DEVELOPMENT OF BRAIN COMPUTER INTERFACE (BCI) SYSTEM FOR INTEGRATION WITH FUNCTIONAL ELECTRICAL STIMULATION (FES) APPLICATION

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ABSTRACT

Brain-Computer Interface (BCI) is a communication tool that translates human desire for other devices. The intention is for the majority of patients who were not able to move as stroke, spinal cord injury and traumatic brain injury. The goal of this study was to develop and analysis of offline and realtime Brain Computer Interface (BCI) system for integration with Functional Electrical Stimulation (FES) application. Here, the study using Electroencephalography (EEG) system for beta wave. PowerLab 8/35 and Dual Bio Amp as the detector signal the brain that will be used in this study. While, for analyze the offline data, LabChart and Matlab software was used but Digital Filter was used to extract the data. Values from statistic of beta band for EEG signals were used as features for extraction. The selected features were classified by using Artificial Neural Network (ANN) application to obtain the maximum classification rate. The output of this study shows that values of standard deviation, standard error, minimum, end value – start value and RMS of the beta band for EEG signal is high for swing motion and low for static. For the hardware, Arduino Mega2560 board to be used as a controller before displayed to the led. Led is ON when the input is for swing motion and OFF when is static data. All result are achieve and same with the feature extraction. For the realtime data analyzes, signal from the PowerLab 8/35 and Dual Bio Amp will be amplified and rectified. The brain signal amplified from microvolt to volt and then to rectified from alternating current (ac) signal to direct current (dc) signal before to Matlab simulink and the Arduino board as a display output. The result obtained can be applied in the Functional Electrical Stimulation (FES) system with a little modification on the future where the simulink output is converted to the pulse signal.

ABSTRAK

Brain Computer Interface (BCI) adalah alat komunikasi yang menterjemahkan keinginan manusia untuk digunakan ke peranti lain. Tujuannya adalah untuk digunakan kepada pesakit yang tidak dapat bergerak kerana strok, kecederaan tulang belakang dan kecederaan otak trauma. Matlamat kajian ini adalah untuk membangunkan dan analisis sistem *offline* dan *realtime Brain Computer Interface* (BCI) untuk diintegrasi dengan aplikasi sistem *Funtional Electrical Stimulation* (FES). Di sini, kajian ini menggunakan electroencephalography (EEG) sistem untuk gelombang beta. PowerLab 8/35 dan Dual Bio Amp digunakan sebagai pengesan isyarat otak yang akan digunakan dalam kajian ini. Walaupun bagi menganalisis data *offline*, perisian LabChart dan Matlab telah digunakan tetapi *Digital Filter* juga telah digunakan untuk mendapatkan data. Nilai dari statistik julat beta untuk isyarat EEG digunakan sebagai ciri-ciri untuk pengekstrakan. Ciri-ciri yang dipilih telah dikelaskan dengan menggunakan *Artifical Neural Network* (ANN) untuk mendapatkan kadar pengelasan maksimum. Dapatan kajian ini menunjukkan bahawa nilai-nilai sisihan piawai, ralat piawai, nilai minimum, nilai akhir - bermula dan nilai RMS julat beta adalah tinggi untuk gerakan ayunan dan rendah untuk statik. Untuk bahagian perkakasan, papan Arduino Mega2560 digunakan sebagai pengawal sebelum dipaparkan ke LED. LED akan menyala apabila masukan adalah untuk gerakan ayunan dan padam apabila data adalah statik. Semua hasil tercapai dan sama dengan pengekstrakan ciri tersebut. Bagi menganalisa data *realtime*, data daripada PowerLab 8/35 dan Dual Bio Amp akan digandakan dan dibetulkan. Isyarat otak akan digandakan daripada mikrovolt kepada nilai volt dan ditukarkan daripada isyarat arus ulangalik (au) kepada isyarat arus terus (at) sebelum ke perisian matlab simulink dan papan Arduino sebagai memaparkan keluaran. Keputusan yang diperolehi boleh digunakan dalam sistem *Fuctional Electrical Stimulation* (FES) dengan sedikit pengubahsuaian pada masa akan datang di mana keluaran simulink ditukar kepada isyarat denyut.

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LIST OF SYMBOLS AND ABBREVIATIONS

BCI	-	Brain Computer Interface
SCI	-	Spinal Cord Injuries
EEG	-	Electroencephalography
CT	-	Computer Tomography
MRI	-	Magnetic Resonance Imaging
fMRI	-	Functional Magnetic Resonance Imaging
PET	-	Positron Emission Tomography
SPECT	-	And Single Photon Emission Computed Tomography
FES	-	Functional Electrical Stimulation
AR	-	Artifact Removal
PSD	-	Power Spectral Density
MMI	-	Mind-Machine Interface
BMI	-	Brain–Machine Interface
CNS	-	Central Nervous System
PNS	-	Peripheral Nervous System
AP	-	Action Potential
ANN	-	Artificial Neural Network
ERP	-	Event Related Potential
ERD	-	Event–Related Desynchronization
FFT	-	Fast Fourier Transform

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CHAPTER 1

INTRODUCTION

1.1 Background Of The Study

Brain Computer Interface (BCI) is a kind of communication tool that translate human's intention to other devices. New developments in BCI have made it possible to use human thoughts in virtual environments (Wolpaw JR et al, 2002). BCI researches have many kind of aspects, and selection of the signal source is one of the most important issues (Saeid Sanei, 2007). BCIs create a novel communication channel from the brain to an output device bypassing conventional motor output pathways of nerves and muscles (Nizan Friedman, 2010). The goal of a BCI system is to detect and relate patterns in brain signals to the subject's thoughts and intentions. BCI has been proved to be a potential method to link the brain and the outward environment directly (Ehsan Tarkesh Esfahani et al, 2011). BCI system is mainly applied for a severely motor disorder patients or call paralysis like spinal cord injuries (SCI), strokes and epilepsy (NHS Choices news, 2013). When a person suffers a SCI, information travelling along the spinal nerves below the level of injury will be either completely or partially cut off from the brain, resulting in Quadriplegia (Tetraplegia) or Paraplegia. The spinal cord is part of the central nervous system. Its main function is to transmit signals to and from the brain and body (Apparelyzed NSI Organisation, 2013). To get the probable signal source must be to use the imaging technique.

