

# **ANN based Epilepsy Classification using EEG**

*A Dissertation*

*Submitted in partial fulfillment of the requirements for the award of degree of*

**Master of Engineering**

**in**

**Electronic Instrumentation and Control**



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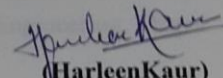
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**JULY 2013**

## DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled "ANN based Epilepsy Classification using EEG" in partial fulfilment of award of degree of **Master in Engineering in Electronic Instrumentation and Control** submitted in Electrical and Instrumentation Department, Thapar University, Patiala, is an authentic record of my own work carried under the supervision of **Dr. Mandeep Singh**, Associate Professor, Department of Electrical and Instrumentation Engineering, Thapar university, Patiala.


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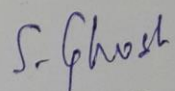
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I certify that the above statement made by the student is correct to the best of my knowledge and belief.

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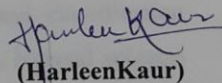
With deep sense of gratitude, I express my sincere thanks to my esteemed and worthy guide, **Dr. Mandeep Singh**, Associate Professor, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala, Punjab, for his invaluable guidance in carrying out the work under his effective supervision, encouragement, enlightenment and cooperation. His feedback and editorial comments were invaluable for writing this dissertation.

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I am also thankful to my family and friends for providing me emotional support and blessings.

Finally, I am very thankful to my husband Mr Rushdeep Singh who reminds me of my positive attributes, strengths and ability to handle a difficult situation.

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## ABSTRACT

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Brain is the most complex organ amongst all the systems in human body. ElectroEncephaloGraph (EEG) is a record of electrical activity of brain, which is used to identify the neurological disorder of brain. There are various neurological disorders like Epilepsy, brain cancer, etc. Epilepsy is one of the most common neurological disorders of brain. Objective detection efficiently is still a challenging task for many neurological disorders. Epilepsy needs to be detected efficiently using required EEG feature extraction such as: variance, power spectral density, energy and entropy. This dissertation discusses the design of the system that detects the epileptic activity with efficacy. Decomposition of the EEG signal to various sub-bands by multi-level wavelet decomposition is followed to extract features from these sub-bands. These sub-bands are delta (0-4.05 Hz), theta (4.05-8.1 Hz), alpha (8.1-12.15 Hz), beta (12.15-32.5 Hz) and gamma (>32.5 Hz). The range of the features in normal and epileptic group of 50 subjects from each data set is analyzed for data available at the Department of Epileptology, University of Bonn. These features are then classified using an artificial neural network (ANN) that detects the EEG data for epilepsy. The performance of the ANN classifier is evaluated in terms of sensitivity, specificity and classification accuracy. Two-class classification is done for normal and epileptic subjects. Normal subjects are further classified for eyes open and eyes closed. Epileptic subjects are further classified for non-seizure and seizure, and non-seizure as hippocampal formation and epileptogenic zone. It is observed that the repeated use of two-class classifier gives better accuracy i.e. in the range of 98.7% - 100%. Multi-class classification is done on normal and epileptic subjects that show lower but reasonably good classification accuracy (88.4%).

## **ORGANIZATION OF DISSERTATION**

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The dissertation begins by introducing ElectroEncephaloGraph (EEG), parts of human brain, different types of waves form during EEG recording, artifacts that are introduced while recording an EEG signal, Epilepsy, seizures, types of seizures, hippocampal formation, epileptogenic zone, treatment in Chapter 1. This is followed by a discussion of previous work that has already been carried out in the detection of epileptic activity in Chapter 2. Chapter 3 demonstrates problem statement of the present work done. Chapter 4 explains the methodology on which the whole work stands and Chapter 5 delves into the results obtained into tabular form and discussions over the result. Finally, Chapter 6 concludes the thesis and outlines directions for future work. The dissertation ends with references and publications from the present research.

