BIOELECTRICAL ACTIVITY OF THE HUMAN BRAIN - A REVIEW

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Abstract

The bioelectrical activity recorded from the human scalp is known as electroencephalogram (EEG). EEG consists of few types of waves in different frequency bands ranging from 0.5 Hz to 100 Hz with very low amplitude in microvolts. EEG is a signal with a good temporal resolution within millisecond range but a very poor spatial resolution. This article reviews some approaches to improve the spatial resolution such as spline surface Laplacian, cortical imaging and spatial deconvolution. In the first part, background of the subject and some EEG related researches will be presented.

Keywords : brain, electroencephalogram, bioelectrical

Introduction

Electroencephalogram (EEG) is the measurement of electromagnetic signals produced from the bioelectrical activity of the human brain. It is the measurement of electrical potential on the human scalp. EEG measurements are commonly used in medical and research applications. The electroencephalographic measurement is a completely non-invasive procedure with no risk that can be applied repeatedly to individuals.

The spatial resolution of EEG recording is very poor compare to other techniques such as single photon emission computed tomography (SPECT), positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) [1]. However, EEG measurement has more advantages such as temporal resolution is excellent, the recording tools are relatively inexpensive and involves no health risk [2]. Interpretation of the low resolution of EEG recording is troublesome and not reliable for diagnosis purposes. Many approaches had been studied by researchers to improve the spatial resolution of the signal such as spline surface Laplacian method, spatial deconvolution method, linear estimation method, local average reference method, numerical method, cortical imaging method and analytical deblurring method [1], [3], [4], [5], [6]. This paper will review some of the common methods that had been studied by researchers. The purpose of this review paper is to present an introduction to EEG and some issues related to the EEG recordings.

The Human Brain

The human brain consists of a large mass of nerve tissue weighing around 1.4 kg (slightly less in the human female) [7], [8]. The human brain approaches its full weight at about the seventh year of life and increases slightly until the twentieth year. From this point it will begin to decrease its weight of a gram each year. Three main components of the brain are brain stem, cerebellum and cerebrum as shown in Figure 1.

Cerebellum being the second largest portion of the brain is made up of cortex (outer area) and medulla (inner area). Its function is to integrate incoming sensory messages to provide muscle movements, balance and equilibrium. The brain stem controls the vital centers like breathing, blood pressure and heart rate as well as involuntary activities like swallowing or sneezing.

Cerebrum is the largest part of the human brain making up 85% of brain tissue. It has two hemispheres, which is connected, by a tract known as corpus callossum. In general, the left hemisphere controls speech, reading, writing, logical thinking and movements on the right side of the body. The right hemisphere is associated with artistic and creative ability and movements on the left side of the body. Damage to a specific part of the cortex results in a loss of function associated with that part. For example, a stroke in the motor area of the left hemisphere will paralyze all or part of the right side of the body, and may affect speech.

The hemispheres are further divided into four lobes namely frontal, parietal, temporal and occipital as shown in Figure 2. The outer layer of the cerebrum is called cerebral cortex, which is a few millimeters thick and highly convoluted. Cerebral cortex consists of several areas (as in Figure 3), which are responsible for different functions as summarized in Table 1, [7], [10].

Electroencephalogram (EEG)

In 1924, Hans Berger had discovered that brain produces waves which can be recorded from the scalp [11], [12], [13], [14]. This brain wave is known as electroencephalogram (EEG). The brain waves are generated by activities of nerve cells called neurons. A neuron stimulated by other neuron will develop action potential. Local current flows are produced when neurons are activated. Electrical signal travels through the conductive tissue and fluids of the brain. Then it passes through the skull, scalp and finally to the electrodes [11], [12], [13], [15]. However, only electrical activity generated by large populations of neurons concurrently active can be recorded on the head surface. Brain waves are found to be chaotic, unstable, nonlinear, non-stationary, non-Gaussian, asynchronous and noisy [11], [16].

