked: These refer to immediate action of the brain cells to external reactions. Mainly used for controlling devices like robots. They are limited to certain tasks due to the interference of the externa stimuli in an unequal fashion. They are further divided mainly into P300 and SSVEP or the steady state visual evoked potential [14]. While the SSVEP measures the signal fluctuation of the neuron (stimulus based reaction); P300 deals with order processing like discovery, categorize, decision making). The 300 is the max process time till when the cognitive activities can be recorded and is measured in milliseconds. The evoked response time is a minimum of two seconds and above for latencies.

Spontaneous: These refer to functional tasks by the subject based on his interest. These are more preferred to evoked types since analysis of the patterns would lead to accuracy. They are further subdivided into slow potential shifts and variations of rhythmic activity. Here the maxima and minima of the wave keep varying and is hence not time-locked. The response time for rhythmic variations is 0.5sec for latencies.

Since every electrode generates a large amount of data the analysis is a bit difficult with different waves characterizing into different shapes and frequencies. These waves are sinusoidal.

The output waveforms for analysis include:

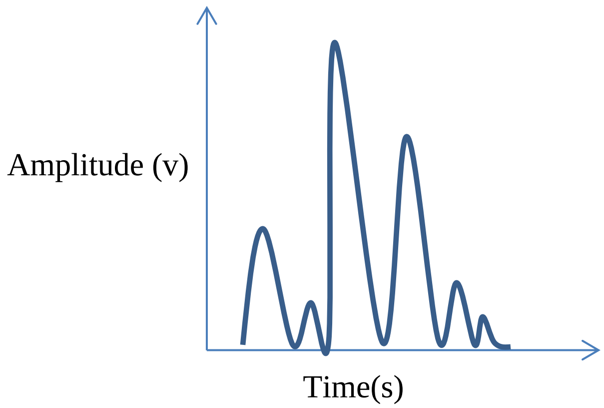


Figure 13: Graphical analysis for EEG

Alpha

Range: 8-13HZ

Here, the amplitude is between 30 and 50V. They focus on awareness, relaxation and attention. The amplitude is reduced when there are sudden jerks or something unfamiliar around.

Beta

Range: 13-30HZ

This relates to focus, inquisitiveness etc. Here, the amplitude range is between 5 and 30V. If there is immense amount of thought process the frequency can reach a high up to 50Hz.

Theta

Range: 4-7HZ

This waveform is associated with emotional changes majorly anger/sadness and also unconsciousness, deep meditation. Here, 20V and greater is the threshold amplitude

Delta

Range: 0.5-4HZ

This is used during moments of sleep or waking up. The actual signals reside in deeper area of the brain causing attenuation which confuses with manual signals due to the muscle and jaw activity which produces larger signals.

Gamma

Range: Equal and above 35HZ

This frequency band helps in rebuilding the sense of consciousness over time by binding together different brain functions.

Mu

Range: 8 – 12HZ

These waves start diminishing during movement. This is similar to alpha wave but the recordings is over occipital cortex.

Among the above waveforms, alpha and Mu are favorable due to ease of varying the amplitude change.

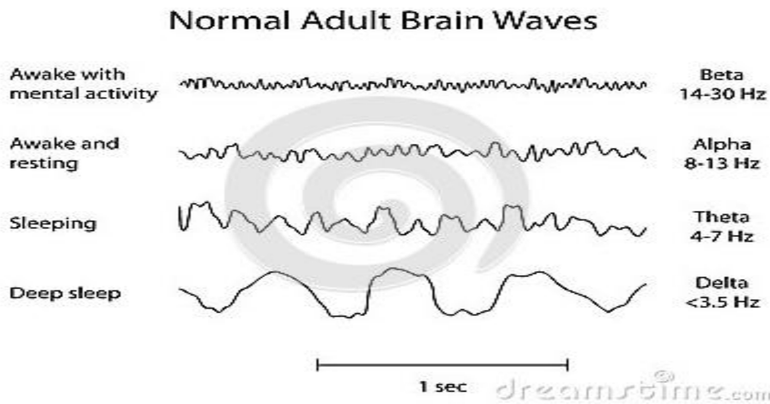


Figure 14: Normal Brain waves of an adult

http://www.dreamstime.com/royalty-free-stock-photo-normal-brain-waves-eeg-image29444815

Method: MEG (magnetoencephalography)

Each neuron in the brain have electrochemical properties which indicates flow of charges through the cell. The current flow generates electromagnetic fields where the magnitude can be negligible. The magnetic field generated from multiple neuron's excitement is measured outside the head. The size of these neuro magnetic signals are extremely small of billionth compared to Earth's magnetic field. So, the MEG scanners also are advocated with SQUID's (superconducting quantum interference device) which are placed into liquid helium cooling unit of -269 degreeC. Since this allows low impedance SQUID's detect the magnetic fields and amplifies them. They can be obtained in sub millisecond range and have no noise.

Method: fMRI (Functional Magnetic Resource Imaging)

This is a diagnostic tool and helps fast scanning of the brain using echo planar imaging. With the cross-sectional images it not only showcases the active areas of the brain but can also tell if there are changes in brain activity. This can be done due to the high scanning speed of 1-2sec. The measurement is the magnetic difference comparison in oxygenated blood to deoxygenated blood. Ratio for oxyhemoglobin to deoxyhemoglobin is calculated which is higher in the active region due to more Oxygen. The recorded signals get preprocessed to address artifacts and then the processed info is analyzed with different machine learning algorithms.

Neuroimaging method	Activity measured	Direct/Indirect Measurement	Temporal resolution	Spatial resolution	Risk	Portability
EEG	Electrical	Direct	~0.05 s	~10 mm	Non-invasive	Portable
MEG	Magnetic	Direct	~0.05 s	~5 mm	Non-invasive	Non-portable
ECoG	Electrical	Direct	~0.003 s	~1 mm	Invasive	Portable
Intracortical neuron recording	Electrical	Direct	~0.003 s	~0.5 mm (LFP) ~0.1 mm (MUA) ~0.05 mm (SUA)	Invasive	Portable
fMRI	Metabolic	Indirect	~1 s	~1 mm	Non-invasive	Non-portable
NIRS	Metabolic	Indirect	~1 s	~5 mm	Non-invasive	Portable

Figure 15: Neuroimaging methods summary

https://www.evms.edu/patient_care/specialties/ear_nose_and_throat_surgeons/patient_education/hearing_and_balance/cochlear_implant/

3.2 Signal Processing

Next steps are to process the signals and the method of examining this signal is known as feature extraction. Those are then translated into commands which is known as signal translation. Combined, they help in controlling the signal and these are done via machine learning algorithms, filters, neural network concepts, various toolsets. The functional mapping is based on spatial and temporal characteristics. They are statistically analyzed with sampling as the basis for signal strength.

