A Review of Eeg Sensors used for Data Acquisition

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ABSTRACT
Electroencephalography makes use of sensors to capture time varying magnitude of electric fields originating from the brain. These fields result from synchronous activities of billions of neurons present in the brain. These fields are measured from scalp through sensors using different techniques developed over the time so that measurement can be precise, which in turn relies on direct and low resistance contact between the sensor and scalp. Recent advancement in EEG monitoring devices has extended its usage into the domains of lifestyle and entertainment. This paper discusses all such techniques used for the acquisition of EEG signal with the help of various sensors available such as wet electrodes, dry electrodes, wireless EEG system etc.

1. INTRODUCTION
Electroencephalography is a technique to analyse the neural activities occurring in the brain. The electric potentials generated by single neurons are far too small to be picked by EEG. EEG activity therefore always reflects the summation of the synchronous activity of thousands or millions of neurons that have similar spatial orientation. EEG analysis is used to monitor cognitive state changes and sleep stages. Accuracy of these analyses highly depends upon the accuracy of the system used to obtain the EEG signals. The electroencephalograms are widely used in biofeedback systems for clinical purposes, but their usage as a computer input devices is limited due to the low level of accuracy. EEG instruments used to acquire data are of two kinds: Analogue EEG instrument and digital EEG instruments. Conventional analogue instruments consist of an amplifier, a galvanometer and a writing device. A galvanometer is a coil of wire inside a magnetic field. The output signal produced by amplifier passes through the wire which causes the coil to oscillate. A pen mounted on the galvanometer moves up and down each time the coil moves. The pen draws the trace on the paper moving below it. The output of amplifier is controlled by high and low frequency filters and sensitivity controls. The sensitivity controls the size of the activity displayed. For example, a sensitivity of 10 µV/mm means that a signal with amplitude of 100
µ V will produce a 1 cm vertical deflection [6]. The speed at which the paper moves on will also affect the appearance of the waveforms. A digital EEG system converts the analogue waveform into a series of digital values. This process is known as Analogue-to-Digital conversion (ADC). Figure1 shows analogue waveform and Figure 2 shows sampled signal at 240Hz.

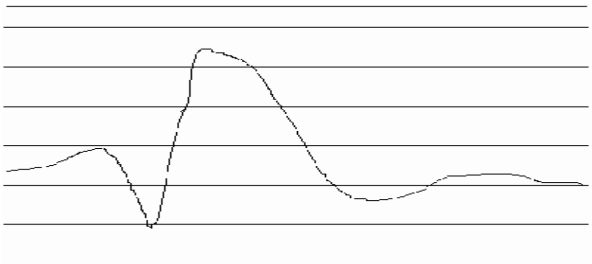


Figure1: Analogue waveform [6]

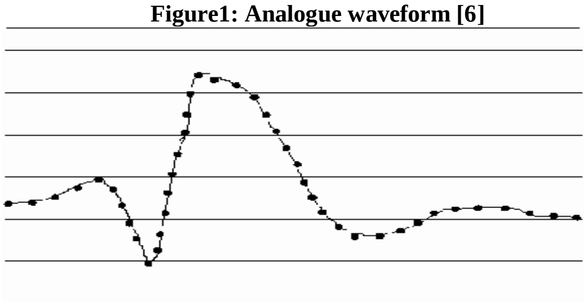


Figure 2: Sampling rate of 240 Hz [6]

The values can be stored in the computer memory, manipulated and then redisplayed as waveforms on a computer screen. The rate at which the waveform data is sampled in order to convert it into a numerical format is known as the sampling rate. The minimum acceptable sampling rate is 2.5 times greater than the highest frequency of interest but most digital EEG systems will sample at 240 Hz. Some recordings which involve recording activity directly from the brain surface may have activity of a higher frequency, for example 200 Hz. Therefore some digital EEG systems also have optional sampling rates of 480 Hz [6]. Most EEG systems these days, however, are digital, and the amplified signal is digitized via an analogue-to-digital converter, after being passed through an anti-aliasing filter. Analogue-to-digital sampling typically occurs at 256–512 Hz in clinical scalp EEG; sampling rates of up to 20 kHz are used in some research applications [12].