Imaging techniques based on different physical principles include electroencephalography (EEG), computer tomography (CT), magnetic resonance imaging (MRI), functional MRI (fMRI), positron emission tomography (PET), and single photon emission computed tomography (SPECT) (M. Teplan, 2002). Many researches use electroencephalography (EEG) as a probable signal source, because of the noninvasiveness and simplicity (Nizan Friedman, 2010). Currently, noninvasive BCIs are mostly based on recording EEG signals by placing electrodes on the scalp (Wolpaw JR et al, 2006). EEG is a medical imaging technique that reads scalp electrical activity generated by brain structures. The EEG is defined as electrical activity of an alternating type recorded from the scalp surface after being picked up by metal electrodes and conductive media (M. Teplan, 2002). Several recent prototypes already enable users to navigate in virtual scenes, manipulate virtual objects or play games just by means of their cerebral activity (Wolpaw JR et al, 2006).

EEG signal will be process by functional electrical stimulation (FES) system before applied to the leg muscles. FES and motor imagery have been extensively applied in the rehabilitation training of stroke patients (J.E.Sillivan, 2007). The idea that FES therapy triggered by the active intention possibly help the stroke patients to recovery by combining the agitation from the central nervous system (CNS), the corresponding muscle stimulation and the afferet sensory feedback (Fei Meng, 2008). Figure 1.1 below shows the system that from the brain signal using EEG technique and applied to FES system and the patient muscles. In the study is an analysis for the system before to applied the FES system. In this study provide two situation are in offline and realtime.

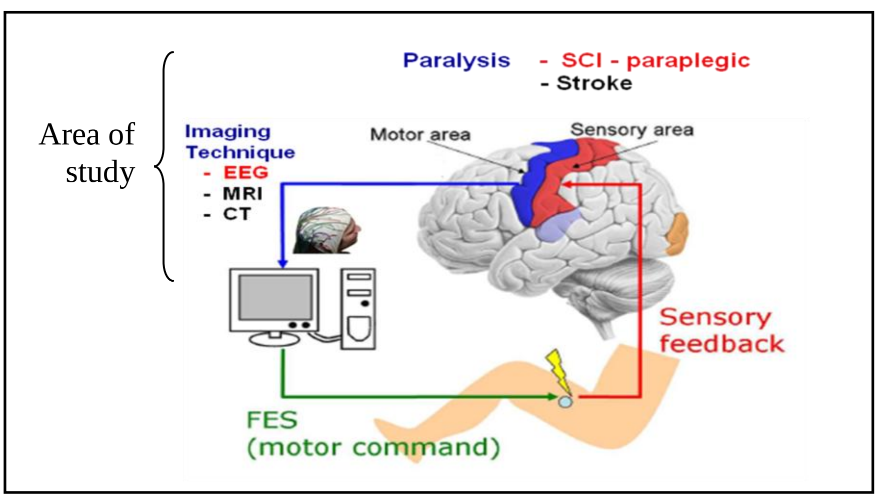


Figure 1.1 : The overall system and the area of study

1.2 Problem Statement

Spinal cord injury (SCI) or stroke is the main cause of disability of human especially paralyze (Mitsuru Takahashi et. al, 2008). The number of paralyze patients increasing every year, but no solid statistics for this category of people in Malaysia and internationally, except US where they have many Non-Profit Societies for this category of people (Anita Ahmad, 2006). This SCI has created function deficits in motor control that will disturb the people daily activities. Regarding the SCI/paralyze patients, it appear that paralyze patient cannot be static and need to do the simple activity or exercise to avoid the more serious health problem as diabetes, loss in function in mobility and other major problems due to passive activities (Carmen Moreno, 1995). On the other hand, functional electrical stimulation (FES) and motor imagery have been extensively applied in the rehabilitation training of the patients (Fei Meng et. al, 2008). However there is still lack of recovery method by the combination of BCI and FES system.

Therefore the in this study the recovery method that combines BCI and FES systems will be investigated. In this method EEG signals will be used to detect a patient's motor intention to activate a paralyzed limb. FES stimulates the corresponding muscles, which return sensory feedback to the brain creating a pseudo motor-loop. This system is expected to accelerate motor recovery by enhancing motor learning and help develop an effective rehabilitation system for severely affected the patients (Mitsuru Takahashi et. al, 2008).

1.3 Aim and Objectives of Study

Development of brain computer interface (BCI) system for integration with functional electrical stimulation (FES) application is the aim of this study. In order to achive this aim, the objectives of this study are formulated as follows :

(i) To obtain the brain signal for quadriceps muscle activity such as swinging motion.

(ii) To select the features that are most suitable to distinguish the swinging leg and static.

(iii) To design and develop an amplifier circuit to amplify the EEG signals.

(iv) To develop a mapping mechanism between BCI for Functional Electrical Stimulation (FES) application.

1.4 Scope of study

The scopes of this study are includes:

(i) Sampels

At least three normal sampels involve in this study.

(ii) Electroencephalogram (EEG) method

This study will use electroencephalography (EEG) recordings as one of the BCI method to get the brain signal.

(iii) Simulate the signal using MATLAB Simulink and coding

Some part in the feature extraction stage as classified using MATLAB to approve the signal.

1.5 Term Definition

Definition of the term is made to define or explain the terms used in this project. These terms need to be clarified to facilitate understanding of the project. Some of these terms are:

1.5.1 BCI

A brain–computer interface (BCI), often called a mind-machine interface (MMI), or sometimes called a direct neural interface or a brain–machine interface (BMI), is a direct communication pathway between the brain and an external device. BCIs are often directed at assisting, augmenting or repairing human cognitive or sensory-motor functions.

1.5.2 EEG

Electroencephalography (EEG) is the recording of electrical activity along the scalp. EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain.

1.5.3 FES

Functional electrical stimulation (FES) is a technique that uses electrical currents to activate nerves innervating extremities affected by paralysis resulting from spinal cord injury (SCI), head injury, stroke and other neurological disorders.

1.5.4 Paraplegic

A person who has paraplegia suffering complete paralysis of the lower half of the body usually resulting from damage to the spinal cord.