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# CHAPTER 1: INTRODUCTION

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## 1.1 ElectroEncephaloGraph (EEG)

Brain is the most complex organ in the human body and is certainly the most remarkable one too. The nerve cells of the brain generate electrical impulses that fluctuate rhythmically in distinct patterns. In 1929 German scientist Hans Berger developed an electroencephalograph, an instrument that measures and records the brain-wave patterns. The recording produced by such an instrument is called an ELECTROENCEPHALOGRAPH, commonly abbreviated EEG. This procedure tracks and records brain-wave patterns. Small metal discs with thin wires (electrodes) are placed on the scalp, and then send signals to a computer to record the results. Normal electrical activity in the brain makes a recognizable pattern. Through an EEG, doctors can look for abnormal patterns that indicate seizures and other problems.

## 1.2 Parts of Human Brain

Human brain is divided into three parts: cerebrum, cerebellum and the brain stem. The cerebrum is the largest part and is responsible for initiation of movement, coordination of movement, sensing temperature, touch, vision, hearing, judgement, reasoning, problem solving, emotions and learning. Cerebrum is divided into four lobes as shown in figure 1.1. These are frontal lobe, occipital lobe, parietal lobe & temporal lobe. Each of the lobes contains a variety of brain areas that have minimal functional relationship. The parietal lobe, for example, contains areas involved in somatosensation, hearing, language, attention, and spatial cognition. The main functions of the frontal lobe are to control attention, abstract thinking, and behaviour, problem solving tasks, and physical reactions and personality. The occipital lobe is the smallest lobe; its main functions are visual reception, visual-spatial processing, movement, and colour recognition. The temporal lobe controls auditory and visual memories, language, and some hearing and speech. The smaller part of the brain is cerebellum. Its purpose is to coordinate voluntary muscle movements and to maintain posture, balance and equilibrium. The brainstem is the midline or middle of the brain. This part is responsible for movement of the eyes and mouth: relaying sensory messages like

temperature, voice pain etc. It also controls hunger, respiration, consciousness, cardiac functions, body temperature etc [1].

EEG has been found a very powerful tool in neurology. The voltage range for EEG signal is 3-100  $\mu$ V which is 100 times weaker than ECG signal. The electroencephalogram (EEG) is a non-invasive, multi-electrode recording of time-varying potentials generated by the millions of neurons. The electrodes are distributed symmetrically around the scalp as shown in Figure 1.2 to provide a temporal and spatial summary of brain surface activity; each electrode responds to the aggregate potential generated by many neurons in the area beneath it. EEG activity of clinical relevance is roughly limited to the frequency band 0.5-50 Hz, and that of seizure activity is further limited to the frequency band 0.5-25 Hz.