3.2.1Algorithms and Filters

There are certain algorithms used for identifying the strengths of the participant and then with the help of other algorithms they are used for classifying the relativity to the output device. Below is a chart showing some of the most common algorithms used. They are classified into three types. Based on the researcher's choice of analysis he could pull up desired factors and appropriately choose which type of algorithm is needed. This section is most complex and challenging.

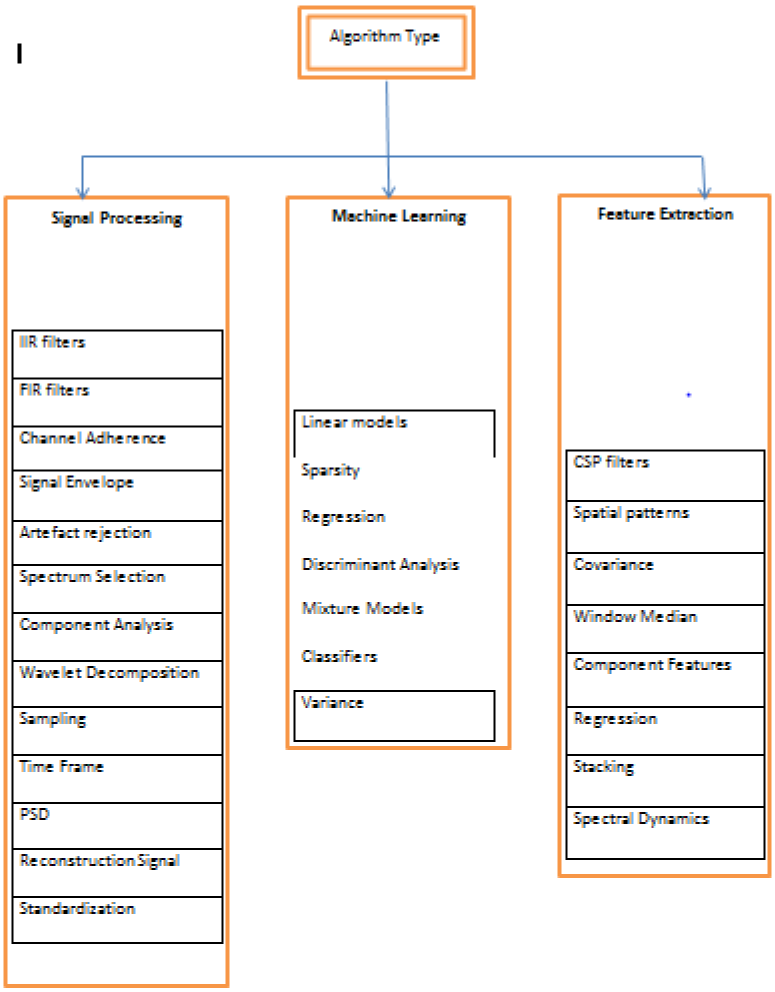


Figure 16: Different algorithm types

The above chart for the different algorithms is given in the next chapter. Researchers have identified time-frequency, temporal-spatial analysis as a way to learn the subject's strength. For time-frequency analysis, FT (Fourier Transform), wavelet transform, AR (Autoregressive model), KF (Kalman filter) are some of the recurrent techniques. For temporal spatial analysis, LF (Laplacian filter), CSP (common spatial patterns) are the common approach. The other general filters include low pass and band pass.

Time-Frequency Analysis:

Fourier Transforms: Derived from Fourier series, this represents a sinusoidal function of a larger signal sampled from smaller waves. The equation derivations are given in [17]. They denote time function by representing frequency domain of the original signal. This model uses a linear approach.

Wavelet transform: A wavelet can be defined as oscillation waves of amplitude wrt time. Parameters obtained from this helps in determining minimum, maximum signals, zero crossing point. They can broadly be divided into Continuous and discrete. The main function of this technique is to fragment signal in both frequency, time domains. It helps in studying of discontinuous signals. Some of the applications for this technique include pattern recognition, epilepsy, Alzheimer's disease, hyperactivity disorder etc.

AR model: This method relies on linear average of the previous values using linear regression equations. Here time domain gets converted to frequency domain where spectral amplitudes are obtained and coefficients are determined. Applications for this include controlling a cursor by using μ, β waves.

Kalman Filter: This technique is used to determine noisy measurements using quadratic equations. Here. The inputs are in series and recursive with which a variable is determined indicating noise. This is then adjusted to the weighted mean thus proving efficient for analysis in real time. It helps in identifying the position and momentum. Applications for this include hand forces in non-humans.

Temporal-spatial analysis:

CSP (common spatial patterns): This algorithm uses statistics and derives information from data. This works on the eigen value approach. They help in analyzing spatial patterns for movements involving hands and foot. The mappings were developed with the help of pattern vectors and linear analysis.

Laplacian Filters: This is mainly to increase signal to noise ratio. This doesn't have dependencies on prior learned information for its calculations. It is focused to normalize the output by taking the boundary off from the actual object and applying it in a kernel with Gaussian value.

3.2.2 Neural networks

The human brain comprises of interconnected neurons which are constantly transmitting information between different brain cells, blood vessels and forming a network. Neural networks represent models to help process information like classification of data, pattern recognition etc. They develop by real time experiences on the fly and has dense interconnecting elements. It is calculation based neuron firing depending on the input.

To understand the complexity of brain's way to adapt learning this theory was introduced. Initially a Perceptron (computational model) can be defined for a situation. This model has many inputs going to a processor with only one output as the result. When the inputs with different values enter the processor they are multiplied by weights (a number between -1 and 1). Then the weighted inputs get summed up and generated as output. In cases where there are two inputs and both being 0 gives 0 output which may not be true and can give wrong results. In order to avoid this another input was introduced named Bias input whose value is always 1. This helps in defining accurate results as it is also weighted. Once perception gets defined it can be coded which helps to store and repeat. The steps involved for the coding include – Defining perceptron class and giving inputs to the perceptron, check if perceptron able to guess the answer, calculate errors if any (error is given as the difference between required output and guessed input), adjustment to weights based on error, repeat first step. The above is a basic linear model. More complex models on neural networks can be defined for 3D data, hidden data, non-linear models etc. [15], [37].

3.2.3 Toolsets

These tools help in building and analyzing machine learning algorithms. Some of them are as follows:

BioSig: This is the oldest open source BCI tool. It was developed in 2002 which uses Matlab for its analysis. Since it does not have GUI and the code is complicated it is not user friendly. There's no real time behavior exhibited. Some of the algorithms it uses are adaptive auto regression, common spatial patterns with classifiers.

BCI2000: This was developed in 1999 at Wordsworth Center and uses C++ code for its analysis. It features real time acquisition, equipment control and hardware support of 19 systems. The drawbacks for this include no advanced processing as .var files are restricted.