1.6 Conclusion

Through this study, these patients can do simple exercises like the swinging through the control of Functional Electrical Stimulation (FES) by using the Brain Computer Interface (BCI). This study will only consider the development of BCI system by producing the brain signals to activate the muscle so that these signals can be used by FES application.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter explains the background for this project, and identifies the main research questions and methods to bring clarity and define the projects focus, based on lessons learned from earlier efforts and new anticipations. To facilitate the process of building this project, case studies have been done on many aspects of the study related to body system, paralysis, brain imaging technique as EEG, MRI or CT that was used before, to choose the most appropriate and reasonable. The BCI system was also studied to understand the techniques and find features that can be used for the project. This will give more information about the technology used or to further increased use and to overcome the problems they have faced before. It is hope that this study will make the planned project will be successful and higher accuracy.

2.2 Paralysis

Paralysis is loss of the ability to move one or more muscles. It may be associated with loss of feeling and other bodily functions. Paralysis is not usually caused by problems with the muscles themselves, but by problems with the nerves or spinal cord that the brain uses to control muscles. Therefore, a person with paralysis will usually have some form of nerve damage (NHS Choices news, 2013).

There are also a number of medical terms used to describe different types of paralysis shown in Table 2.1. The three most common causes of paralysis are stroke, spinal cord injury (the spinal cord is a bundle of nerve tracts that runs through the spine and helps control the body's muscles) and multiple sclerosis (NHS Choices news, 2013).

Table 2.1 : Types of Paralysis and Part of Limb (NHS Choices news, 2013)

Paralysis Type	Part of Limb
monoplegia	one limb is paralysed
hemiplegia	the arm and leg on one side of the body are paralysed
paraplegia	both legs and sometimes the pelvis and some of the lower body are paralysed
tetraplegia	both the arms and legs are paralysed (also known as quadriplegia)

When a person suffers a spinal cord injury (SCI), information travelling along the spinal nerves below the level of injury will be either completely or partially cut off from the brain, resulting in Quadriplegia (Tetraplegia) or Paraplegia (Apparelyzed NSI Organisation, 2013). The spinal cord is part of the central nervous system. Its main function is to transmit signals to and from the brain and body (NHS Choices news, 2013). Figure 2.1, shows the area and type of paralysis due to SCI.

The body will still be trying to send messages from below the level of injury to the brain known as sensory messages, and the brain will still be trying to send messages downwards to the muscles in the body, known as motor messages. These messages however, will be blocked by the damage in the spinal cord at the level of injury. Nerves joining the spinal cord above the level of injury will be unaffected and continue to work as normal (Apparelyzed NSI Organisation, 2013).

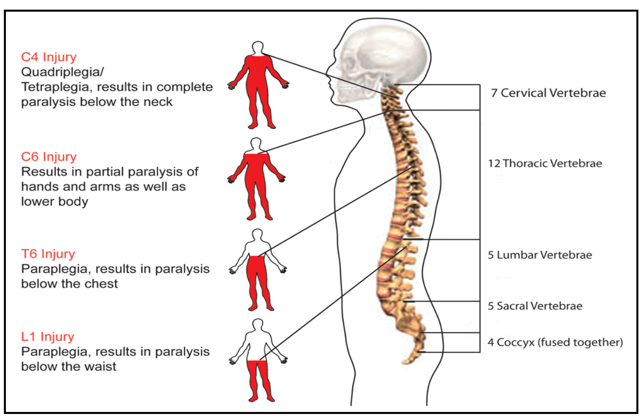


Figure 2.1 : Area of Paralysis due to Spinal Cord Injury
(Apparelyzed NSI Organisation, 2013)

2.3 Nervous System

The nervous system composed of nerve cells or neurons that communicate with each other and with other cells in the body (Mark Rhothery biology web, PATTS, 2001). It includes the central nervous system (CNS), which is made up of the brain and spinal cord, and the peripheral nervous system (PNS), which includes all of the nerves and other nervous structures in the rest of the body (Eric Chudler, 2013). Figure 2.2, shows the nervous system in human body. PNS is subdivided into autonomic nervous system (control smooth and visceral muscles) and somatic nervous system (control skeletal muscle) (PATTS, 2001).

The nervous system is a network of fibers that starts in the brain and spinal cord and branches out to the rest of the body, with each branch getting progressively smaller. The CNS includes the brain, which is encased in the skull, and the spinal cord, which is a long tube that extends. These nerves receive information from body tissues and the outside world and pass it along to the brain and spinal cord. These nerves also carry the signals from the CNS to make body parts move or function (Saeid Sanei et al, 2007).

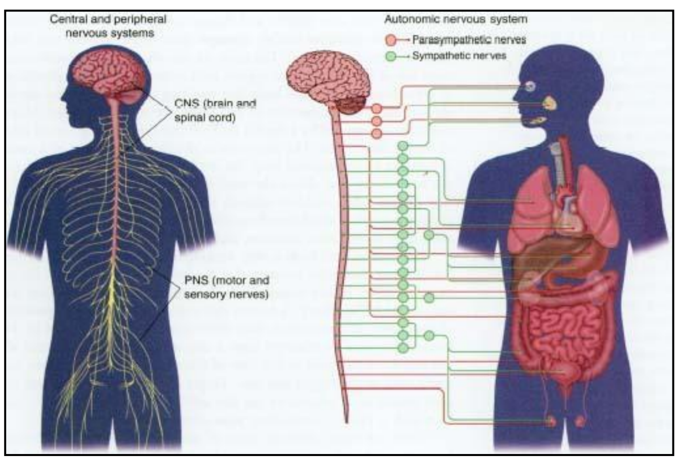


Figure 2. 2 : Nervous System (Eric Chudler, 2013)

The function of the spinal cord is to relay messages or signals from the body to the brain and from the brain to the body. There are three kinds of functional messages or signals which travel along the spinal cord are sensory (feeling), motor (movement) and autonomic (Mark Rothery biology web).

2.3.1 Neural Activities

The CNS generally consists of nerve cells and glia cells, which are located between neurons. Each nerve cell has three parts consists of axons, dendrites and cell bodies (Saeid Sanei et al, 2007, PATTS, 2001). In the human brain each nerve is connected to approximately 10,000 other nerves, mostly through dendritic connections (Saeid Sanei et al, 2007).