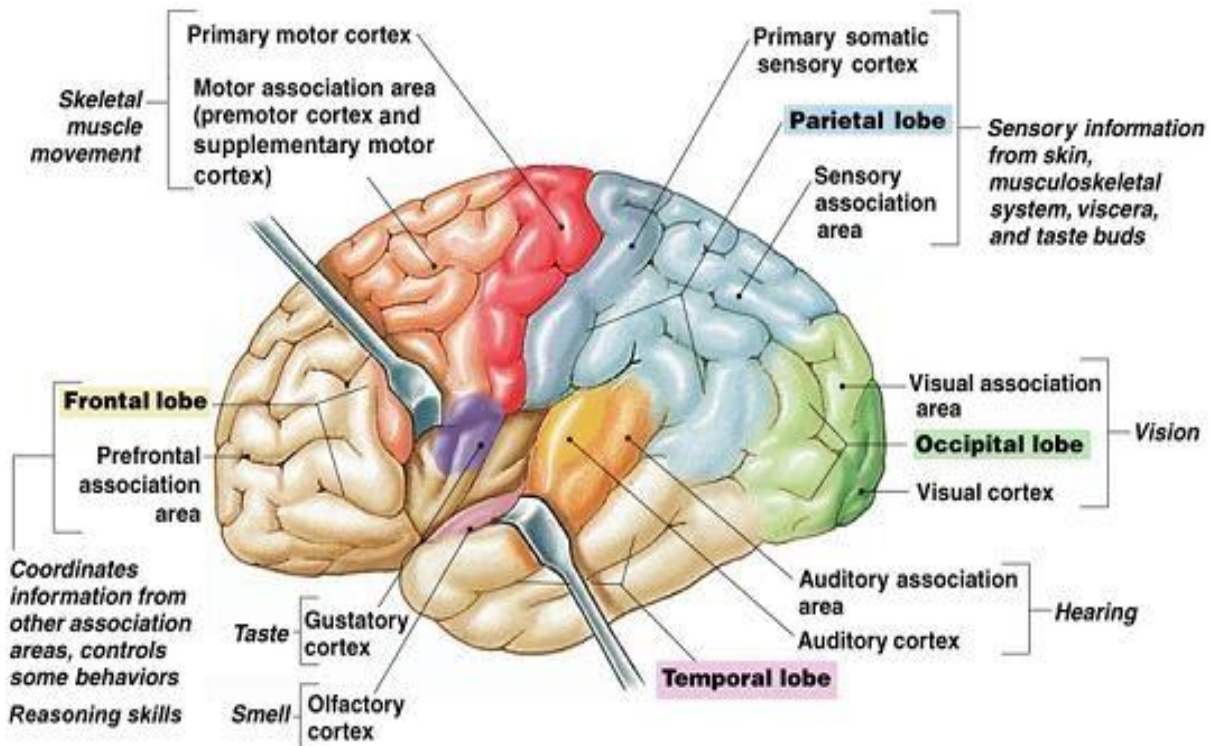


Figure 1.1: Cerebrum divided into four lobes

### 1.3 EEG Recording

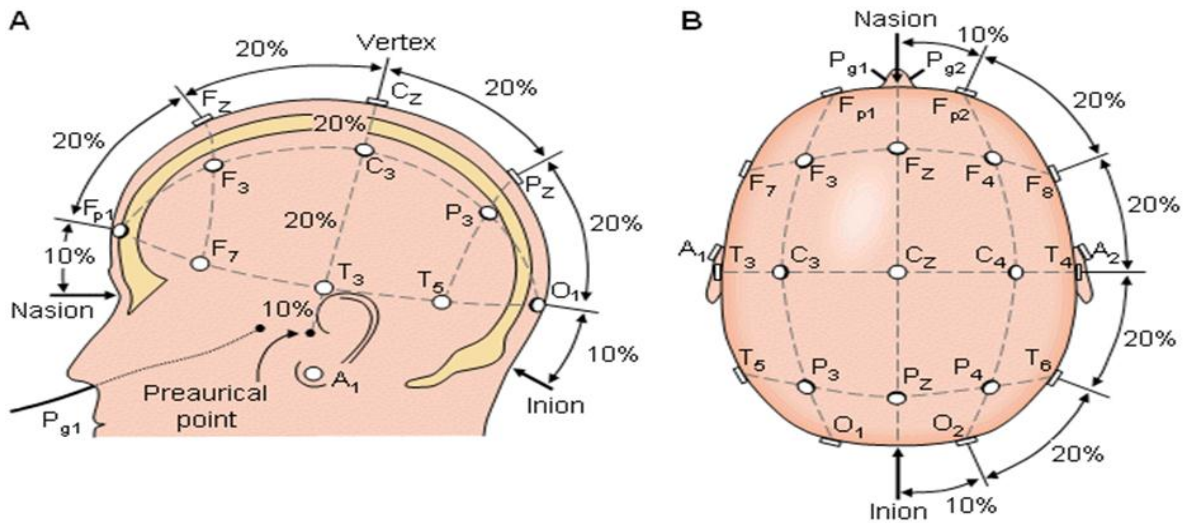


Figure 1.2: 10-20 electrode placement system

The 10-20 system or International 10-20 system is an internationally recognized method to describe and apply the location of scalp electrodes in the context of an EEG test or experiment as shown in figure 1.2. This method was developed to ensure standardized reproducibility so that a subject's studies could be compared over time and subjects could be compared to each other. This system is based on the relationship between the location of an electrode and the underlying area of cerebral cortex. The "10" and "20" refer to the fact that the actual distances between adjacent electrodes are either 10% or 20% of the total front-back or right-left distance of the skull.

