Electrodes Used in Brain Computer Interface

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Abstract: ***Brain Computer Interface (BCI) has been developed since last 30 years and now it has profounded in diverse areas. In 1964, the description of BCI was first given by Dr. Grey Walter .BCI, is a method of communication between the brain and any external device which helps brain signals to guide some external activities.BCI provides a means of communication to disabled people who are totally paralysed or 'locked in' by neurological neuromuscular disorder such as spinal cord injury ,brain stem stroke and amyotrophic lateral scierosis. First, the review deals with the classification of electrodes in which we have discussed contact and non contact electrodes. Second, the review deals with various types of dry electrodes ,its fabrication and characteristics which is a type of contact electrodes .It comprises multipoint spiked dry electrodes, carbon nano tube. Third, the review deals with water and gel electrodes and its setup for measuring EEG recording, which is also a type of contact electrode. Fourth, the review deals with capacitive electrodes, which is non contact type electrode, its design and advantages. Fifth, the review deals with various setup of EEG with three different types of electrodes regarding signals that is P300,Motar imagery and SSVEP. Sixth, the review deals with comparison between various electrodes such as active and passive; dry ,gel and water ;contact and non contact electrodes.***

Keywords: Contact electrode, Capacitive electrode, Multipoint Spiked Dry Electrode, Carbon nanotubes, Water electrode

1. Introduction

Brain –Computer Interface or Direct Neural Interface(DNI) and Mind Machine Interface(MMI), is a method of communication between the brain and any external device which helps brain signals to guide some external activities. A BCI system allows its users suffering from motor disabilities to control the substances around it by using their brain signals. There are five stages into which a BCI methodology can be categorised, namely,
First stage - Brain Activity Measurement
Second stage- Pre-processing
Third stage- Feature Extraction
Fourth stage- Classification
Fifth stage- Control Interface.

Two techniques namely, invasive and Non-Invasive are used for determination of Brain signals. In Invasive technique, Electrocorticogram (ECoG) and Intracortical Neuron recording are used. In Non- Invasive technique, electroencephalogram (EEG), Magneto-encephalography (MEG) and Near –Infrared Spectroscopy (NIRS) are used .The method of ECoG, in order to receive signals from cerebral cortex, needs a surgery to implant pads of electrode on brain surface. Placing field sensing electrodes on the scalp of the subject is a part of EEG process.

Active electrode and Passive electrode are the two categories in which Electrodes are classified. Taking case of passive electrode, signals are first received and then they are amplified for further Feature Extraction and Translation. The signals lie in micro volts range, henceforth, there occurs voltage drop occurs which in the process of sensing to the amplification leads to information loss. Case with active electrodes are different as both reception and amplification of signals take place simultaneously. The result of this is good signal quality which can be used for further processes[1].Different areas where the research have been mainly focused, are light and television control, yes/no questions, text processing, wheelchair control, robotic prosthetics, autonomous vehicles, autocalling using brain activity, virtual reality games etc. The focus of this paper lies in the types of electrodes, their pros and cons as well as the comparison between them.

2. Types of Electrodes

The EEG measurements are classified into two types , on the basis of the way in which electric current is collected from the brain tissues and how the potential difference is measured:

Contact Electrode

Non-Contact Electrode / Capacitive Electrode
1. Contact Electrode: These electrodes come in direct contact of the skin [2,3]and are composed of metal. This galvanic contact indicates an electric current transfer between the tissues and sensors. For the transfer of electric currents, an electrically conducive gel is applied. Use of this gel on the electrode leads to a term called Wet electrode , absence of which refers to dry electrodes[3,4].

Various Dry Electrodes types:
Multipoint Spiked Dry Electrode[MSDE]: This type of electrodes are designed to penetrate the scalp as they comprise of an array of micro-dimensioned extremely sharp spikes, which help in providing better mechanical fixation, electrical attachment and also prevent the problems of high impedance that relates to the skin's outer layer. These spikes have been evolved over time in different ranges such as millimetres, micrometers(MEMS) and nanometers[5].