EEG can be categorized as alpha, beta, theta, delta and mu waves [13], [17] which lies in the range of 0.5 to 40 Hz [3] having amplitude in microvolts unit in the range of 10-100 μV [12], [13], [17]. These waves are:

a. Alpha waves are large and slow occuring at 8 to 13 Hz with relatively large amplitude, as high as 50μV. These waves are produced when the subject is awake, relaxed or eyes closed [11], [14], [19]. It can be recorded from the occipital and parietal lobes of the cerebral cortex and the waves will diminish when a subject opens the eyes or solving mental arithmetic [18].

b. Beta waves resulted from heightened mental activity and typically show rapid oscillations with small amplitudes and seen at frequencies 13-30 Hz. It can be measured from the motor area of the frontal region [13], [14].

c. Theta waves seem to be associated with feelings of emotional stress and are characterized by moderately low frequencies at 4 to 7 Hz. The amplitude of theta wave increases with laughter, crying, hunger and unpleasant stimulus [13], [19]. It can be recorded from the temporal and adjacent parietal region of the brain [13].

d. Delta waves resulted from an extremely low frequency at 0.5 to 4 Hz that occurs during periods of deep sleep. [13], [19].

e. Mu waves are associated with physical movements or the intention to move. They will disappear when the subject thought of moving their limbs [13],[19]. Mu waves are normally recorded from the central region of the brain.

f. Gamma waves are very low in magnitude with frequency in the range of 35 to 50 Hz. This wave is associated with vision [13] and spreads over the parietal region as well as frontal region of the brain [14].

The sampling of few waves is shown in Figure 4

Some interesting observations about EEG are yoga meditation increases the amplitude of alpha waves and abnormal EEG is produced by persons who often have headaches [13]. Another finding studied by researchers [16], [19] is brain waves varies from one individual to another for the same mental task.

Although there exists advance technology in neuroimaging, EEG is still playing an important technique for epilepsy investigation [12]. Other research and clinical applications of the EEG are monitoring alertness (as well as coma and brain death), locating areas of damage due to head injury, monitoring cognitive engagement, controlling anesthesia depth, etc [2]. Besides that, many researchers have used EEG for their studies in lie detection machine [20], behavioral performance [21] and brain-computer interface for severe neuromuscular disorder individuals [22].

Recording Technique

In general, an EEG recording system consists of scalp electrodes, amplifiers, filters, analog to digital converter and a recording device [2]. A standardized electrode placement that had been adopted by the International Federation in Electroencephalography and Clinical Neurophysiology [23], which is known as 10-20 electrode placement system [2] as shown in Figure 5.

The electrode will be pasted by electricity conducting gel like Ag-AgCl to the scalp according to the points as in Figure 5. It is important to make sure the impedance of each electrode contact on the scalp is below 5 kΩ to prevent signal distortions [2]. Recording can be employed using either bipolar and reference electrode placement. With bipolar recording, differential measurements are made between pairs of scalp electrodes [2], [18]. In reference recording, each electrode is referred to either distant reference electrode which is usually on the linked ears [2], [18]. Other physical references are vertex, linked mastoids, ipsilateral ear and contralateral ear [2]. However, the choice of reference electrode does not affect the measurement [2]. One pair of electrodes is for one channel EEG. If many channels of EEG are recorded at the same time, then this condition is referred as multi-channel recording. This can be achieved by using more pairs of electrodes.

The weak signal generated from the scalp will be amplified by a differential amplifier with high input impedance (at least 100 MΩ) [2], high gain in the order of 100-100,000 [2], high common mode rejection ratios (CMRR) at least 100 db [2] so that its amplitude will be acceptable to a recording device [2], [17]. Other basic requirements are these amplifiers will not distort the measured signal, provide isolation for the patient to prevent electric shocks and the amplifier will not influence the signal being monitored [2].