2. SENSORS
A. *Wet Electrodes*
EEG electrodes are small metal plates that are attached to the scalp using a conducting electrode gel. They can be made from various materials. Most frequently, tin (Sn) and silver/silver-chloride (Ag/AgCl) electrodes are used but there are gold (Au) and platinum (Pt) electrodes as well. Figure 3 shows electrodes

used with conductive paste to capture EEG signal.

Figure 3: EEG electrodes

Correct EEG electrode placement is important to ensure proper location of electrodes in relation to cortical areas so that they can be reliably and precisely maintained from individual to individual. The International 10–20 System of Electrode Placement is the most widely used system which describes the location of scalp electrodes. The 10–20 system is based on the relationship between the location of an electrode and the underlying area of cerebral cortex. Each site has a letter which identifies the lobe and a number or another letters to identify the location of hemisphere. Figure 4 shows the international 10-20 electrode placement system. The letters used are: "F"-Frontal lobe, "T"-Temporal lobe, "C"-Central lobe, "P"-Parietal lobe, "O"-Occipital lobe. Even numbers such as 2,4,6,8 refer to the right hemisphere and odd numbers such as 1,3,5,7 refer to the left hemisphere. Letter "Z" refers to an electrode placed on the midline. The smaller the number, the closer is the position of electrode to the midline. "Fp" stands for Front polar. "Nasion" is the point between the forehead and nose. "Inion" is the bump at the back of the skull.

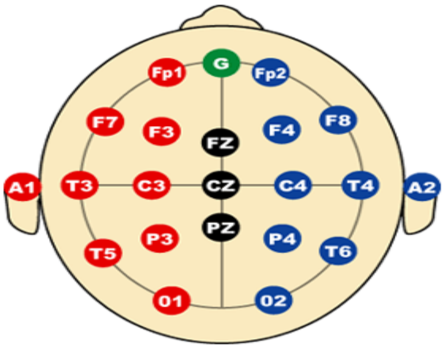
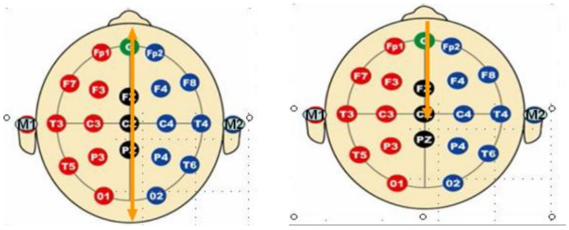


Figure 4: International 10-20 Electrode Placement System[13]

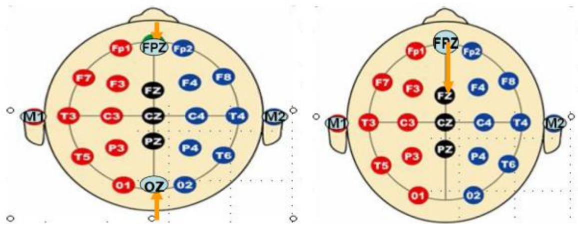
The letters used are:
F - Frontal lobe
T - Temporal lobe
C - Central lobe
P - Parietal lobe
O - Occipital lobe
"Z" refers to an electrode placed on the mid-line.

The description of placement of electrode is as follows:
Mark the Nasion and Inion. Get the total. Mark 50% of the total. This is the first mark of CZ.



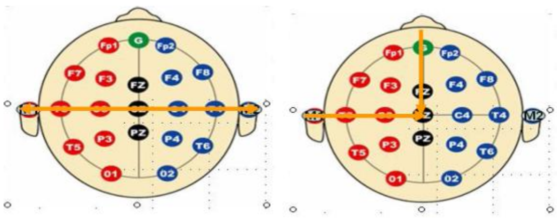
(a) (b)

Mark 10% up from the nasion and 10% up from the inion. This is the first mark of FPZ and OZ. Mark 20% up from either the first mark of FPZ or CZ. This will be the first mark of FZ.