Each site has a letter to identify the lobe and a number to identify the hemisphere location. The letters F, T, C, P and O stand for frontal, temporal, central, parietal, and occipital lobes, respectively. Note that there exists no central lobe; the "C" letter is only used for identification purposes only. A "z" (zero) refers to an electrode placed on the midline. Even numbers (2,4,6,8) refer to electrode positions on the right hemisphere, whereas odd numbers (1,3,5,7) refer to those on the left hemisphere.

Two anatomical landmarks are used for the essential positioning of the EEG electrodes: first, the nasion which is the point between the forehead and the nose; second, the inion which is the

lowest point of the skull from the back of the head and is normally indicated by a prominent bump.

When recording a more detailed EEG with more electrodes, extra electrodes are added utilizing the spaces in-between the existing 10-20 system. 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 theinion-to-nasion distance respectively. The introduction of extra letters allows the naming of extra electrode sites. Note that these new letters do not necessarily refer to an area on the underlying cerebral cortex.

## 1.4 EEG Wave Recording

The analysis of continuous EEG signals or brain waves is complex, due to the large amount of information received from every electrode shown in figure 1.3. Different waves, like so many radio stations, are categorized by the frequency of their productions and, in some cases, by the shape of their waveforms. Although none of these waves is ever emitted alone, the state of consciousness of the individuals may make one frequency range more pronounced than others.

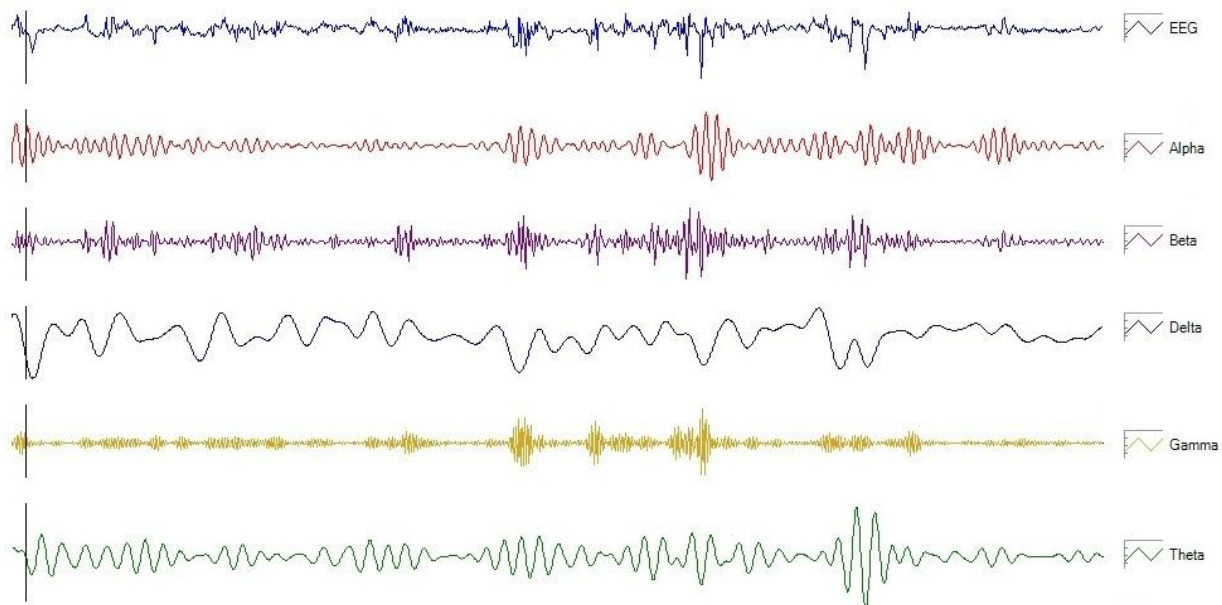


Figure 1.3: EEG signals

**Delta ( $\delta$ ):** has a frequency of 3 Hz or below. It tends to be the highest in amplitude and the slowest waves. It is normal as the dominant rhythm in infants up to one year and in stages 3 and 4 of sleep. It may occur focally with subcortical lesions and in general distribution with diffuse lesions, metabolic encephalopathy hydrocephalus or deep midline lesions. It is usually most prominent frontally in adults shown in figure 1.4.