Common recording devices available are pen or chart recorder. EEG is recorded on a long sheet of continuous paper. This type of recording is commonly used for clinical diagnosis purposes. However other recording device, which is being used by researchers, is computer. The EEG signal from the amplifier will be converted into digital format by an analog to digital converter. Then this data will be stored and can be visualized on the computer's monitor or can be used for further analysis [2]. A study was made by Binnie [12] to record EEG using telemetry system so that a prolonged recording to detect a very frequently occurring attacks for epilepsy patient is possible. Binnie [12] also mentioned that advance method of recognition of EEG signal is needed so that interpretation will not depend on human.

Poor Spatial Resolution Of Eeg Recordings

Major disadvantage of EEG recording is poor spatial resolution [1], [3],[6], [24]. Malmivuo and Sihko [24] had concluded that EEG and magnetoencepahalogram (MEG) signals had about the same spatial resolution even though there were claims that MEG gave better resolution than EEG. The low resolution is due to high-resistivity of the skull about 15 times compare to brain and scalp [24]. The skull acts like a low pass spatial filter and blurs the important spatial details [1], [3], [6]. Scalp potential distributions are affected by two factors; inverse problem that is same electric field can be generated by large number of different current sources in the brain and volume conductivity of the head which varies from one person to another [1], [5]. Nunez [4] had suggested four types of current sources related to EEG phenomena.

They are localized and stationary, distributed and stationary, localized and non-stationary and distributed and non-stationary (see details [4]). Nunez [4] also suggested two methods that can improve the spatial resolution are spatial deconvolution and surface Laplacian or current source density . Spatial deconvolutuion method uses models of volume conductive and different source models [1], [4]. Surface Laplacian method calculates an estimate of the normal skull current density and does not take into account the assumption made for volume conductor model and other field generating sources [1],[4], [5].

A study made by Law and Nunez [5] had suggested that spline Laplacian method can filter the EEG signal to emphasize the local sources. In another study, Nunez et al [25] had investigated high resolution EEG using New Orleans spline Laplacian and Melbourne cortical imaging algorithms. They found that both methods can be used to provide accurate estimates of scalp potential and these approaches improve spatial resolution of EEG by factor three compared to conventional methods [25]. Another approach that can improve the time required in computation for numerical method had been studied by Zhan and Yang. They adopted finite resistance network that can estimate the cortical potential within 30 seconds using ordinary personal computer [6]. Gunter et al [1] had proposed analytic solution based on a concentric and heterogenous N-shell spherical head model assuming all current sources of electrical activity of the brain are within the innermost of the brain. They [1] found that this approach out performed the surface Laplacian method for distances between electrodes less than 2.5 cm. Another interesting approach by MettingVanRijn et al [26] is the use of active electrode as an alternative to the commonly used passive electrode to acquire high quality signal. This active electrode is designed with a miniature biopotential amplifier had shown to improve the signal quality, however some other factors need further research such as flexibility, cost of production, electrode material and pastes which also contribute to the poor quality of EEG signal [26].

All these studies will help to enhance the poor spatial resolution of EEG and thus will support the use of high resolution EEG (HREEG) in clinical and research applications.

Conclusions

EEG is an important tool for research and clinical applications due to its simplicity in the recording system, non-invasiveness and low cost. EEG recordings are excellent for their temporal resolution compared to other techniques, however the main drawback is its low spatial resolution. The challenge facing by most researchers is to obtain the accurate information of EEG for their applications. Although enormous effort had been studied by researchers to improve the spatial resolution of EEG recording, but it is still a long way of adopting such technique. Further researches are required in improving the spatial resolution and methods to extract the desired features embedded in EEG.