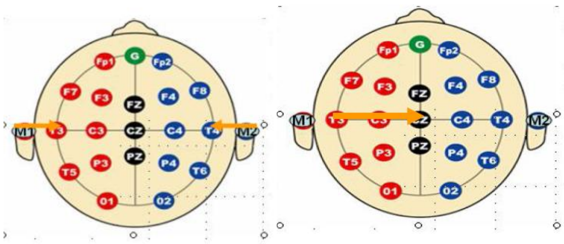
(c) (d)

Measure the distance from preauricular point to preauricular point. Have the patient open his mouth slightly. Lightly run the finger up and down just anterior to the ear; the indentation above the zygomatic notch is easily identified. Obtain the total. Mark half of the total (this number should intersect with the first 50% mark). This is the true CZ

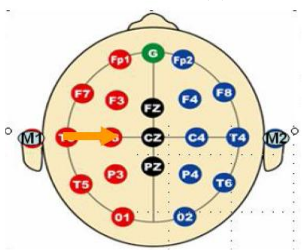


(e) (f)

Mark 10% up from each pre-auricular point. These are the first marks of T3, and T4. Measure from the first mark of T3 to your CZ and obtain the total. Mark half of the total. This is the first mark of C3.

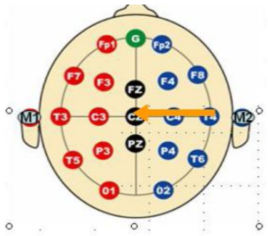
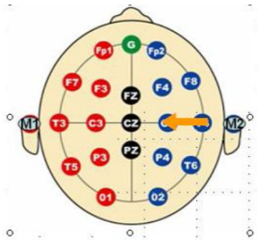


(g) (h)



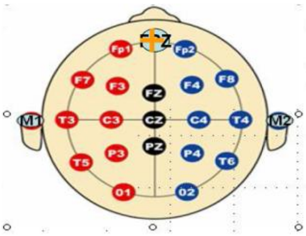
(i)

Measure from the first mark of T4 to CZ and obtain total. Mark half of the total. This is the first mark of C4.

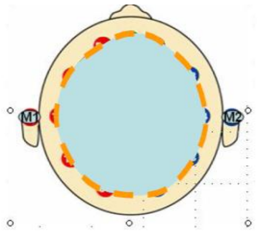
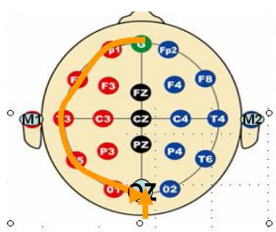
(j) (k)

Draw a cross-section on the first mark of FPZ. This is the true FPZ mark.



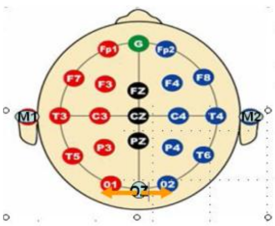
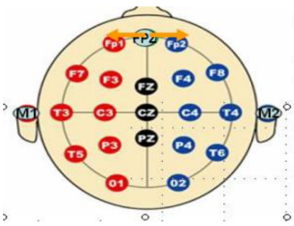
(l)

Encircle the measuring tape all across the 10% mark; obtaining the total circumference. Mark half of the total. This will be the true mark of OZ.

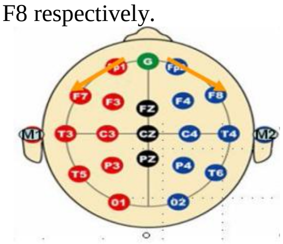
(m) (n)

Mark 5% of the half to the left and right of OZ. These will be the true marks of O1 and O2 respectively. Mark 5% to the left and right of FPZ. These will be the true marks of FP1 and FP2 respectively.