A neuron has a cell body containing the nukleus with extensions leading off it (PATTS, 2001). Numerous dendrons and dendrites provide a large surface area for connecting with other neurons, and carry nerve impulses towards the cell body. A single long axon carries the nerve impulse away from the cell body. The axon is only 10µm in diameter but can be up to 4m in length in a large animal. Nerve impulse can be passed from the axon of one neuron to the dendron of another at a synapse (Mark Rothery biology web). Figure 2.3, shows the structure of a neuron. Humans have three types of neuron as sensory neurons, motor neurons and inter neurons (Saeid Sanei et al, 2007)

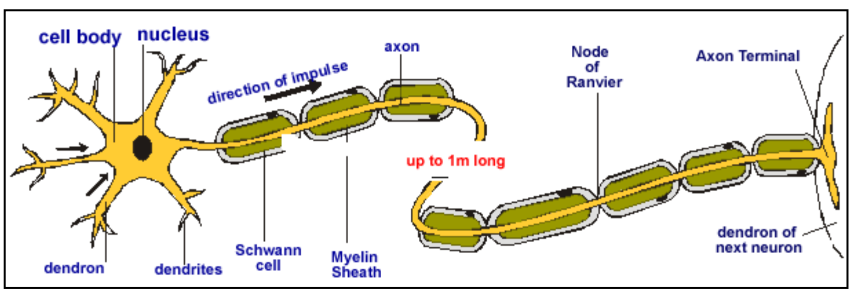


Figure 2.3 : Structure of a neuron (Mark Rothery biology web)

Neurons and muscle cells are electrically excitable cells, which means that they can transmit electrical nerve impulses. These impulses are due to events in the cell membrane, so to understand the nerve impulse we need to revise some properties of cell membranes (Saeid Sanei et al, 2007). Relationship between sensory neuron and motor neuron in the body system are sensory neuron to moving away from a central organ or point and relays messages from receptors to the brain or spinal cord. For the motor neuron is moving toward a central organ or point and relays messages from the brain or spinal cord to the muscles and organs. Figure 2.4 shows the situation.

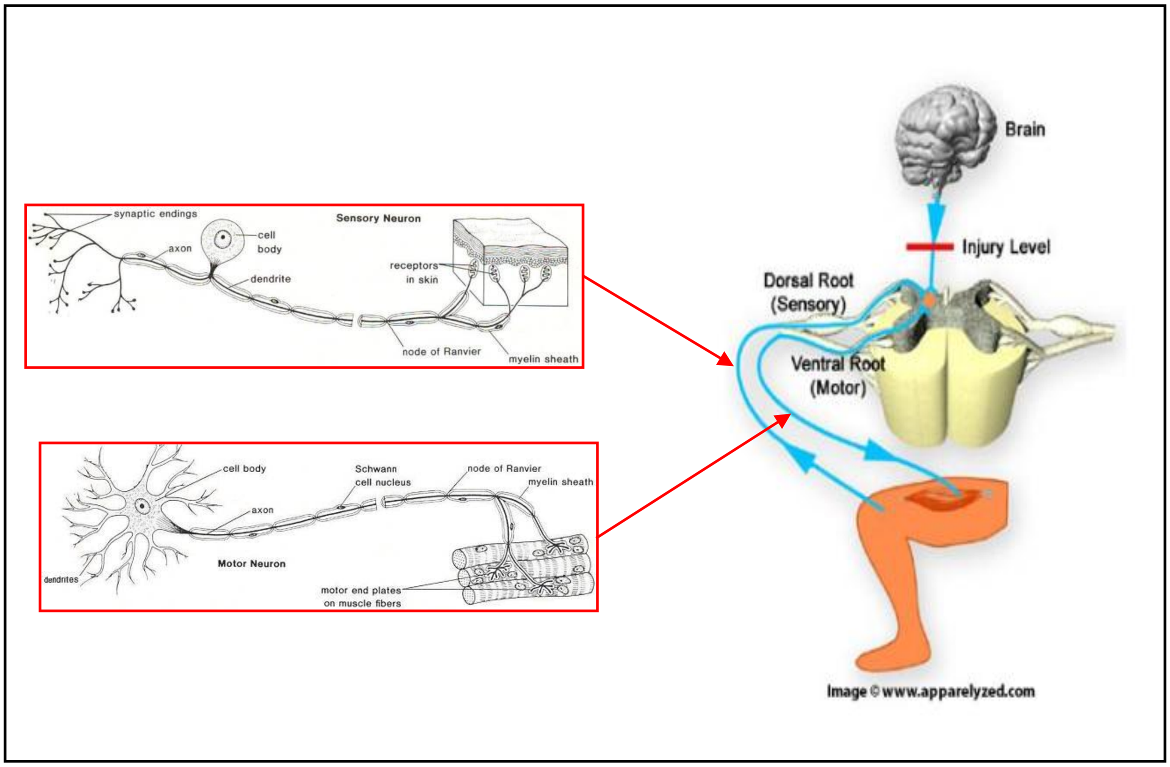


Figure 2.4 : Sensory neuron and motor neuron system

2.4 Brain

The human head consists of different layers including the scalp, skull, brain and many other thin layers between (Saeid Sanei et al, 2007). The human brain is the site of the major coordination in the nervous system. It contains around 10^{10} (10 billion) neurons, each making thousands of connections to others, so the number of pathways through the brain is vast. Different regions of the brain can be identified by their appearance, and it turns out that each region has a different role (Saeid Sanei et al, 2007, Mark Rothery biology web).

Studies like these have shown that the various functions of the cortex are localised into discrete areas. These areas can be split into three groups which sensory areas, motor areas and association areas . Sensory areas which receive and process sensory input from the sensory organs. There are different sensory areas for each sense organ (visual, auditory, smell, skin, etc.). Motor areas, which organize and send motor output to skeletal muscles. The motor neurons originate in these areas but are usually processed by the cerebellum before going to the muscles. So the cortex may decide to walk up stairs, but the cerebellum will organize exactly which muscle cells to contract and which to relax. Association areas, which are involved in higher processing (Mark Rothery biology web). Figure 2.5, shows the basic functional brain map.

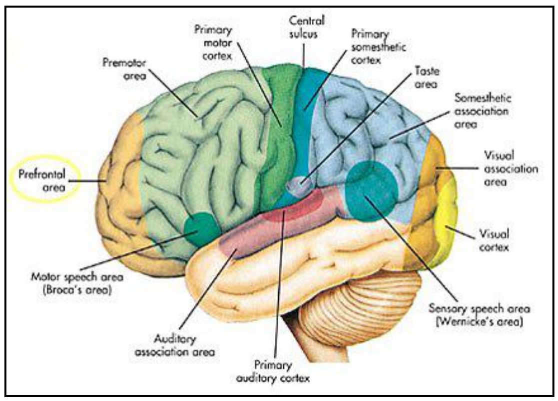
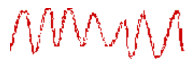
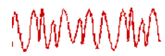
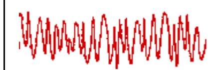


Figure 2.5 : Basic functional brain map (Universe-review.ca, n.d.)