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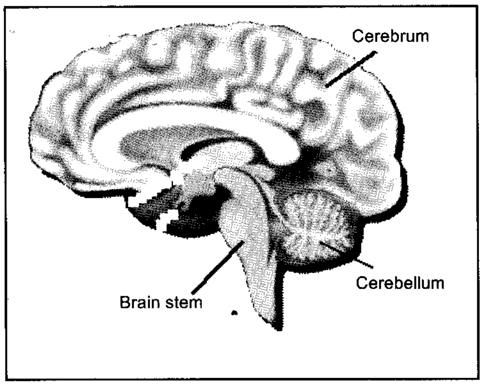


Figure 1 Three main components of the human brain

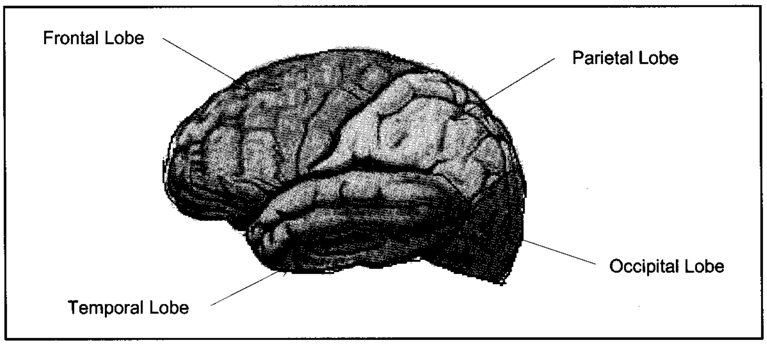


Figure 2 Lobes of the Cerebrum

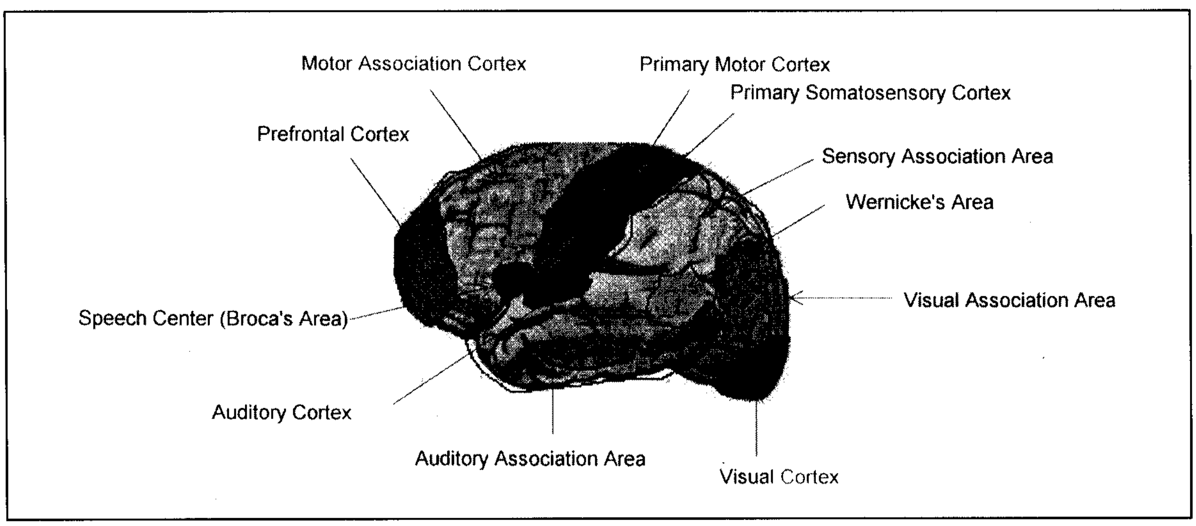
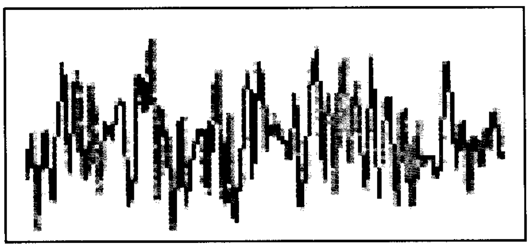