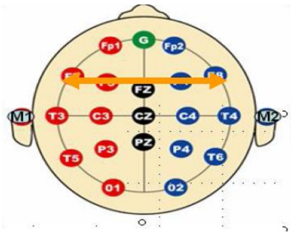
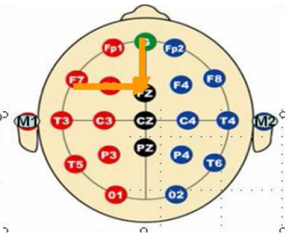
(o) (p)

Mark 10% further down from FP1 and FP2. These will be the marks for F7 and F8 respectively.



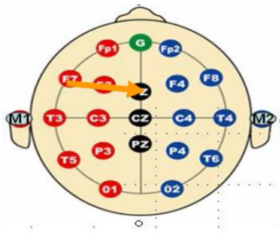
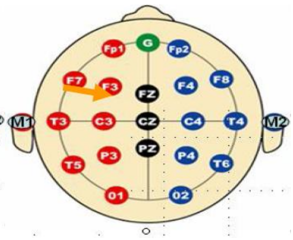
(q)

Where first mark of FZ and this second mark of FZ intersect is true mark of FZ.

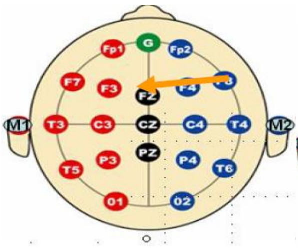
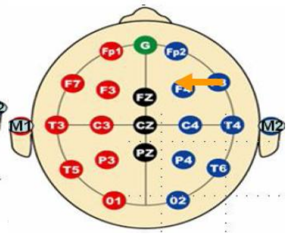
(r) (s)

Measure the distance from F7 to FZ. Obtain the total. Mark half. This will be the first mark of F3.

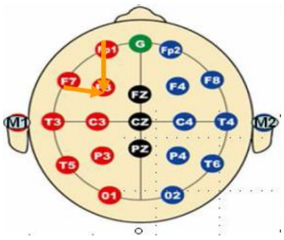
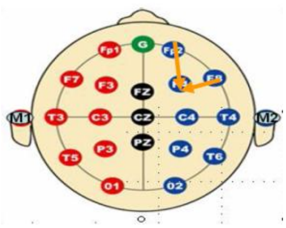
(t) (u)

Measure the distance from F8 to FZ. Obtain total. Mark half. This will be first mark of F4.

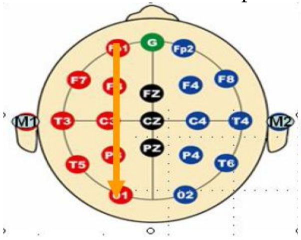
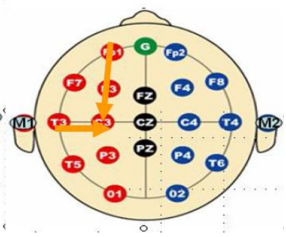
(v) (w)

Measure 20% from FP1to F3.This will be final mark of F3. Measure 20% from FP2 to F4.This will be the final mark of F4.

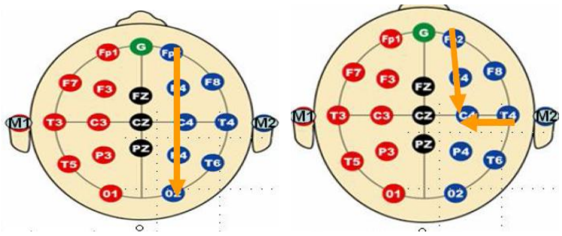
(x) (y)

Measure the points from FP1 to first mark of C3 to O1. Obtain the total. Mark half of the total. Where first and second marks intersect will be the true placement of C3.

(z) (α)

Measure the points from FP2 to your first mark of C4 to your O2. Obtain the total. Mark half of total. Where the first and second marks intersect will be the true placement of C4 [13].