OpenVibe: This uses C++ along with visual and dataflow programming. It has user friendly documentation and supports hardware of up to 15 systems. It can run on windows or Linux. The drawback for this include weak support for machine learning algo. The graphics are good since it supports GUI.

g.B.Sanalyze: This is a commercial tool developed by g.Tec and uses Matlab for its simulation. This includes a broad range of algorithms and evaluation methods. It also features in-house amplifiers and has a high quality GUI.

BCILab: This was developed in 2010 at SwartzCenter which uses Matlab based cross platform. It has one of the largest collection of BCIalgo. This is being worked on to extend their framework to support real time behavior.

Certain others include **FieldTrip**(MEG toolbox with online features), **PyFF**(Python based BCI stimulus presentation and has easier feedback code) **BCI++**(new C++ system with a focus for virtual reality).

3.3 Device Output

For analysis purposes, algorithms based on spike detection, encoding/decoding systems etc are used. With all the setup in place, a primary factor for this technology involves feedback and its accuracy. They are the base for controlling of responses and can help in increasing the performance by speeding up the discovery or learning process. After the analysis from the computer, the result is fed to the device to generate required output say controlling of cursor, moving of limb etc.

Types of BCI Systems: Based on the analysis and computation there exists types of BCI. The various subtypes in BCI are given as

Active BCI: In this case the output obtained from the activity of the brain has the user's control in conscious. In other words focusing on a thought and manipulating it.

Example: Limb movement

Reactive BCI: In this case the output obtained from the activity of the brain is a reaction to the external stimulation where the user modulated to control applications. In other words, utilize brain processes functioning in external event.

Example: Flickering light

Passive BCI: In this case the output obtained from the activity of the brain has no voluntary control.

In other words, picking any random process and utilize in interaction.

Example: Excitement levels

3.4 EEG as an example

Since EEG is the most widely used technique for BCI, it is taken as an example. Below figure represents the block diagram for EEG. The hardware and software for this BCI approach are classified as follows:

Hardware:

- Consists of the EEG setup and its electrodes.
- Responsible for recording the signal

- Placement over the skull zone and connections to the external device.

Software:

- Consists of algorithms like FFT or fast fourier transforms, classifiers like AAN or artificial neural networks etc.
- Responsible for analyzing the input of the subject like its intensions and generating respective output by interpreting the information with the help of classifiers.
- Placement varies with the type of need chosen.

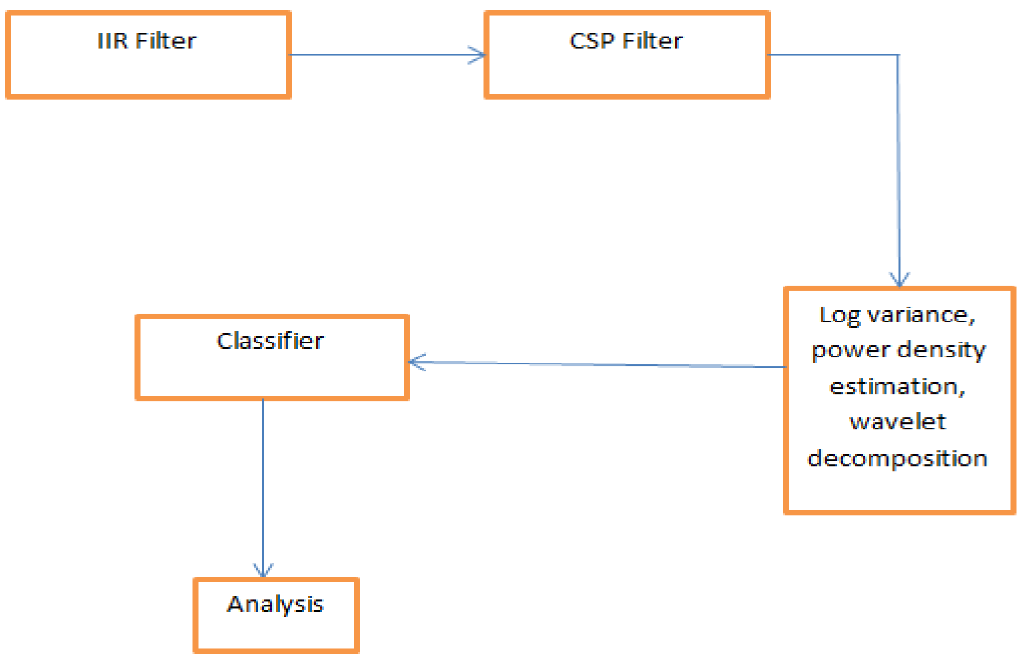


Figure 17: Block diagram of EEG analysis

IIR and CSP filter combined form the preprocessing block.

IIR stands for Infinite impulse response and works as a bandpass filter. It is basically to eliminate the frequency range outside α and β. CSP stands for common spatial patterns which separates multiple signals having larger differences in variance into smaller components.

Log variance, power density estimation, and wavelet packet decomposition combined form the feature extraction block.

The feature extraction measures include log variance (used for approximating values during computation), power density estimation (used for measuring relative parameters in the spectrum for algorithms), wavelet packet decomposition (sampled signal based on time is further sent through different filters).

Analysis and feedback block comprises of classifiers. Classifiers are used to shadow large vector dimensions and combines different object classes. A well noted example for a classifier is the linear discriminant analysis wherein the characteristics of different events are combined in a linear fashion.

Chapter 4: Cochlear implant

Cochlear implant can be defined as an electronic device implanted cynically and is responsible for restoring a person's ability of hearing to its utmost by providing sense of sound with the help of a speech processor. Users of implant have default allocation of frequency to electrode strategies which can result in frequency mismatch. The design of electrodes and the process of implant showcase its own flexibility for each individual. This is due to the fact of an individual reacting differently to divergent disciplines.

In the normal hearing process, the sound signal moves along the three parts of an ear namely outer ear, middle ear and inner ear. The sound is initially collected by the outer ear where the sound strikes the canal and is directed towards the eardrum causing vibrations. This follows a reaction in the middle ear involving three tiny bones whose motion brings about fluid in the inner part of the ear, namely cochlea. During the moment of the fluid the hair cells move back and forth which causes triggering of electrical impulses to be sent to brain where they are processed and thereby the interpreted sound is heard.

If the hair cells are damaged, the sound is not heard. The degree of hearing loss depends on the amount of hair cells damaged. If the candidates suffer from mild/moderate hearing loss then the hearing aids can take care of the needs. But otherwise an implant is done where the sound is captured by the microphone and delivered to implant's electrodes present in the cochlea from the speech processor in the device.