2.4.1 Brain Rhythm

For obtaining basic brain patterns of individuals, subjects are instructed to close their eyes and relax. Brain patterns form wave shapes that are commonly sinusoidal. Usually, they are measured from peak to peak and normally range from 0.5 to 100 μV in amplitude, which is about 100 times lower than ECG signals. By means of Fourier transform power spectrum from the raw EEG signal is derived. In power spectrum contribution of sine waves with different frequencies are visible. Although the spectrum is continuous, ranging from 0 Hz up to one half of sampling frequency, the brain state of the individual may make certain frequencies more dominant. Brain waves have been categorized into four basic groups (M. Teplan, 2002). Table 2.2, shows the most used frequency bands and their relations, of the human brain wave activity.

Table 2.2 : Frequency bands and their relations, of the human brain wave activity (Newbrainnewworld.com, 2013, Saeid Sanei et al, 2007, Andreas Larsen, 2011)

Rhytm	**Unconscious**		**Conscious**	
	Delta (δ)	**Theta (θ)**	**Alpha (α)**	**Beta (β)**
Signal Pattern				
Frequency Component	0.5 to 3.5 Hz	3.5 to 7.5 Hz	α1 (7.5 to 9.25 Hz) α2 (10 to 11.75 Hz)	β1 (13 to 16.75 Hz) β2 (17 to 29.75 Hz)
Amplitude	100 μV	Child: 20 μV Adult: 10 μV	Baby: 20 μV Child: 75 μV Adult: 50 μV	10 to 20 μV
Main Scalp Area	Front	Temporal	back of the head and in the frontal lobe	β1 (central and frontal) β2 (Both sides of central)
Human Condition	Deep Sleep Dreaming Coma	Feeling Trace states Sleepy	Thinking Relaxed Closed Eyes	Alert Concentration Opened Eyes Motion

2.4.2 Electrode Placement System

The International Federation of Societies for Electroencephalography and Clinical Neurophysiology has recommended the conventional electrode setting for 21 electrodes (including the earlobe electrodes) as in Figure 2.6 (Saeid Sanei et al, 2007, M. Teplan, 2002).

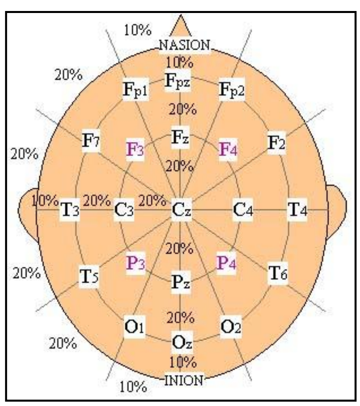


Figure 2.6 : Labels for points according to 10-20 electrode placement system (Saeid Sanei et al, 2007, M. Teplan, 2002)

Even numbered electrodes are placed on the right side of the head, and odd are placed on the left. The electrodes in this arrangement are placed along a bisecting line drawn from the nose (nasion) to the back of the head (inion), first at the position 10% of the distance along the line, then at 20% intervals (Saeid Sanei et al, 2007). Electrode placements are labeled according adjacent brain areas as in Table 2.3 (M. Teplan, 2002). The earlobe electrodes called A1 and A2, connected respectively to the left or right earlobes are used as the reference electrodes (Saeid Sanei et al, 2007, M. Teplan, 2002).

Table 2.3 : Identified the letter of 10-20 EEG electrodes
(M. Teplan, 2002)

Letter	Description
A	Earlobe electrode used as the reference
F	Frontal lobe
T	Temporal lobe
C	Central lobe
P	Parietal lobe
O	Occipital lobe
Z	Refer to an electrode placed on the mid-line

As it is known from tomography different brain areas may be related to different functions of the brain. Each scalp electrode is located near certain brain centre, e.g. F7 is located near centre for rational activities, Fz near intentional and motivational centre, F8 close to sources of emotional impulses. Cortex around C3, C4, and Cz locations deals with sensory and motor functions. Locations near P3, P4, and Pz contribute to activity of perception and differentiation. Near T3 and T4 emotional processors are located, while at T5, T6 certain memory functions stand. Primary visual areas can be found bellow points O1 and O2. However the scalp electrodes may not reflect the particular areas of cortex, as the exact location of the active sources is still open problem due to limitations caused by the non-homogeneous properties of the skull, different orientation of the cortex sources, coherences between the sources, etc. (M. Teplan, 2002). The general configuration is called montage (Saeid Sanei et al, 2007, M. Teplan, 2002).

2.5 BCI System

Like any communication or control system, a BCI has input, output, components that translate input into output, and a protocol that determines the onset, offset, and timing of operation. Figure 2.7, shows these elements and their principal interactions.

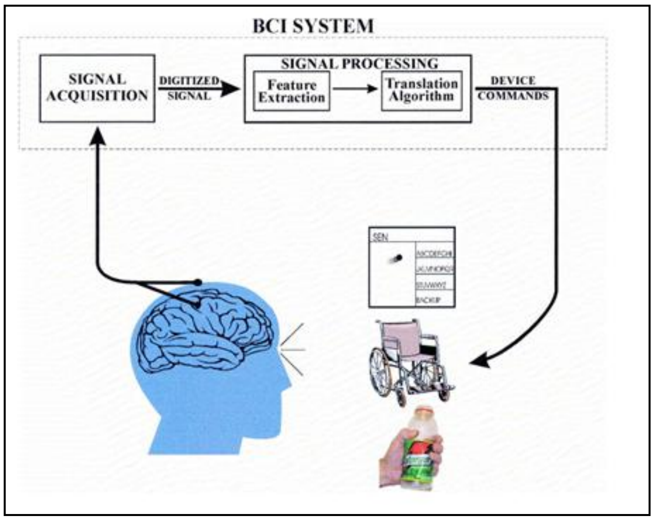


Figure 2.7 : Basic design and operation of any BCI system
(Walpow JR et al, 2002)

2.5.1 Signal Acquisition

In the BCIs the input is EEG recorded from the brain are acquired by electrodes on the scalp or the surface of the brain or neuronal activity recorded within the brain (Walpow JR et al, 2002). In the signal acquisition part of BCI operation are the recording electrodes, amplified and the signal is the digitized for analysis (Saeid Sanei et al, 2007). Recording sites for electrophysiological signals used by brain–computer interface (BCI) systems. Electroencephalographic activity (EEG) is recorded by electrodes on the scalp (Walpow JR et al, 2006). .