Etching of Silicon wafers(As described in US patent No. 6,256,533 by Yuzhakov et al.) and then electroplating them is the method to create Microneedle electrode arrays. The electroplating is done using conductive material such as Gold. 2D neural probes record signal only from the planar regions of brain in spite of the fact that 2D structures can be precisely shaped[6,7]. Henceforth, to obtain more information from Nervous system, the existence of 3D microneedle electrodes came into being[8,9]. There are two ways to fabricate 3D microneedles:

-Etching bulk material in the 3D devices:: Dependency on bulk materials is more in fabrication technologies.
-Collating 2D probe combs in 3D::Standard planar surface micromachining is done to generate 2D neural probes and then their assembly is done in specially designed platform to create 3D probe array[10,11].

e.g. for fabrication of plane microneedle structure, reactive-ion etching [2] anisotropic wet etching[3,12,13] is done. When electroplating process is done over a seeding layer predefined by polymer micromold[14], then metal microneedle structures are formed. For creating 3D polymer microneedle structures, following are used:-

Stainless steel molding technology[15].
-Inclined UV(ultraviolet) exposure technology[16].
-polydimethylsiloxane molding technology [17],[18].
-etched lens backside exposure technology[19].

However, these microneedle structures are time consuming and expensive, since they require special equipment /platform. Additionally, a limitation to 3D microneedle electrodes is the mechanical properties mismatch between hard , rigid substrate & soft biological tissues.

Device's mechanical characteristics were explored to accommodate the microneedle electrode arrays' application on the curved portion of brain. Kim et al. [20],proposed a mathematical model to determine the bending energy and bending stiffness. The equation is as follows:

$$El = E_{Pl} bh(\frac{1}{3}h^2 - hy_0 + y_0^2) + (E_{Au} - E_{Pl}) n h_m b_m [\frac{1}{3}h_m^2 + h_m(h' - y_0) + (h' - y_0)^2]$$

$$y_b = \frac{El}{2R^2 b}$$

where $E_{PI=}$Young's Modulus of the polyimide
E_{Au} =Young's Modulus of the Au metal layers
$b \times h$ =Dimensions of the polyimide layer
$b_m \times h_m$ = Dimensions of the n gold bricks
$y_{0=}$ Distance between the neutral axis and the bottom of the polyimide layer
R = bending radius.

The total bending energy of device's flexible substrate was much lesser than adhesive energy of wet surfaces , as per the mathematical model[21]. Owing to the surface tension of the body fluid of adhesive body, the flexible substrate can remain affixed to the surface of the brain after the microneedle structure has penetrated the brain. The deformed substrate will not induce a shear force on brain tissues via inserted microneedles as it is conformal to the brain , owing to its mesh structure and excellent flexibility. There must be enough stiffness in the microneedles to penetrate successfully. The strength of microneedle electrodes that are polymer based is enough to penetrate successfully in the brain tissues as well as communicate with low impedance contacts with the neural system. There were several 'in vivo' tests done over rats that clearly depict that flexible microneedle electrodes can be successfully implanted in a brain with curved surface and its neural signals can also be recorded. The mesh of flexible 3d electrode acts as a platform to integrate itself with other electronic devices to monitor chronic neural activities[22].

Carbon nanotubes(CNT) were used to create nano structured, implantable microelectrodes. CNTs are conductive in nature and increase the overall surface area of the electrode as well as the signal to noise ratio. However CNT dry electrodes achieved limited success [23,24,25,26,27].

1) CNT tips had dense surface that resulted from the fact that CNTs were not patterned within the electrodes.
2) Height of CNTs was small(tens of micrometer range)

Then WCNT (walled CNT) and MWCNT(Multi-walled CNT) came to existence. Due to the strength and conductivity, MWCNT proved to be better than WCNT. Also the arrays in MWCNT were designed to penetrate the SC and led to pain-free and comfortable interface due to minute size of spikes. Using an ensemble of arrays of MWCNT which found the pillars vertical to circular stainless steel (ss) substrate , patterned vertical CNT(pvCNT) was created. By using a technique called Chemical Vapour Deposition (CVD), pvCNT's were created which showed stable impedance over time when compared with other ECG electrodes that were commercially available. Also extended period monitoring of physiological signals with minimum degradation of impedance is possible using pvCNT dry electrode[28]. This technology of using nanotubes(diameter: 50nm, length: 15 nm) led to lower risk if infection as compared to microneedles.