Cochlear implant, designed for bypassing damaged areas of the inner ear is divided into two sections:

1) Internal part: consists of receiver, electrodes
2) External part: consists of transmitter, speech processor

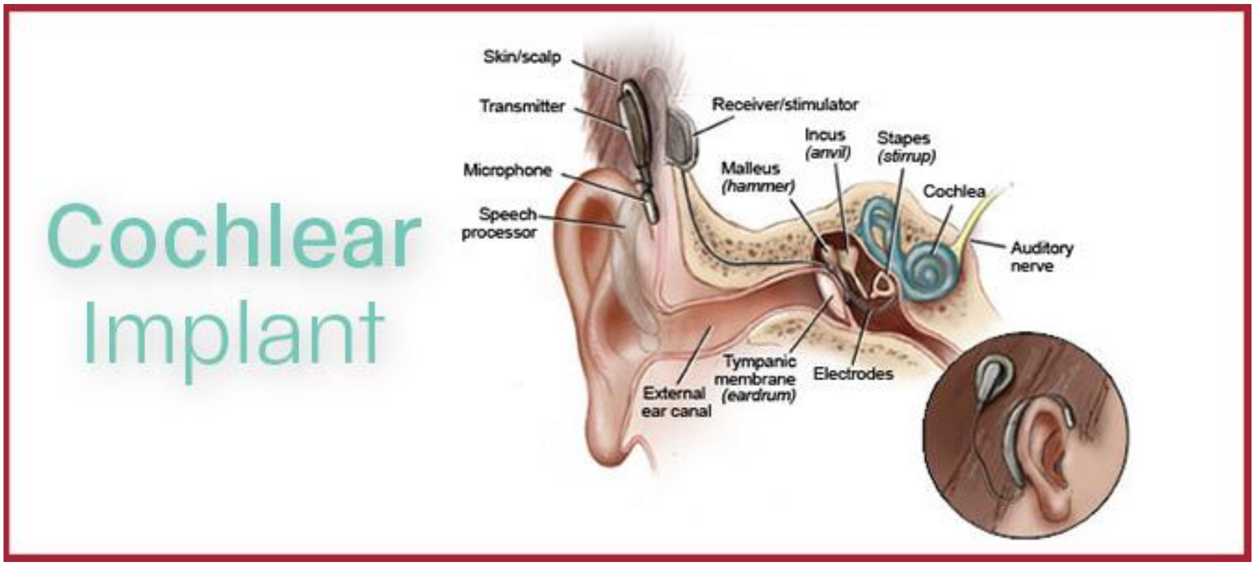


Figure 18: Structure of Cochlear Implant

http://kidshealth.org/en/parents/cochlear.html

The receiver's purpose is to convert sound signals to impulses and direct them towards electrodes by an internal cable. It is placed under the skin on the bone's surface where a space is made during the surgery. The array of electrodes which is placed inside the inner ear skips the hair cells which are damaged thereby stimulating the hearing nerve followed by sending of signals via auditory nerve system.

The transmitter which works on the principle of electromagnetic induction helps in power transmission and also processes the signals towards internal device. Its placement is to the back of the external ear where the coil is adhered by magnet by the principle of attraction to the internal receiver. The signal from transmitter to the receiver is via RF link across the depth of the skin. This RF link consists of inductive coupled coils for both data and power transmission. The purpose of the speech processor deals with splitting of sound and sending the electrical form of the signal to the transmitter over a thin cable.

The implant can be of either single channel or multi-channel. For single channel implants the electrical stimulation occurs at each site of the cochlea using an electrode. For multiple channel implants the stimulation occurs with the help of electrode array. The electrode array helps the nerve fibers to get stimulated at various sites inside cochlea advocating frequency coding techniques. The frequency which is responsible for stimulating the electrodes is criterion for determining feature extraction strategies. This is the preferred method compared to waveform strategies. Section 4.4.2 provides insight to some of the current day techniques.

A recent research brought up another way of implementing the process. Initially, the sound travels as usual to the eardrum via the ear canal and thus produces vibrations. The point at which the eardrum gets secured with malleus or in other words the umbo, there exists placement of a tiny accelerometer which collects those vibrations. This accelerometer is adhered to the chip providing a combination of a microphone which collects the vibrations of the sound and thereby converting them in electrical signals which reaches cochlea through electrodes.

Damaged circuit of the cochlea jump over to auditory nerve with the help of encoder-transducer. There are several codes used for the purpose of experiment. In such cases, the results are usually found to be better than normal prosthetics.

The detailed description flow of each part of Cochlear Implant can be found below:

4.1 Internal Components

4.1.1 Receiver-Stimulator

This is part of internal components and otherwise called as internal coil. The placement of this includes in the flat part of the skull and the auricle (pinna). Receiving power it decodes information from the speech processor. Its function is to change the electrical signals to digital form and back to electrical; then pass it to electrodes in cochlea. The stimuli info is received by RF transmission via the external coil from the headpiece.

4.1.2 Electrode arrays

Auditory nerve fibers are stimulated via electrode array. Sound energy is transformed to electrical energy by the internal implant which will cause the auditory nerve to stimulate by initiating impulses. It completely depends on individuality for absorbing speech perception mapping to the number of electrodes in the array. Multichannel devices can contain up to 22 electrodes as active. Research indicated that if the electrode is placed close to the ganglion cells (spiral ganglion – see Fig. 19) the stimulation for auditory nerves is at its best.

If the electrode is placed near the Modiolus (see Fig. 19) which can be done by inserting pre-curved array response from the auditory nerve requires lesser current which drives in for lesser power and hence has lesser channel interaction. For lesser traumatic insertion, lateral wall electrodes are preferred. Shorter electrodes are inserted ion those patients who have severe hearing loss. Here residual hearing of low frequency is preserved. The patients combine their low frequency hearing along with high frequency stimulation. Double electrode arrays are characterized for cochlea which are stiff and bony.

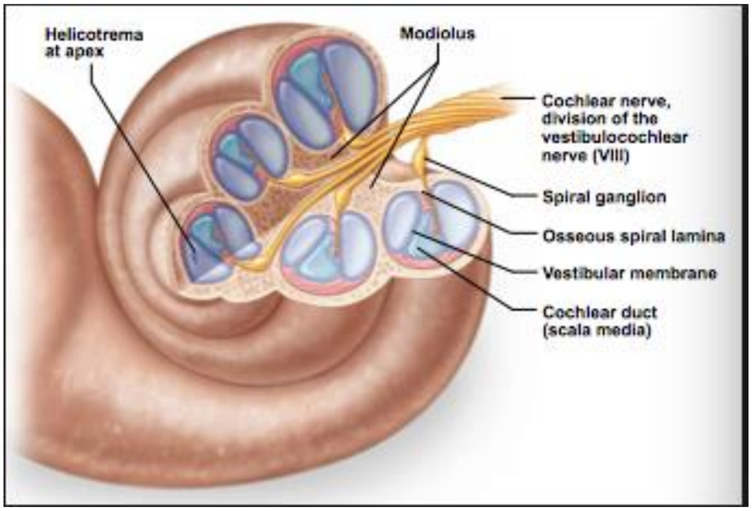


Figure 19: Parts of cochlea

https://www.google.com/search?q=parts+of+cochlea+image+studyblue.com&biw=1920&bih=903&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwjFkYHXqL_OAhVBy2MKHWhFA98QsAQIGw#imgrc=uIZFyhbvqqhACM%3A

4.2 Stimulating Electrodes

The two electrode stimulation modes are Monopolar and Bipolar.