(β) (γ)

Other important electrodes are Reference and Neutral electrodes. The reference electrode is critical. It is the second input for the digital amplifiers for all head electrodes being recorded. The reference electrode is commonly placed half way between Cz and Pz or half way between Cz and Fz. Another method is to use two electrodes at A1 and A2 linked together. The principle is the same, to try to use a location that is as electrically silent as possible. It is a very important electrode while recording as if it comes off, data from all other channels is recorded as interference. A scalp electrode affixed to the midline forehead or other relatively neutral site. The neutral or ground electrode is important as it is used by the system to reduce the effect of external interference. Its position is not so critical, if this electrode comes off during the recording; one may or may not have a problem depending on the environment.

When more detailed EEG has to be recorded, extra electrodes are added utilizing the spaces in-between the existing 10-20 system as shown in figure 5.This new electrode-naming-system is more complicated giving rise to the Modified Combinatorial Nomenclature (MCN). This MCN system uses 1, 3, 5, 7, 9 for the left hemisphere which represents 10%, 20%, 30%, 40%, 50% of the inion-to-nasion distance respectively. The introduction of extra letters allows the naming of extra electrode sites.

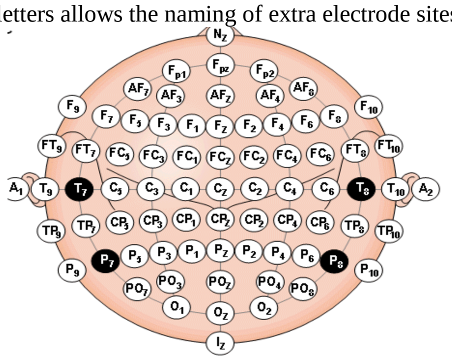


Figure 5: Advanced International 10-20 Electrode Placement System

Two issues limit the use of these systems. The first is that electrically-conductive gel is required for a good contact between the sensors and the scalp. It takes a lot of time to apply sensors on the scalp, it may diffuse through the hair to create shorts between the sensors and it tends to dry out, which limits the recording time. The second limiting issue with these EEG systems is that they are not mobile. Moreover, it consumes high power [3].

For reduced application time and increased subject comfort, EEG cap can be used for recording multiple EEG channels. Electrodes are pre-positioned in the international 10/20 montage. So, even novice EEG researchers can minimize electrode placement errors. Figure 6 shows an EEG cap used to record multiple channels.

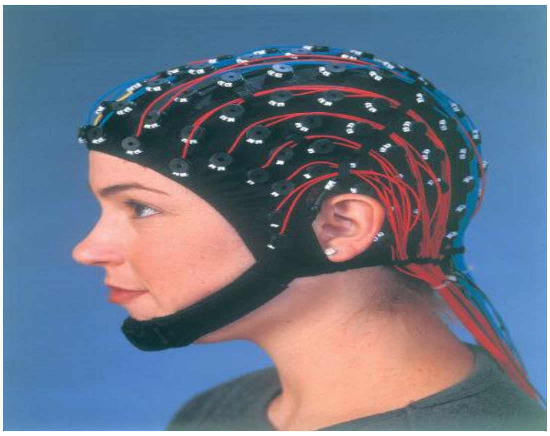


Figure 6: EEG Cap

B. *MEMS-based, dry electrodes*

One key problem researchers face is how to measure the signals without applying sticky electrodes or using conductive gel.one such type of electrode used is Micro-Electro-Mechanical System based dry electrodes that create a good contact with the skin without requiring gel.

Micro-Electro-Mechanical Systems, or MEMS, is a technology that is defined as miniaturized mechanical and electro-mechanical devices and structures that are made using the techniques of microfabrication. As shown in figure 7, the functional elements of MEMS are miniaturized structures, sensors, actuators, and microelectronics, the most notable (and perhaps most interesting) elements are the microsensors and microactuators. Microsensors and microactuators are appropriately categorized as “transducers”, which are defined as devices that convert energy from one form to another.