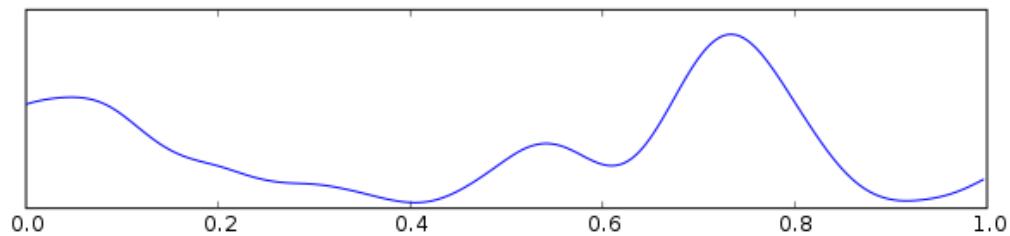


Figure 1.4: EEG delta wave recording

**Theta ( $\theta$ ):** has a frequency of 3.5 to 7.5 Hz and is classified as "slow" activity. It is perfectly normal in children up to 13 years and in sleep but abnormal in awake adults. It can be seen as a manifestation of focal subcortical lesions; it can also be seen in generalized distribution in diffuse disorders such as metabolic encephalopathy or some instances of hydrocephalus shown in figure 1.5.

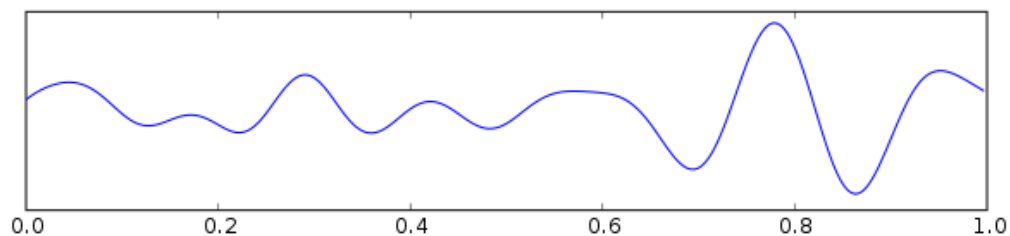


Figure 1.5: EEG theta wave recording

**Alpha ( $\alpha$ ):** has a frequency between 7.5 and 13 Hz. Is usually best seen in the posterior regions of the head on each side, being higher in amplitude on the dominant side. It appears when closing the eyes and relaxing, and disappears when opening the eyes or alerting by any mechanism (thinking, calculating). It is the major rhythm seen in normal relaxed adults. It is present during most of life especially after the thirteenth year shown in figure 1.6.

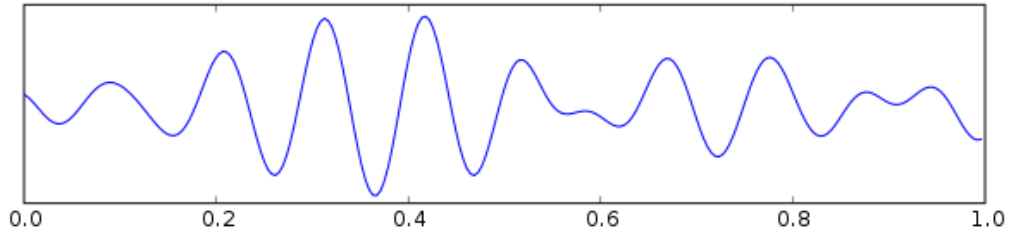


Figure 1.6: EEG alpha wave recording

**Beta ( $\beta$ ):** beta activity is "fast" activity. It has a frequency of 14 and greater Hz. It is usually seen on both sides in symmetrical distribution and is most evident frontally. It is accentuated by sedative-hypnotic drugs especially the benzodiazepines and the barbiturates. It may be absent or reduced in areas of cortical damage. It is generally regarded as a normal rhythm. It is the dominant rhythm in patients who are alert or anxious or have their eyes open shown in figure 1.7.