Monopolar: Here every electrode gets stimulated with reference to a ground electrode. This electrode is remote from the cochlea and can be found in the internal device or on a tube which extends from the receiver-stimulator. Amount of current required is lesser than bipolar. This mode is the default stimulation for contemporary implants.

Bipolar: Here the intracochlear electrode gets stimulated with another intracochlear electrode where the flow of current is among the electrodes with one being the grounded electrode.

Number of electrical pulses (current) in a second provided to the contact electrode is defined as Stimulation rate and is measured in pps (pulse per sec). The stimulation rates for earlier implantinmg devices were lower 250 pps and lesser compared to the present implants generating upto 5000pps. High pps rates represent >2000pps help in obtaining finer amplitudes by exciting more nerves. However, optimal rate of stimulation varies with the individual.

4.3 External Components

4.3.1Microphone

This device catches incoming sound and process it by converting the variations in pressure to electrical format and then sent to a preamplifier in order to get a higher SNR.

4.3.2Speech Processor

The sound from the microphone is developed into an electrical stimuli and sent for analyzing to a DSP where input signal is segregated based on different domains like frequency, time, and intensity. These are constituted at the cochlear nerve. The electric signal is then transferred from the speech processor to the headpiece by means of a cord. The processor runs on batteries (rechargeable/standard) and the lifetime for them surround 12 hours; behind the ear is slightly lesser compared to body-worn. The improvements or changing schemes to this technology can be done by updating the software (soft refresh) in the processor or replacing it as a whole.

4.3.3 Headpiece

Here, the external coil is maintained on top of internal coil by magnets. It transmits electromagnetic signal via RF to the receiver-stimulator which acts as a power supply to the internal stimulation.

4.4 Measurement Factors dependency

4.4.1 Mapping

The mapping is based on two parameters which are thresholds (minimum sound identification), level of comfort (maximum or loudest sound). The electrodes are programmed based on these. Telemetry also comes in to play while designing as they deal with providing status information, stimulates nerves, record potentials etc. It is also termed as NRI or Neural Response Imaging in the world of Advanced Bionics.

4.4.2 Frequency Coding

Coding techniques help in providing different information wrt speech and hearing. The parameters of the code are modified in a way to match up the patient thus enhancing his communication. Previous approaches relied on formants () which are depicted as resonances in a wideband spectrum. The coding mechanism had combinations of various formants say F1, F3 etc with reference to fundamental frequency F0. The calculation was done as F0/F1, F1/F3, F0/F1/F3. Here F1 represents the highest energy of resonance, F3 third highest and so on. The frequency bands were overlapping and utilized simultaneous stimulation. The resonance from the vocal tract involved selective extraction   The extraction processors included Wearable Speech Processor and Mini Speech Processor for some individuals who had a better response.

Another strategy included analog compression technique wherein the band filter was divided into various acoustic information bands where the amplitude relativity was maintained and sent over to electrodes. In this technique, the stimulation of electrodes were simultaneously done which caused heavy channel interactions in amplitude and frequency thus leading to a high power consumption.

Neural firing is another technique as a speech coding mechanism. A neuron gets fired when it is sufficiently stimulated to conduct the action potential. The neurons travel all over unsynchronized within the auditory system in a normal hearing process. When the neurons are stimulated with low pulse rate they initiate synchronicity as part of the implant. Continuous Interleaved Sampling and high stimulation rates have been developed to maintain the same relativity as of the natural hearing.

Continuous Interleaved Sampling are the higher rate stimulation coders and is popular with the implant manufacturers since the domain gets updated quickly and the improved performance results have been demonstrated. The pulses do not overlap and are picked up only at the peaks. It relies on filters in order to provide the shape of the signal and uses non-simultaneous stimulation to reduce interactions between electrodes.

Compared to the above fixed location of electrodes may not be that effective in responsivity due to different neuron density in different people. Also depending on insertion depth number of sites are calculated. But a major disadvantage in this technique is the ability to program therefore limiting the performance.

Paired Pulsatile Sampler stimulates 2 channels at once so the rate of repetition is obtained by lesser channel interaction. It uses the paradigm of bin averaging for waveform extraction. This technique differs from CIS strategies by electrode pair sets (1/5, 2/6, 3/7 and so on...) and within each pair both the electrodes get harmonically stimulated. The mode of coupling for this is always monopolar and it requires low current. Due to the fact that pairs of farther electrodes get simultaneously stimulated and pair itself in a non-simultaneous fashion leads to doubling the rate of stimulation with minimum interactions for the stimulating electrodes. Another name of this technique is Multiple Pulsatile Sampler.

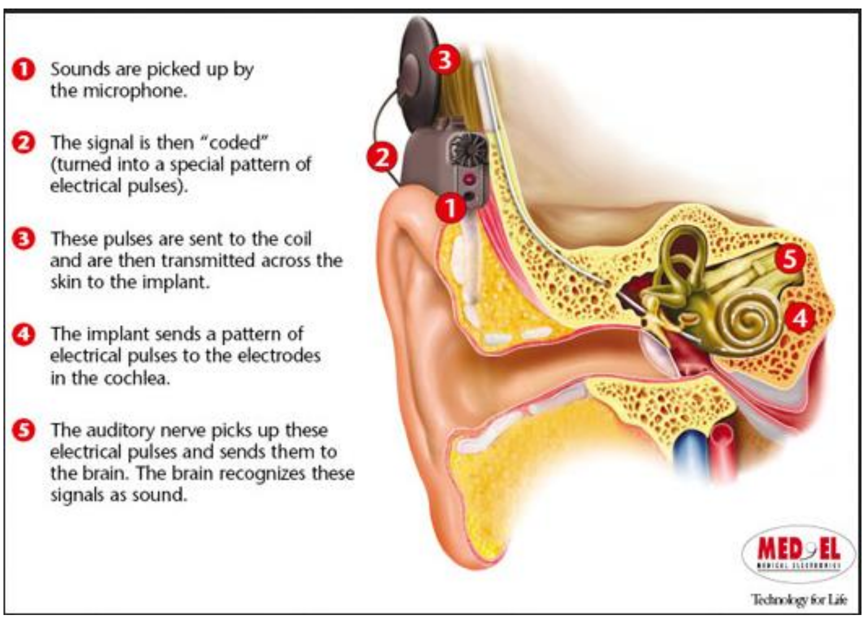


Figure 20: Description of Cochlear Implant

https://www.evms.edu/patient_care/specialties/ear_nose_and_throat_surgeons/patient_education/hearing_and_balance/cochlear_implant/

Chapter 5 Wireless Approach

5.1 In BCI

The wireless approach to this technology was first tested in animals like pigs and monkeys. Main advantage for wireless is that the subject is in free motion and need not be wired to the computer. The device setup is done in a cap/headset which is attached to the subject's skull. The headset consists of a processor for signal amplification, gyroscope for controlling cursor, digitized circuits and radio for communication with the receiver. The first wireless bci's factors are transmit range is about 24Mbps, receiver distance can range up to few meters, frequency range 3.2, 3.8 GHz, power 100mW.