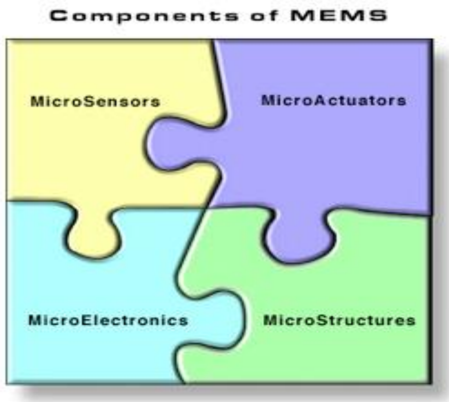


Figure 7: Components of MEMS

Figure 8 shows dry electrodes which are fabricated using MEMS technology and are used in EEG data acquisition without the requirement of electrolytic gel as used in wet electrodes system for the placement of electrodes on the scalp.

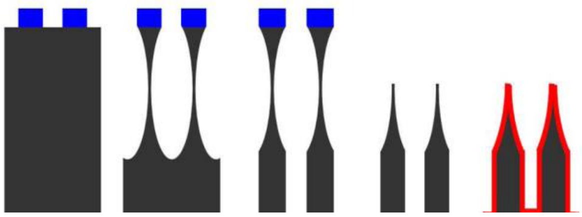


Figure 8: Dry Electrodes

Structure of skin consists of three layers - the epidermis, dermis, and subcutaneous tissue. The skin anatomy is shown in figure 9. The epidermis is the outer layer of skin. The thickness of the epidermis varies in different types of skin. It is the thinnest on the eyelids at .05 mm and the thickest on the palms and soles at 1.5 mm. The epidermis contains 5 layers.

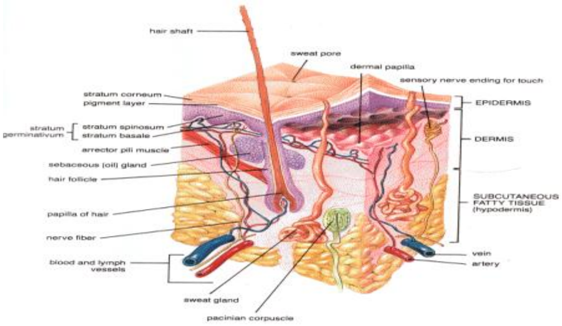


Figure 9: Skin Anatomy

From bottom to top the layers are named:

- stratum basale
- stratum spinosum
- stratum granulosum
- stratum licidum
- stratum corneum

Stratum basale and stratum spinosum together are called stratum germinativum. The dermis also varies in thickness depending on the location of the skin. It is .3 mm on the eyelid and 3.0 mm on the back. The subcutaneous tissue is a layer of fat and connective tissue that houses larger blood vessels and nerves. The fabricated dry electrode is designed to pierce the stratum corneum into the electrically conducting tissue layer stratum germinativum, but not reach the dermis layer so as to avoid pain and bleeding. Since the dry electrode is expected to circumvent the high impedance characteristics of the *SC*, thus, skin preparation and electrolytic gel application are not required. [2] A system using these dry electrodes provides convenient experiment setup and enables experiments which require long-term recording. Also, the number of wires needed to interface with a large number of electrodes is reduced since the power, clocks and measured signals are daisy-chained from one board to another. Also, mobility is possible because only a small amount of power is required for the whole signal processing system. This system consumes only 3 mW of power making battery power feasible. Small batteries can be employed to power the system for an extended period of time. Figure 10 and Figure 11 show the system using MEMS based dry electrodes. The signal is obtained from the dry electrode. They are located on the inside brim of the baseball cap as shown in Figure10. The microscopic needles that jut out from the silicon plane increase the surface area of the electrode and achieve a lower contact resistance than typical dry electrodes [1].