Gel Electrodes:
To obtain low electrode-skin impedance the recording of EEG is done with the help of Gel-based electrodes on the surface of the head. In order to reduce impedance when using passive electrodes the skin must be scraped. Active electrodes contain an Amplifier inside and when using these electrodes there is an injection of electrode gel between the skin and electrode material. This helps the system of electrode to be more quickly mounted. The electrolyte gel and the abrasive paste are sticky substance and are bound to dirty the hair and scalp, though they are incisive and barely harmful. Furthermore it can take very long time to reduce the impedance to an accepted value. To solve this problem i.e. speed up the impedance reduction process massive electrolyte can be used. But it has its own repercussions as it could create electrical bridges between electrodes especially with dense arrays and thus be counterproductive. Additionally the countdown keeps ticking even after the acceptable electrode impedance is achieved , till the gel dries which causes a disappearance of transductive properties. Keeping in view the long term measures the gel based electrodes are unsuitable for the above said reasons.

Water Electrodes:
A technology came into existence in which plain (tap) water is used in the sensor to measure EEG signals .Its Specifications are superb and is very comfortable to wear.
A water based EEG electrode was developed during the European BRAIN project in which integrated AgCl pellet electrode was used as a cardinal component.A sponge were incorporated within the sensor housing which was soaked with water. The EEG signals were recorded after making the sponge and water in contact with the skin .A

sensor housing was placed in a rubber fitting to reduce the movement artifacts and to increase the comfort. An another type of headwrap was designed which was very quick and easy to apply .It was having a number of sensor fitting in which sensors were placed. Sensor fitting contains soft rubber ring which helps the sensor not to dry out fastly and stops the movement of sensor with respect to the skin. Results of several tests conclude that DC stability of the water electrodes is a little bit better and noise is slightly lower as compared to the EEG cup electrode.

Capacitive or Non-Contact Electrode:

Capacitive electrodes consist of a conducting plate with insulation that is placed in contact close to the surface of the body. The electric signals are derived from the capacitor that is formed by the surface of the body and the plate. This arrangement is known as capacitive-coupling-measurement [29,30].

The electrodes that are capacitively coupled can be used on unprepared skin without using any electrolytic gel. The resistance changes between the skin and the electrodes give rise to a voltage drift, however, these electrodes are immune to these as well[29,31,32].[33]Non-contact capacitive electrodes do not need any ohmic connection to the body which is in direct contrast to wet or dry contact electrodes. There are many advantages for body sensor application:

-They need no preparation.

-They can be easily embedded within the layers of fabrics.

- They are not sensitive to any skin condition.

The Design of A Capacitive Electrode

The acquisition of bio-potentials in Capacitive electrodes is allowed via displacement currents and not real charge currents owing to the fact that a dielectric insulating film is used instead of electrolyte-electrode-skin interface. Capacitive electrodes behave differently to skin contact because of the lack of electrolytes.