As previously discussed, an electrode is used to receive neural input. There are three main methods by which neural signals are currently recorded ie invasive

BCI, partially invasive BCI and non-invasive BCI. The familiar is non-invasive BCI because non-invasive technique, relatively inexpensive and can be tested on a large human population. The Electrode is placed on surface of scalp and measures electroencephalogram (EEG) signals (Nizan Friedman, 2010).

2.5.2 Signal Processing

In this stage is to conversion of the raw signal EEG data into a useful device command. This data is usually not clean so some preprocessing steps are needed.

2.5.2.1 Feature Extraction

Feature extraction is the process of extracting useful information from the EEG signals. Features are characteristics of signal that are able to distinguish between motion method.

Due to the non-linearity and non-stationary nature of the EEG signal, the classical methods based on Fourier transform (FT) are, in general, not efficient for feature extraction because they obtained features do not provide any time domain information, these features do not analyze the time-varying spectral content of the signals. Typically, EEG is analyzed using Fast Fourier Transform (FFT) because EEG signals are often quantified based on frequency domain characteristics.

However, Anderson and Sijercic (1996) claimed that EEG signals cannot be considered as stationary even under short time duration, since it can exhibit considerable short-term non-stationary signals. Because of this reason, instead of using Fast Fourier Transform (FFT), Wavelet Transform (WT) method more suitable to use to extract the EEG signals. It is because Wavelet Transform (WT) method is using to analyze non-stationary signal and it can capture both frequency and location information. But, FFT based spectral analysis required the signals is to be stationary (Muruggapan, M., 2010).

These often include the application of filters, such as a high-pass filter to remove the DC components of the signals and also the drifts (usually a frequency cut-off of 1 Hz is enough). A low pass filter can also be applied to remove the high frequency components. In EEG currently rarely study frequencies above 90 Hz which correspond to the Gamma range (Nizan Friedman, 2010). Band pass filter removes all frequencies outside f 1 - f 2 (Used often in EEG measurements) (JA Putman, 2007). This analysis extracts the signal features that encode the user's messages or commands.

Figure 2.8,,shown the narrow band-pass filters remove all except a narrow range of frequencies. The centre frequency (Hz) is the mid-point of the range of frequencies which are passed by the filter. Transition width - the width between the two frequencies where the output amplitude rises above 1% of the input amplitude. The default value is automatically adjusted depending on sampling rate and centre frequency (ADinstruments, 2012).

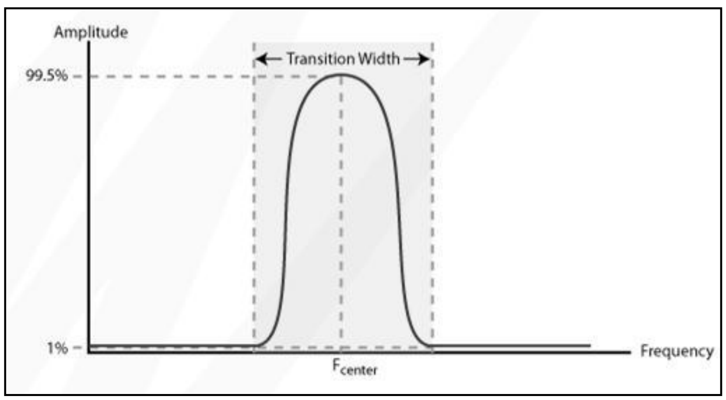


Figure 2.8 : Bandpass filter (Wan Afif, 2013)

BCIs can use signal features that are in the time domain or the frequency domain. The location, size, and function of the cortical area generating a rhythm or an evoked potential can indicate how it should be recorded, how users might best learn to control its amplitude, and how to recognize and eliminate the effects of non-CNS artifacts. It is also possible for a BCI to use signal features, like sets of autoregressive (AR) parameters, that correlate with the user’s intent but do not necessarily reflect specific brain events (Walpow JR et al, 2002). In A BCI could conceivably use both time-domain and frequency-domain signal features, and might thereby improve performance (JA Putman, 2007).

2.5.2.2 Translation Algorithm

The first part of signal processing simply extracts specific signal features. The next stage, the translation algorithm, translates these signal features into device commands-orders that carry out the user's intent. This algorithm might use linear methods (e.g. classical statistical analyses) or nonlinear methods (e.g. neural networks). Whatever its nature, each algorithm changes independent variables (i.e. signal features) into dependent variables (i.e. device control commands).

Like activity in the brain's conventional neuromuscular communication and control channels, BCI signal features will be affected by the device commands they are translated into: the results of BCI operation will affect future BCI input. In the most desirable case, the brain will modify signal features so as to improve BCI operation (Walpow JR et al, 2002).

2.5.3 The Output Device

The overt command or control functions that are administered by the BCI system. These outputs can range from word processing and communication to higher levels of control such as driving a wheel chair or controlling a prosthetic limb. All of these elements work in concert to give the user control over his or her environment (Saeid Sanei et al, 2007).

2.6 Classification

After extracting the desired features, a classifier is needed to find the movement signal. A classifier is a system that divides some data into different classes and is able to learn the relationship between the features and the movement that belongs to that part of the EEG signal.

There are five categories that covers the most used algorithms in BCI classification systems, and they are: linear classifiers, nonlinear Bayesian classifiers, nearest neighbor classifiers, neural networks, and a combination of classifiers (Lotte et al., 2007). The most popular in BCI research are neural networks and is the chosen method to classify in this study.

2.6.1 Artificial neural network

Artificial Neural Networks (ANN) are nonlinear information (signal) processing devices. ANN is an information-processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information (S.N. Sivanandam. et al., 2003).