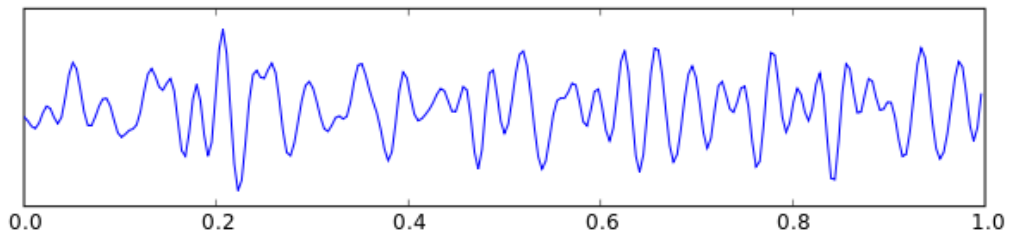


Figure 1.7: EEG beta wave recording

**Gamma ( $\gamma$ ):** has a frequency between 26-100 Hz. This wave is thought to represent binding of different populations of neurons together into a network for the purpose of carrying out a certain cognitive or motor function shown in figure 1.8.

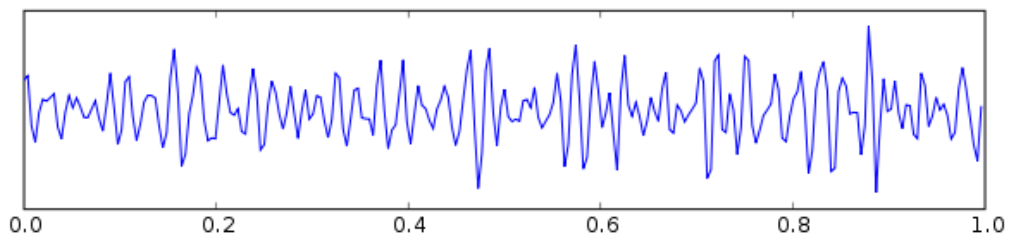


Figure 1.8: EEG gamma wave recording

**Mu ( $\mu$ ):** has a frequency between 8–13 Hz and partly overlaps with other frequencies. It reflects the synchronous firing of motor neurons in rest state. Mu suppression is thought to reflect motor mirror neuron systems, because when an action is observed, the pattern extinguishes, possibly because of the normal neuronal system and the mirror neuron system "go out of sync", and interfere with each other shown in figure 1.9.

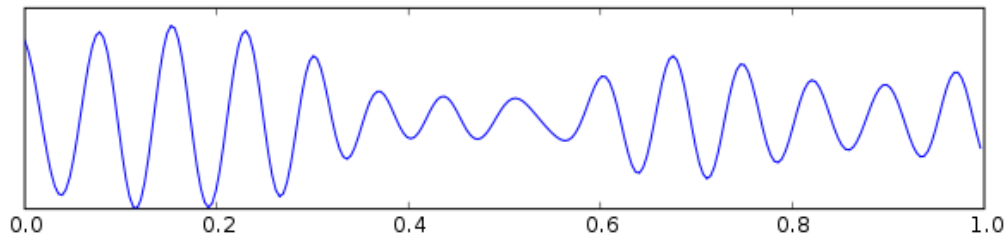


Figure 1.9: EEG mu wave recording

## 1.5 ARTIFACTS

Electrodes used in EEG recording do not discriminate the electrical signals they receive. The recorded activity which is not of cerebral origin is termed artifact and can be divided into physiologic (generated from the subject from sources other than the brain) and extra physiologic artifacts arise from outside the body (equipment including the electrodes and the environment).