Along with the headset one also receives a game/task handler where the subjects are needed to perform various activities (ex. Dropping of object, Pushing an object etc.) so that the electrode in the headset does the recording of brain wave patterns. The emotional states like meditation, excitement etc. are auto recognized based on theta waves. Once the pattern is known it is stored as a function for its future interpretations.

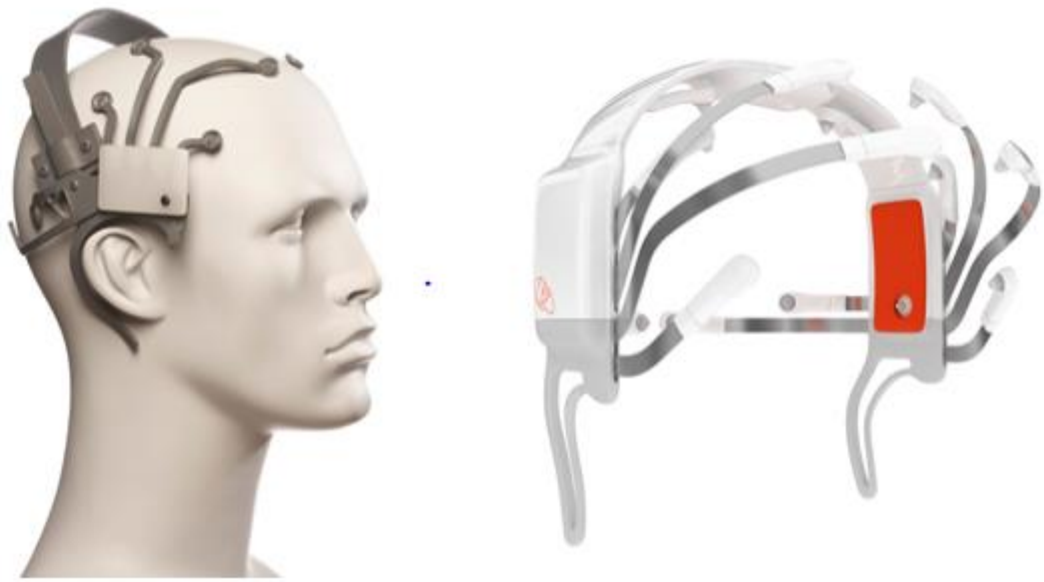


Figure 21: BCI wireless headset

https://www.ideo.com/work/epoc-headset

The above has been rolled out in 2008 and is mainly focused for gaming. Researchers have also developed the neural interface microsystem which is more stable and is designed for social interaction. Here, the translation for machine learning algorithms is hosted in a laptop/PC.

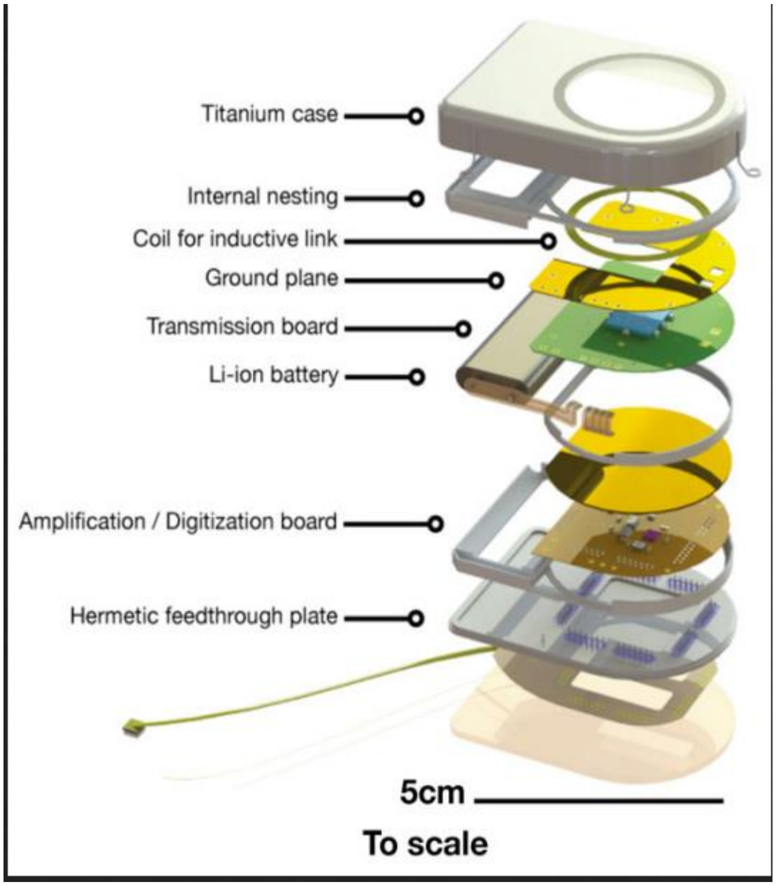


Figure 22: BCI wireless neural interface structure

http://www.extremetech.com/wp-content/uploads/2013/03/wireless-bci-exploded-view.jpg

The steps involved in the signal processing for the above figure include:

1) Initially a chip of electrodes are implanted in the motor cortex.
2) The sensor is responsible for picking up impulses from the neurons.
3) The process and transmission of the neural data is done via the titanium case components.
4) The processor in the case helps to amplify the spikes, digitize the info and then transmit.
5) This is then fed by a wireless link to the receiver which thereby becomes the control signal in the computer.
6) Algorithms from multiple choices are chosen based on the desired action to drive the required commands.

Here the BCI's factors are transmit range of 48mbps, power of 30mW. Recently, the device has been commercialized for humans. The device is known as Cereplex – W and is sold to research labs. It costs around $15k. Below illustrates how Cathy, a volunteer for the BCI study was successful in drinking coffee with her mind.