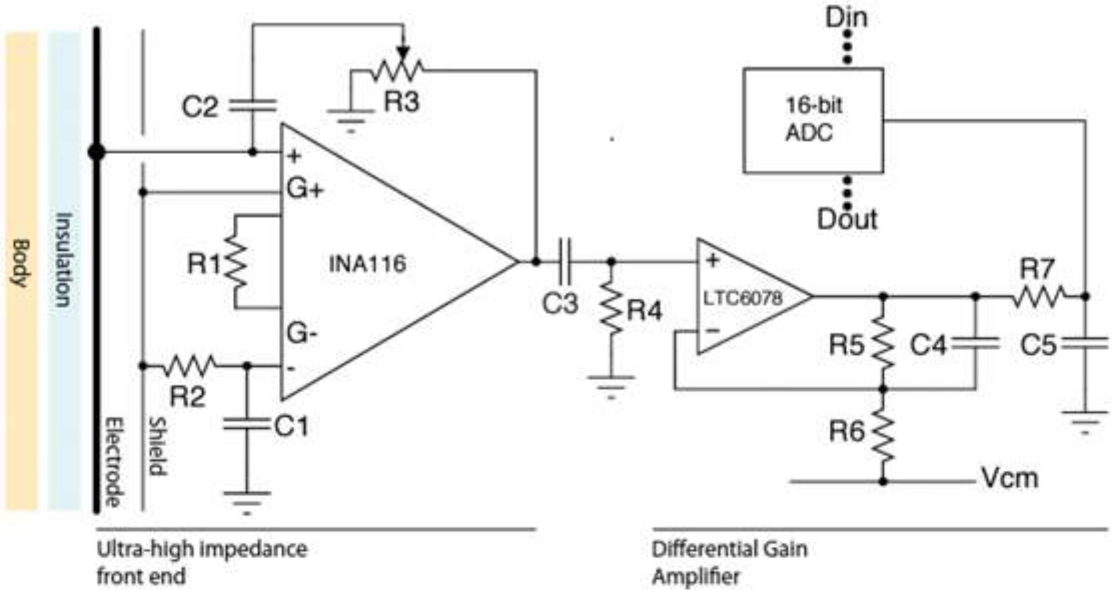

Figure: Full schematic of non contact electrode showing the ultra-high input impedance front-end,differential amplifier and 16 –bit ADC

The designing of capacitive electrode was done with a motive that the input impedance should be substantially larger than the skin- electrode impedance so that it can be utilised to minimize the interference that is caused by motion artifacts and the unwanted common-mode voltages. To achieve capacitive effect, signals on the skin couples capacitively to the sensing plate which has a coating of dielectric material. There is a coupling capacitance formed between the subject's body and the electrode. The thickness and dielectric constant of the material, placed between the electrode and subject's skin[31], are the two properties over which the coupling capacitance is dependent.

The amount of capacitive coupling 'Cs' can be determined using the capacitor model formula:

$Cs=Ae_0e_r/d$

Where,

A=Surface area of the plates

d= Thickness of the dielectric

e_0=Permittivity of free space

e_r=Relative static permittivity of dielectric.

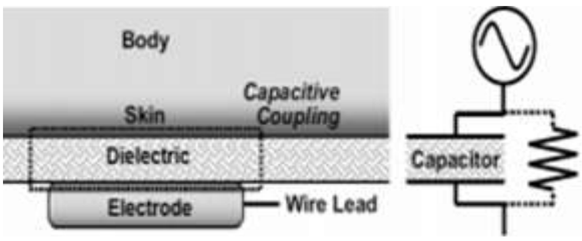

Figure 1: Capacitive Sensing method

The need of skin abrasion and electrolytic gel can be eliminated using the capacitive coupling technique in the process of acquiring very low amplitude of brain signals. Mechanical stability of the placed electrode over the body to improve the signal quality would be pivotal in the subsequent works over sensors and prove to be the next step in the direction of portable monitoring devices. To summarize, in order to monitor the brain continuously for longer period of time, a tailor made combination of analog and off the shelve embedded system is needed. A BCI device having a direct connection to an external device is an excellent option. E.g. robot or prosthesis without employing a personal computer(PC)[34].

Various Setups of EEG with three different types of electrodes:

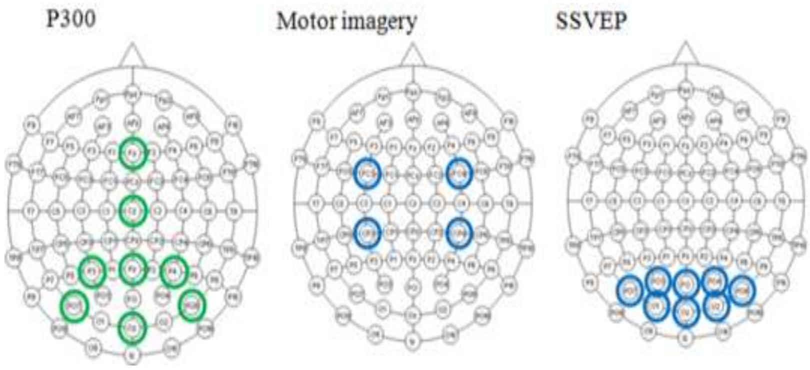

Figure: Different setups and location of 8 electrodes

[35]SSVEP shows the strongest response at occipital and parietal sites and it is where 8 electrodes were positioned in all the above setups. In accordance with international 10-20 system, the 8 electrodes are located at positions O1,O2,Oz,PO4,POz,P1 & P2. The position of conducive gel ground electrode has been at the right collar bone of the participant in all setups.