- **Electromyogram (EMG) activity**

EMG activities are common artifacts: the myogenic potentials generated in the frontal muscles (raising eyebrows) and the temporal muscles (clenching of jaw muscles) are of shorter duration than those generated in the brain. These artifacts can be identified on the basis of duration, morphology and rate of firing (frequency). Particular patterns of EMG artifacts can occur in some movement disorders: essential tremor and Parkinson disease can produce rhythmic 4 to 6 Hz sinusoidal waveforms.

- **Eye movements**

The eyeball acts as a dipole with a positive pole oriented anteriorly (cornea) and a negative pole oriented posteriorly (retina). When the globe rotates about its axis, it generates a large amplitude alternate current field detectable by any of the electrodes positioned near the eye. A blink causes

the positive pole (the cornea) to move closer to front polar FP1, FP2 electrodes, producing symmetric downward deflections.

- **Skin artifacts**

A further difficulty arises due to properties of certain layers of the skin. A significant DC potential exists between the stratum corneum and the stratum granulosum and any local deformation of the skin will alter this potential. The only reliable way to eliminate the source of artifact is to create a low resistance pathway through the layers of skin by skin cleaning (alcohol swab). Also, sodium chloride (electrolyte) from sweating reacting with metals of the electrodes may produce a slow baseline drift.

- **Electrodes**

Surface electrodes such as the ones used in EEG must create an interface between an ionic solution (the subject) and a metallic conductor (the electrode). This leads to a half-cell potential which can be quite large relative to the signal being recorded. To minimize this problem of polarization of the electrode, some electrodes are coated with silver chloride, but all are maintained away from the skin through an intermediate layer of conductive paste. Touching the electrodes during recording can produce artifacts. An electrode which is not contacting the skin very well acts like an antenna with resulting 60-cycle interference.

- **60-Hz artifact**

The problem arises when the impedance of one of the active electrodes becomes significantly large between the electrodes and the ground of the amplifier. In this situation, the ground becomes an electrode that, depending on its location, produces the 60-Hz artifact. Interference from high-frequency radiation from other electronic devices can overload EEG amplifiers.

## **1.6 Applications**

The EEG is indicated in all paroxysmal phenomena in which the cause is suspected to be of cerebral origin and in all situations of brain dysfunction, especially in characteristic phase. For example in epilepsy, encephalopathy, coma, diagnosis of brain death, brain tumours and other space-occupying lesions, dementia, degenerative diseases to the nervous system, cerebrovascular

disease, head injury, headache, vertigo and psychiatric disorders. EEG is the most common and most useful test performed in evaluating patients suspected of epilepsy.

- **Epilepsy**

Epilepsy is a brain disorder that causes people to have recurring seizures. A seizure is usually defined as a sudden alteration of behaviour due to a temporary change in the electrical functioning of the brain, in particular the outside rim of the brain called the cortex. It is usually diagnosed after a person has had at least two seizures that were not caused by some known medical condition like alcohol withdrawal or extremely low blood sugar. An epileptic attack may result in a series of involuntary contractions of the voluntary muscles, abnormal sensations, abnormal behaviours, or some combination of these events.

Epilepsy has many possible causes, including illness, brain injury and abnormal brain development. In many cases, the cause is unknown. There is no cure for epilepsy, but medicines can control seizures for most people. When medicines are not working well, surgery or implanted devices such as vague nerve stimulators may help. Special diets can help some children with epilepsy.

- **Sleep**

Sleep is a physical and mental resting state in which a person becomes relatively inactive and unaware of the environment. In essence, sleep is a partial detachment from the world, where most external stimuli are blocked from the senses. The brain repeats a cycle along the normal sleep that lasts about 90-120 minutes and is repeated four or five times each night. In this cycle is differentiated by dramatically different forms of brain activity the different stages.