Neural Network (NN) gained its knowledge from past experiences to deal with a problem and situation. NN take a solution before to build up the system in decision making neurons. NN which consist of three layers of neurons will learn through the adjustment between the weights and the associated layer. The answer to this network was compared with that required answer over and over during the training phase (Ariffuddin Joret *et al.*, 2012).

In contrast, if the network has too many hidden nodes it will follow the noise in the data due to over-parameterization, leading to poor generalization for untrained data. With increasing number of hidden layers, training becomes excessively time-consuming. The most popular approach to finding the optimal number of hidden 16 layers is by trial and error (Basheer and Hajmeer, 2000; Fausett, 1994; Haykin, 1994). The basic building blocks of the ANN are:

i) Network architecture – the arrangement of neurons into layers and the pattern of connection within and in between layer. The number of layers in the net can be defined to be the number of layers of weighted interconnected links between the particular slabs of neurons.

ii) Setting the weights – The method of setting the value the weights enable the process of learning or training. The process of modifying the weights in the connections between network layers with the objective of achieving the expected output is called training a network.

iii) Activation function – to calculate the output response of a neuron. The sum of the weighted input signal is applied with an activation to obtain the response. The nonlinear activation functions are used in a multilayer net (S.N. Sivanandam. et al., 2003).

The multilayer feed forward neural network is the workhorse of the Neural Network Toolbox software. It can be used for both function fitting and pattern recognition problems. The work flow for the general neural network design process has seven primary steps data collection, network creation, network configuration, weights and biases initialize, network training, network validation (post-training analysis) and network usage (Wan Afif bin Wan Anwar 2013). The multilayer perceptron for the three layer ANN shown in figure 2.9.

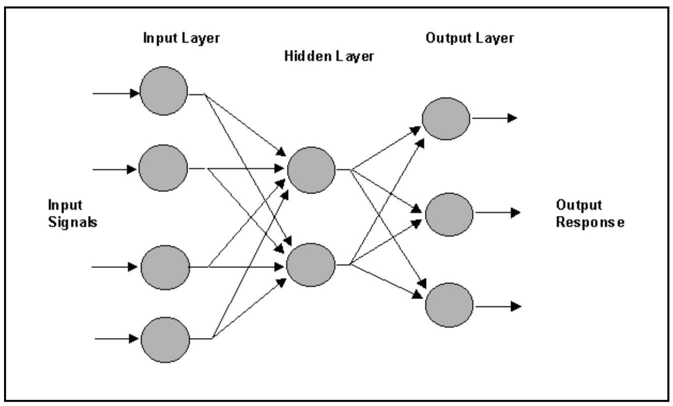


Figure 2.9: Multilayered perceptron (www.gopixpic.com)

2.6.2 Back Propagation

The back propagation (BP) training algorithm involves three stages the feed forward of the input training pattern, the calculation and back propagation of the associated weight error and the weight adjustments (C. R. Hema et al., 2007).

The most frequently used training algorithm in classification problems is the backpropagation (BP). The process of BP is each neuron receives a signal from the neurons in the previous layer, and each of those signals is multiplied by a separate weight value. The weighted inputs are summed, and passed through a limiting function which scales the output to a fixed range of values. The output of the limiter is then broadcast to all of the neurons in the next layer. So, to use the network to solve a problem, we apply the input values to the inputs of the first layer, allow the signals to propagate through the network, and read the output values (B. Sumathi, Dr. A. Santhakumaran, 2007).

2.7 Brain Imaging Techniques

Brain imaging techniques allow doctors and researchers to view activity or problems within the human brain, without invasive neurosurgery. There are a number of accepted, safe imaging techniques in use today in research facilities.

2.7.1 EEG

Electroencephalography (EEG) is an amplified recording of the waves of electrical activity that sweep across the brain’s surface. When brain cells (neurons) are activated, the synaptic currents are produced within dendrites (Saeid Sanei et al, 2007). These wave are measured by electrodes placed on the scalp (Mayoclinic.com, 2012). The resulting traces are known as an EEG and represent an electrical signal from a large number of neurons.

EEGs are frequently used in experimentation because the process is non-invasive to the research subject. The EEG is capable of detecting changes in electrical activity in the brain on a millisecond-level. It is one of the few techniques available that has such high temporal resolution (M. Demitri, 2007). Figure 2.10, shows electrode cap with electrodes placed after 10-20 electrode placement system.

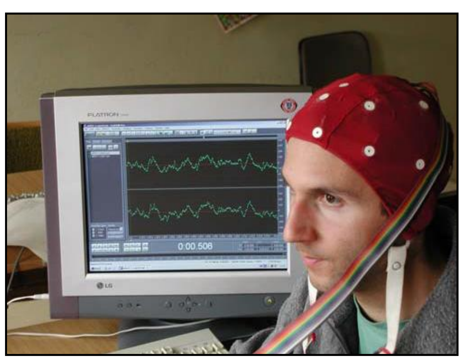


Figure 2.10 : Electrode cap with electrodes placed after 10-20 electrode placement system (M. Teplan, 2002)

2.7.1.1 EEG Recording Technique

To define the good signal from the EEG system must be have the technique. EEG measurements employ recording system consisting of electrodes with conductive media, amplifiers with filters, A/D converter and recording device.

Electrodes read the signal from the head surface, amplifiers bring the microvolt signals into the range where they can be digitalized accurately, converter changes signals from analog to digital form, and personel computer (or other relevant device) stores and displays obtained data.

Scalp recordings of neuronal activity in the brain, identified as the EEG, allow measurement of potential changes over time in basic electric circuit conducting between signal (active) electrode and reference electrode (M. Teplan, 2002). Extra third electrode, called ground electrode, is needed for getting differential voltage by subtracting the same voltages showing at active and reference points. Minimal configuration for mono-channel EEG measurement consists of one active electrode, one (or two specially linked together) reference and one ground electrode. The multi-channel configurations can comprise up to 128 or 256 active electrodes.

2.7.1.2 EEG Artifacts

Since EEG signals are very weak (ranging from 1 to 100 μV), they can easily be contaminated by other sources. An EEG signal that does not originate from the brain (Arthur C. Clarke, 2009) or the basic evaluation of the EEG traces belongs scanning for signal distortions is called an artifacts (M. Teplan, 2002). The complete removal of artifacts will also remove some useful information of EEG signals (Murugappan, M., Nagarajan, R. & Yaacob, S., 2010). Therefore, that is impossible to remove all the artifacts in EEG signals.