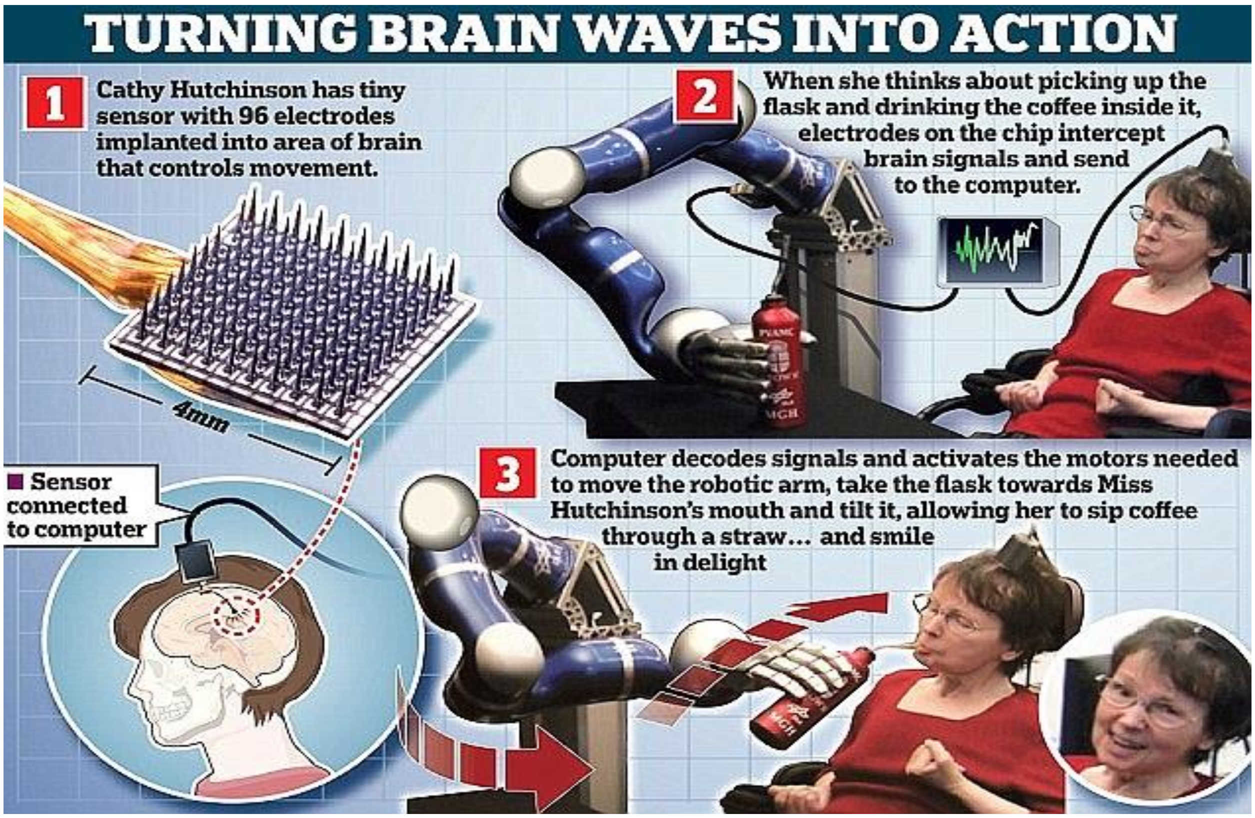


Figure 23: Example of BCI wireless

http://www.dailymail.co.uk/sciencetech/article-3254682/Controlling-computer-MIND-Paralysed-patients-screen-cursor-using-just-brain-waves.html

The explanation from figure 22 is the basis for signal processing in this case. The researchers from Brown University had accomplished this [32].

5.2 In Cochlear Implant

Maestro's system of cochlear Implant contains audio processor which is worn externally while the placement of the implant is under the skin through a surgical process. The audio processor and the implant combined works fast and go hand in hand. An electrode deep inside the cochlea is inserted which helps in electrical stimulation of large number of frequencies. The microphone in the audio processor picks up the sound. Then the audio processor does analysis and forms a digital pattern representing electrical signals of sound. This transmitted code is then forwarded to the implant which is placed surgically inside the skull creating electrical pulses. It is then relayed along the electrodes. The hearing nerve transfers these pulses to auditory cortex in the brain where they are distinguished as sound.

There has also been invention of the MIT chip which helps in middle ear implant a little variation to the conventional cochlear implant. Its sole purpose is to replace external parts and utilize the natural microphone from middle ear. A sensor is implanted in the middle ear and is used to sense bone movements from which the signal is transmitted to the chip. The chip then helps in converting signals into electrical stimuli which travels from the electrode into the cochlea and then get stimulated allowing hearing for the patients. The chip requires a smaller setup and low power. The charger of a smartphone could be used for charging in less than 2min. Alternative to the above is usage of accelerometer for sound detection in the middle ear by university of Utah.

Cochlear implant has made progress in the wireless approach by developing its components. This illustrates how scientists were able to prove that their cochlea chip by introducing biological battery for self-charging which eliminates the need for power from an external source[27]. Additional features for sound processor have been implemented in SmartSound IQ to improvise the hearing. The main focus for this was adjusting automatically to different sounds. The frequency requirement here was 2.4GHz. The wireless cochlear also helps in pairing external devices like iPod, phone etc. using technology such as Bluetooth, NFC etc.

Chapter 6 Conclusion and Future Scope

6.1 Applications of BCI

This technology leaves a strong impact in numerous fields such as:

Medicine: Mainly focused for disabled people, treat diseases such as Parkinson's etc

Science: Movement control of robots, devices like wheelchairs etc

Gaming: Developing control channels

Space: Control the state of astronaut from ground (like telepathy), microgravity

Monitoring: Can range from sleep stages to different states of mind

Military: Send out warning signals by a commander to the troop, alerts based on prototypes

Entertainment: Develop user friendly multimedia

6.2 Challenges

In BCI: Each scalp has different on-going types of neural activities. Hence, it gets difficult to find the reaction from thoughts. This technology being under developing stage has many challenges. Factors considerations include:

1) Knowledge Base in operating different theories such as electronics, mathematics etc.
2) Accuracy in measurement of unknown parameters such as sensor placement, reaction times etc.
3) Fine tuning of detectors / algorithms in order to limit the effects of errors to minimum

4) Post stability after the implant leaning towards betterment of the subject
5) Building effective data acquisition systems where the driver software compatibility is of importance.
6) Performances under inconsistent conditions say if the brain is not responding normally.

In Cochlear Implant: The main task for the recipients of the implant will be perception of music.

Frequency maximization is the key area to be addressed which can lead to:

1) General risks such as anesthesia
2) Facial nerve injury
3) Meningitis (swelling of membranes protecting the brain)
4) Fluid / blood leak during the surgery
5) Numbness
6) Effecting other sense organs such as tongue
7) Implant fail risks leaning towards detoriation of hearing making it more worse
8) Upgrade of software for the traditional implant as device has to be surgically removed, upgraded and then put back.
9) Infections

6.3 Ongoing Project Developments

Below showcases some of the current project developments.