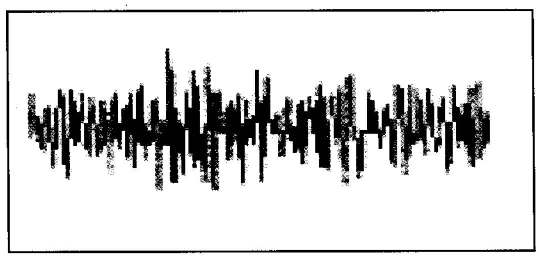
Figure 3 Cortical Areas

Table 1 Functions of Cortical Areas

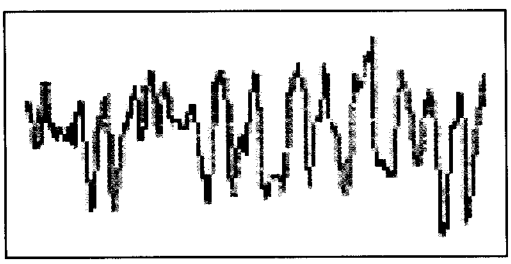
Cortical Area	Functions
Primary Motor Cortex	Initiation of voluntary movement
Primary Somatosensory Cortex	Receives tactile information, pain, pressure and heat
Prefrontal Cortex	Planning, emotion and judgment
Motor Association Cortex (Premotor Area)	Coordination of complex movements
Speech Center (Broca's Area)	Speech production and articulation
Auditory Cortex	Auditory perception and hearing
Auditory Association Area	Complex processing of auditory information
Sensory Association Area	Processing multi-sensorial information
Visual Association Area	Complex processing of visual information
Visual Cortex	Primary visual perception
Wernicke's Area	Comprehension of spoken language



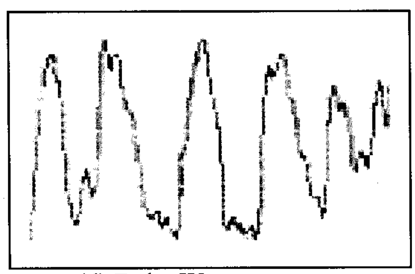
(a) Alpha Waves



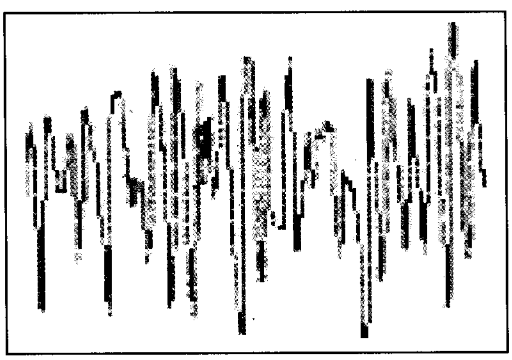
(b) Beta Waves



(c) Theta Waves



(d) Delta Waves



(e) Mu Waves

Figure 4 Periodic Sampling of Brain Waves
Source: J. Johnson, "A Sampling of Brain Waves", Scientific American, 1999

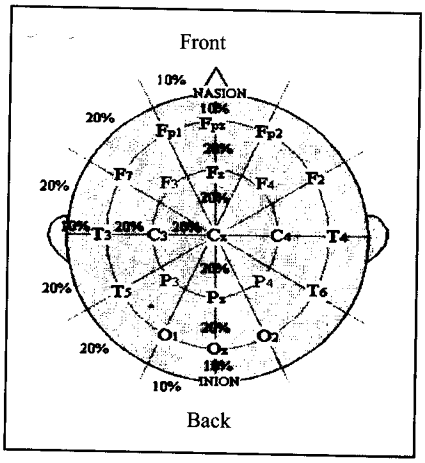


Figure 5 10-20 Electrode Placement (top view)
(F: Frontal, C: Central, T: temporal, P : Posterior and O : Occipital. The letters are accompanied with numbers by odd number at the left side of the head and even number at the right side of the head)