Artifacts can be divided into two categories: physiologic or patient-related and non-physiologic or technical (M. Teplan, 2002, Arthur C. Clarke, 2009). Any source in the body which has an electrical dipole or generates an electrical field is capable of producing physiologic artifacts. These include the heart, eyes movement, muscle, tongue and sweating can also alter the impedance at the electrode scalp interface and produce an artifact (Saeid Sanei, 2007, Arthur C. Clarke, 2009). Non-physiologic artifacts include 60 Hz interference from electric equipment, kinesiologic artifacts caused by body or electrode movements, and mechanical artifacts caused by body movement (Arthur C. Clarke, 2009). Figure 2.11, shows the EEG signal contaminated with noise and eye blink artifacts.

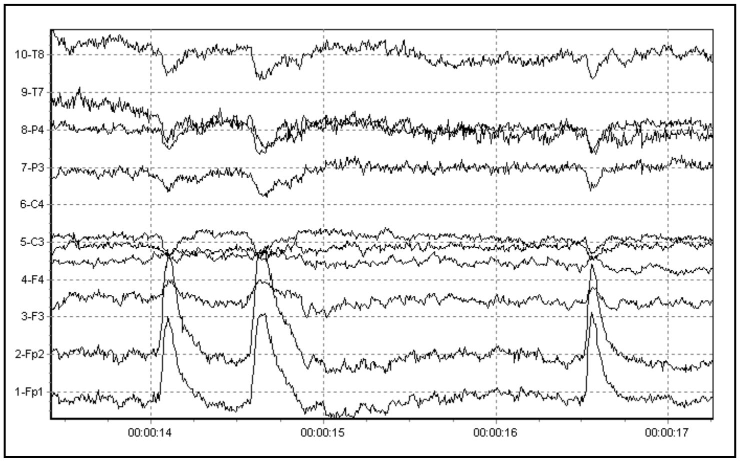


Figure 2.11 : The EEG signal contaminated with noise and eye blink artifacts (Arthur C. Clarke, 2009)

2.7.2 MRI

Magnetic Resonance Imaging (MRI) is a technique with high resolution that uses magnetic field and radio waves to produce computer-generated images that distinguish among different types of soft tissues, allows us to se structures in the brain (Mayoclinic.com, 2012).

It is based on the principle that changes in regional cerebral blood flow and metabolism are coupled to changes in regional neural activity involved in brain functioning. Significant contrast in tissue can be attributed to changes either in blood flow alone, or in metabolism alone, or in blood flow and metabolism (M. Dimitri, 2007). Figure 2.12 shows example of MRI scanner cutaway.

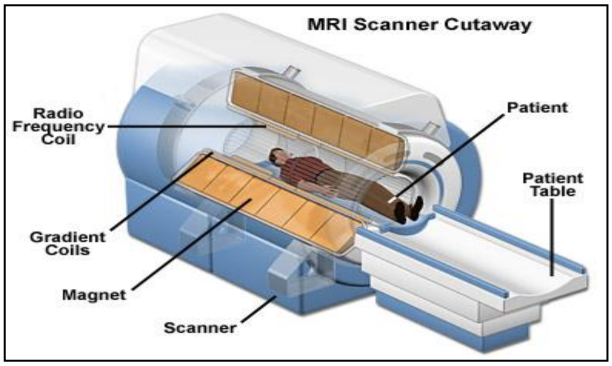


Figure 2.12 : MRI Scanner Cutaway (Albert Wong, 2009)

2.7.3 CT

Computed tomography (CT) scanning builds up a picture of the brain based on the differential absorption of X-rays. During a CT scan the subject lies on a table that slides in and out of a hollow, cylindrical apparatus. An x-ray source rides on a ring around the inside of the tube, with its beam aimed at the subjects head. After passing through the head, the beam is sampled by one of the many detectors that line the machine's circumference. Images made using x-rays depend on the absorption of the beam by the tissue it passes through. Bone and hard tissue absorb x-rays well, air and water absorb very little and soft tissue is somewhere in between. Thus, CT scans reveal the gross features of the brain but do not resolve its structure well (M. Demitri, 2007). Figure 2.13 shows example of CT scanner operate.

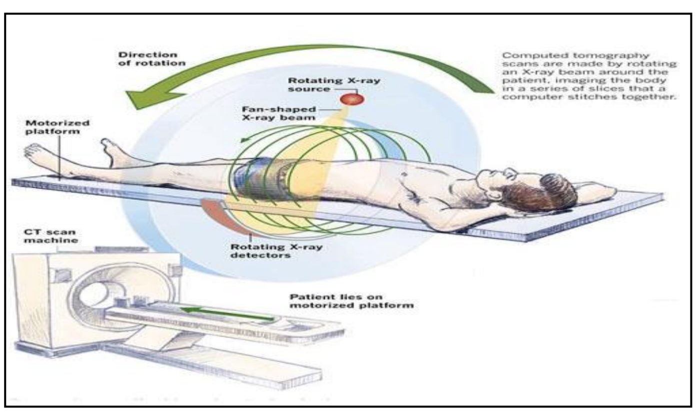


Figure 2.13 : CT Scanner (Mayoclinic.com, 2012)

2.7.4 Compare of EEG, MRI and CT

Table 2.4 shows comparison the characteristics for EEG, MRI and CT system to choose the better system in this study.

Table 2.4 : Comparison between EEG, MRI and CT scan
(M. Teplan, 2002, Albert Wong, 2009)

Item	EEG	MRI	CT scan
Definition	- Electroencephalography	- Magnetic Resonance Imaging	- Computerized Tomography
How to work	- EEG analyzes brain wave functioning using electrical impulses generated by the neurons.	- Basically the MRI scanner uses magnetic fields and radio waves to create an image of the brain	- Combined a series of X-ray views taken from many different angles and computer processing to create cross-sectional images of the bones and soft tissues inside the body.
What material to use	- Uses electrical impulses	- Uses magnetic fields and radio waves	- Use X-rays (invisible radiation)
How strong	- Amplitude of 0.5-100 microvolts and a frequency spectrum from 0.1 to 60 Hz.	- The Earth's magnetic field is about 0.5 gauss (1 Tesla = 10,000 gauss). So MRI is about 60,000 times more powerful than the earth's magnetic field.	- Require a dose of radiation that can be 100 times that of a standard X-ray.

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