Bionic Eye: Treat blindness by weeks of learning from the brain

BrainGate : Owned previously by Cyberkinetics, they focus on prosthetics/paralysis.

Gaming Control: Playing games with mind

Honda Asimo Control: Project where user thinks with mind and controls robot

Nasa's neuro signal study: Integrated tele-operation devices

Neural Dust: Sprinkle electronic sensors of dust particles with a purpose of having low power and high spatial resolution.

Related work for BCI: This technology is being globally embraced and various research centers are established in order to handle BCI in a better way and serve mankind. Certain research groups and labs throughout the world are mentioned in [31].

6.4 Conclusion

This study is being done to learn the model of BCI and its components and taking Cochlear Implant as an epitome. It is seen that BCI is thus an advancing technology with some of the key focuses on:

1) Enhance movement restoration
2) Develop communication devices
3) Control of the subjects during unreachable conditions like fire/water etc.
4) Stepping up a level in the world of gaming
5) Promising R&D for higher level applications

This technology thereby persuades interest towards change of artificial intelligence to a new height involving superhuman power by involving silicon chips which will help in controlling environment. This development needs attention to prevent unimaginable destruction since its aim of controlling objects are at a high involving novel and innovative approaches.

6.5 Future Work

Few of the major limitations that need to be further looked out for approaching a better solution are as follows:

1. Classifying errors/alarms as generalization and providing appropriate solve
2. Improving data transfer rate
3. Effectiveness of the technology as a whole to identify its benefits and make it work right
4. Quality/Quantity of electrodes implanted

5. Replace use of conductive gel to avoid drowsiness and hair wash
6. Support this for people with locked-in syndrome
7. Better wireless transmission techniques
8. Three dimensional analysis for interpretation of brain waves with machine learning algorithms

This technology needs to be expanded and implemented for the betterment of mankind. Hence, security becomes a primary concern. With wireless taking its place directly in the stages where the technology is still being developed, use of secure programming should be the next initiative for protection of the control from malicious users; thus the authorized user has full control over the system/machine. Authentication can also bring in the concept of smart systems binding together different application codes. Another aspect which is trending in today's world is virtualization. So, after wireless fulfillment next step should be eyeing on building of virtual environment. That will definitely bring about the dream of future come true.

References

1. Understanding of EEG from https://web.csulb.edu/~cwallis/482/eeg/eeg.html
2. Md. Ibrahim Arafat 2011 Brain-Computer Interface: Past, Present & Future from http://www.academia.edu/1365518/Brain_Computer_Interface_Past_Present_and_Future
3. What the Frog's eye tells Frog's brain from http://hearingbrain.org/docs/letvin_ieee_1959.pdf
4. Hearing Preservation in cochlear Implant Surgery from http://www.hindawi.com/journals/ijoto/2014/468515/
5. Cochlear Implant Programming: A global survey on the state of the art from http://www.hindawi.com/journals/tswj/2014/501738/
6. Real time BCI with Neurofeedback from http://www.brain.riken.jp/bsi-news/bsinews34/no34/research1e.html
7. Brain-Chip Interfaces: animating the future? From http://biomed.brown.edu/Courses/BI108/BI108_2005_Groups/03/physio.html
8. The neuron from http://webspace.ship.edu/cgboer/theneuron.html
9. Artificial neural network from http://neurosciencenews.com/bioelectronic-artificial-neuron-2157/
10. Researchers create brain-computer interface that bypasses spinal cord injury paralysis from http://oc1dean.blogspot.com/2012/05/researchers-create-brain-computer.html
11. Brain Computer Interface from https://kin450-neurophysiology.wikispaces.com/Brain-Computer+Interface
12. Regeneration beyond the glial scar from http://www.nature.com/nrn/journal/v5/n2/full/nrn1326.html
13. Materials Interactions in brain from http://www.ncbi.nlm.nih.gov/books/NBK3934/

14. Non-Invasive brain machine interfaces from http://www.esa.int/gsp/ACT/doc/ARI/ARI%20Study%20Report/ACT-RPT-BIO-ARI-056402-Non_invasive_brain-machine_interfaces_-_Martigny_IDIAP.pdf
15. Neural networks from https://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol4/cs11/report.html
16. Comparison of three types of dry electrodes from https://www.tuilmenau.de/fileadmin/media/bmti/ieee_2014/Fiedler_Acta_IMEKO_2014_dry_electrodes.pdf
17. Fourier transform from http://mathworld.wolfram.com/FourierTransform.html
18. EEG electrode placement from http://www.dreamstime.com/stock-photos-eeg-electrode-placement-image29444803
19. G.tec's BCI research system from http://www.gtec.at/Products/Complete-Solutions/cortiQ-Specs-Features
20. Trends in biotechnology from http://www.cell.com/trends/biotechnology/fulltext/S0167-7799%2810%2900138-1
21. Normal adult waves from http://www.dreamstime.com/royalty-free-stock-photo-normal-brain-waves-eeg-image29444815
22. Brain Computer Interfaces from www.studyblue.com
23. Brain Computer Interfaces, a review from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3304110/table/t1-sensors-12-01211/
24. Cochlear Implant from https://www.evms.edu/patient_care/specialties/ear_nose_and_throat_surgeons/patient_education/hearing_and_balance/cochlear_implant/
25. Bionic eye and wireless BCI from http://www.extremetech.com/wp-content/uploads/2013/03/wireless-bci-exploded-view.jpg

26. Controlling a computer with your mind from http://www.dailymail.co.uk/sciencetech/article-3254682/Controlling-computer-MIND-Paralysed-patients-screen-cursor-using-just-brain-waves.html
27. Inner ear implant uses biological battery to self-charge from http://arstechnica.com/science/2012/11/inner-ear-implant-uses-biological-battery-to-self-charge/
28. Cochlear releases wireless and automated features for CI from http://www.hearingreview.com/2015/02/cochlear-releases-wireless-automated-features-ci/
29. Cochlear Implant losing their external hardware from http://www.gizmag.com/fully-internal-cochlear-implant/30778/
30. Middle ear microphone helps to improve cochlear implants from http://www.gizmag.com/middle-ear-microphone/22343/
31. Other BCI researches and labs from http://braincomputerinterface.weebly.com/other-bci-researchers-and-labs.html
32. Cathy drinking coffee with her mind from http://gizmodo.com/5910949/this-paralyzed-woman-just-drank-a-bottle-of-coffee-with-her-mind
33. What is cochlear-implant from http://kidshealth.org/en/parents/cochlear.html
34. Human electroencephalography from https://ccsn.uchicago.edu/sites/ccsn.uchicago.edu/files/uploads/Chapter%202.pdf
35. BCI from “Brain-Computer Interfaces” by Theodore W.Berger et al.
36. Wireless BCI concepts from https://www.ideo.com/work/epoc-headset
37. Neural networks from http://natureofcode.com/book/chapter-10-neural-networks/