For the construction of dry electrode setup, eight commercially available sintered Ag/AgCl ring electrodes[Inner diameter: 5 mm, Outer diameter: 10mm] with twelve rigid pins having 2 mm length were used. The electrodes of this type are fastened to a soft flexible patch which in turn is attached to an elastic headband with the help of six velcro straps i.e. three each side. To accommodate the shape and size of the head of different participant, the Velcro straps are used. Shielded cables are used to connect these electrodes to TMsi porti acquisition system. The entire setup is mounted as headband on the subject's head. Thus , first 'easy-to-mount' EEG setup aimed at measuring SSVEP response having a multitude of dry contact electrode is said to be created.This setup underwent performance evaluation.

Water- based electrodes need tap water instead of electrolytic gel. Such electrodes are developed under the framework of BRAIN project. The setup made up of silver-chloride palet & rolled up cotton was connected via covered cables to porti system. Water-based sensors are positioned on the head using the screwing mechanism of commercially available EEG.

Conductive gel is required for Gel-based setup. TMsi port EEG acquisition system used standard thirty-two channel head-caps using shielded cables. However, Only 8 selected channels out of 32 channels were filled with the gel.

The Gel based configurations can be replaced completely with the use of Dry and Water based configuration as depicted by the analysis. However, it reduces the performance. When water-based electrodes are used the accuracy rate falls by 10-25% and 35-45% when dry electrodes are used. ITR or Information transfer rate of these electrodes as compared to water based or dry electrodes is one half and one third respectively. Low levels of accuracy for dry electrodes and values lower than expectations for gel based electrodes were observed when using only occipital sites i.e. O1, O2 and Oz. Gel based electrodes can be a preferred choice in situations where practical aspects of the EEG systems are considered over communication speeds. With advancements in design, usage of more advanced signal analysis methods, improvements in amplifier technology, signal quality the performance of water based or dry electrodes can reach that of gel based ones.

Table 1: Comparision of Active and Passive Electrode

No.	Active Dry Electrode	Passive Dry Electrode
1.	Large size and inflexible.	Thin and flexible.
2.	Electrode can not be embedded in clothes.	It is possible to integrate them in garments or clothes. e.g.textile electrode.
3.	They have local active electronics.	They have no local active electronics.
4.	In EEG application,dry electrode signals are affected from large movement artifacts.	They are durable,washable and reusable.

Table 2: Comparison of Water, Gel and Dry Electrode

NO.	Dry Electrode	Water Electrode	Gel Electrode
1.	Neither gel nor water is required.	No gel is required ,only plain tap water.	Electrolytic gel is required.
2.	Scratching may be required.	No scratching of the skin is required.	No Scratching of the skin is required.
3.	Lower signal quality due to motion artifact.	Measure 6-8 hours without losing signal quality.	Signal quality get degraded when conductive gel dries.
4.	Very comfortable to wear.	Comfortable to wear.	Not comfortable to wear.

Comparison of Contact and Non- Contact Electrode

NO.	Contact Electrode	Non –Contact Electrode
1.	Electrode requires ohmic connection to the body.	Electrode do not requires ohmic connection to the body.
2.	Requires skin preparation before measuring signals.	Requires zero preparation and completely insensitive to the skin conditions.
3.	It can not be imbedded within layers of fabric.	It can be imbedded within comfortable layers of fabric.
4.	Non immune to voltage drift.	Immune to voltage drift.

3. Conclusion

This paper dealt with the types of electrodes used in BCI system. Additionally, it also throws light on signal measuring techniques of the electrodes as well as their advantages and disadvantages. By the means of above discussions, it can be concluded that Non-contact electrodes perform better than Contact Electrodes.

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