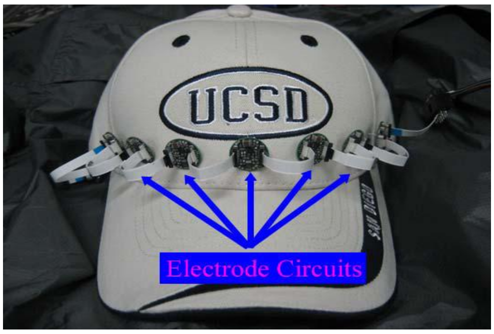


Figure 10: Electrode circuit [1]

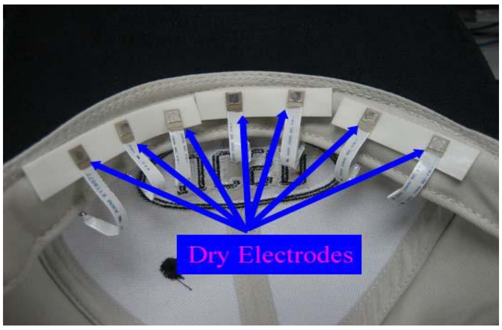


Figure 11: Dry electrodes [1]

MEMS dry electrodes are fabricated and characterised to bring EEG monitoring to operational environment where skin preparation and conductive paste are not desired.

C. *Wireless EEG system*

In clinic, insomnia that is sleeplessness is a main sleep disorder. It leads to severe fatigue, anxiety, depression and lack of concentration. For insomnia, it is important to study patient's status of wake by detection of alpha wave in EEG of all night. Polysomnography (PSG) is used for recording EEG all night [7]. There are two deficiencies by PSG in recording EEG. The one is that the patient whose EEG is recorded by PSG doesn't feel relaxed as longer electrode wires always wrap his head and body, which causes patient to not to sleep on both ears so that he is often in the status of wake. In this situation, doctor may think it as a sleep disorder. The other limitation of PSG is power-line interference suppression. Power-line interference is very prominent in EEG, which can even lead to saturation of the amplifier of EEG which may lead recording of EEG to fail. The detection software cannot detect characteristic wave in EEG properly [9]. So, to overcome these limitations a wireless EEG sensor system has been designed. The system includes an EEG amplifier and a wireless transmitter and receiver. A personal computer is also used. The wireless EEG sensor system is good at detecting alpha wave and power-line interference suppression [10][11]. And patient feels relaxed as it is small in size and has very short electrode wires [4].

A wireless EEG platform and headset is also available which offers new perspectives towards a fully integrated, high performance, wearable EEG monitoring system. Figure 12 shows wireless EEG platform and figure 13 shows wireless EEG headset which uses electrodes without gel or skin preparation [8].

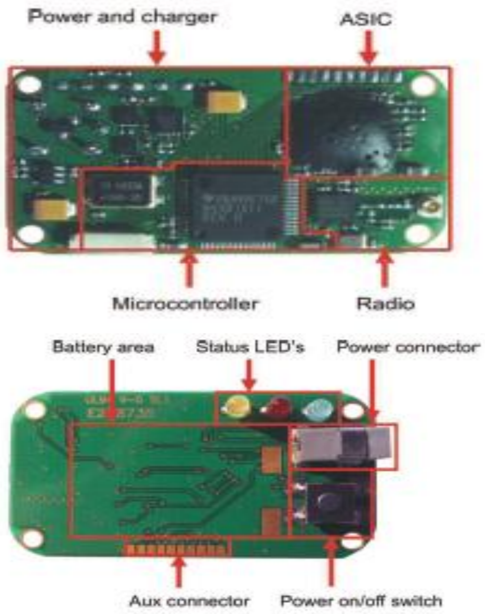


Figure12: Wireless EEG platform [9]

Figure13: Wireless EEG headset [9]

This wireless EEG headset works reliably in a controlled environment where movement and interference are minimised. Dry electrodes provide signal quality comparable to gel electrodes. Low power wireless system enables the transition from lab to real life environment.

3. FUTURE WORK

Research is required in the field of wireless EEG systems to tackle the issues like robustness to motion artifacts to increase autonomy so that the system could be used anywhere under any condition. The electrodes used in headset make contact with the skin, hence reducing the wear ability and comfort. So, wear ability must be improved by developing the electrodes which do not require contact with the skin. Further research may be carried out to reduce the power consumption of the system to improve its overall performance. Due to limitation of available technology, the height of MEMS based dry electrodes is not sufficient to penetrate human hairs to contact even epidermis. Much of work is required to fabricate longer electrodes.

4. REFERENCES

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