- **Sleep states**

We can divide the normal sleep in two main types, the REM (Rapid eye movement) which involves intense brain self-activation and NREM (non-rapid eye movement) states. NREM sleep is subdivided into 4 sub-states. 70-80% of the time during a night the brain is in NREM sleep and the other time in REM. Most dreaming takes place during REM sleep. At least in mammals,

a descending muscular atonic is seen in this state, the brain blocks signals to the muscles to remain immobile so dreams will not be acted out.

## **1.7 Epilepsy**

The brain is made up of cells that are like tiny little building blocks. These cells carry an electrical charge and are called neurons. In a normal brain electrical charges pass between nerve cells and to all parts of the body. Those cells “fire” in an orderly and controlled manner. In the brain of a person with epilepsy, overactive nerve cells send out powerful, rapid electrical charges that disrupt the brain’s normal function. During a seizure, brain cells can fire at up to four times their normal rate, temporarily affecting how a person behaves, moves, thinks, or feels.

Epilepsy was one of the first brain disorders to be described. It was mentioned in ancient Babylon more than 3,000 years ago. The strange behaviour caused by some seizures has contributed through the ages to many superstitions and prejudices. The word epilepsy is derived from the Greek word for "attack" [2]. People once thought that those with epilepsy were being visited by demons or gods. However, in 400 B.C., the early physician Hippocrates suggested that epilepsy was a disorder.

A serious disorder of central nervous of the brain system which results in recurrent, unprovoked epileptic seizures due to chronic abnormal bursts of electrical discharge in the brain. The epileptic seizure activity is classified mainly on basis of its generation and area of brain in which it is localized. In a partial seizure epileptic activity begins and remains localized in one part of the brain on the other hand a generalized seizure involves the epileptic activity in entire brain. In children and young adults, genetic disorders, congenital abnormalities, and birth trauma affecting the brain are most often blamed for the onset of epileptic symptoms; in middle-aged adults and the elderly, strokes, tumors, and cerebrovascular disease are more frequent explanations. People affected by epilepsy do not suffer from an increasingly worsening disorder and are capable of leading normal career and family lives. At the same time, they cannot engage in activities during which a seizure episode could lead to death; for example, driving an automobile. Furthermore, the side-effects of anti-epileptic drugs, episodes of loss of consciousness and motor control; and the public's misconception of the disorder force patients to deal with challenging clinical and psychosocial issues. Epilepsy is best known for causing convulsions. But seizures can trigger a

wide range of symptoms, from starting to fall to fumbling with clothes. Doctors divide seizures into several types depending on how the brain is affected. Each type has a distinct set of symptoms.

### **1.7.1 Classification of Epilepsy**

Epilepsies are classified in five ways:

1. By their first cause (or etiology).
2. By the observable manifestations of the seizures, known as semiology.
3. By the location in the brain where the seizures originate.
4. As a part of discrete, identifiable medical syndromes.
5. By the event that triggers the seizures, such as reading or music.

### **1.7.2 Causes of Epilepsy**

In 7 out of 10 cases the cause of epilepsy is unknown. Doctors call this idiopathic. Most people with idiopathic seizures are between the ages of 5 and 20 and have no brain injuries or abnormalities of their brain.

The following is a list of factors that have the potential to cause epilepsy:

- Abnormal brain development
- Brain injury with loss of consciousness
- An infection of the brain
- High fever in children under 5 years old
- Loss of oxygen to the brain
- Stroke

- Brain lesion/tumor
- Toxins/poisons

## 1.8 Seizure

A seizure occurs when there is abnormal and overactive electrical activity of brain cells. The seizure may include brief stares and muscle spasms (shaking, lip smacking). Some people with epilepsy have strange or odd sensations (bad smells, unusual or bad tastes, and changes in vision) right before they have a seizure. This “warning” sign of a seizure is called an aura. Seizures can occur in any part of the brain. The person’s symptoms will vary with the part of the brain where the seizure occurs. If the seizure occurs in the part of the brain that controls arm movement, then the seizure may consist of thrashing arm movements. If the seizure occurs in the part of the brain responsible for sensation, then the seizure may include an unusual feeling like pins and needles.

## 1.9 Types of Seizure

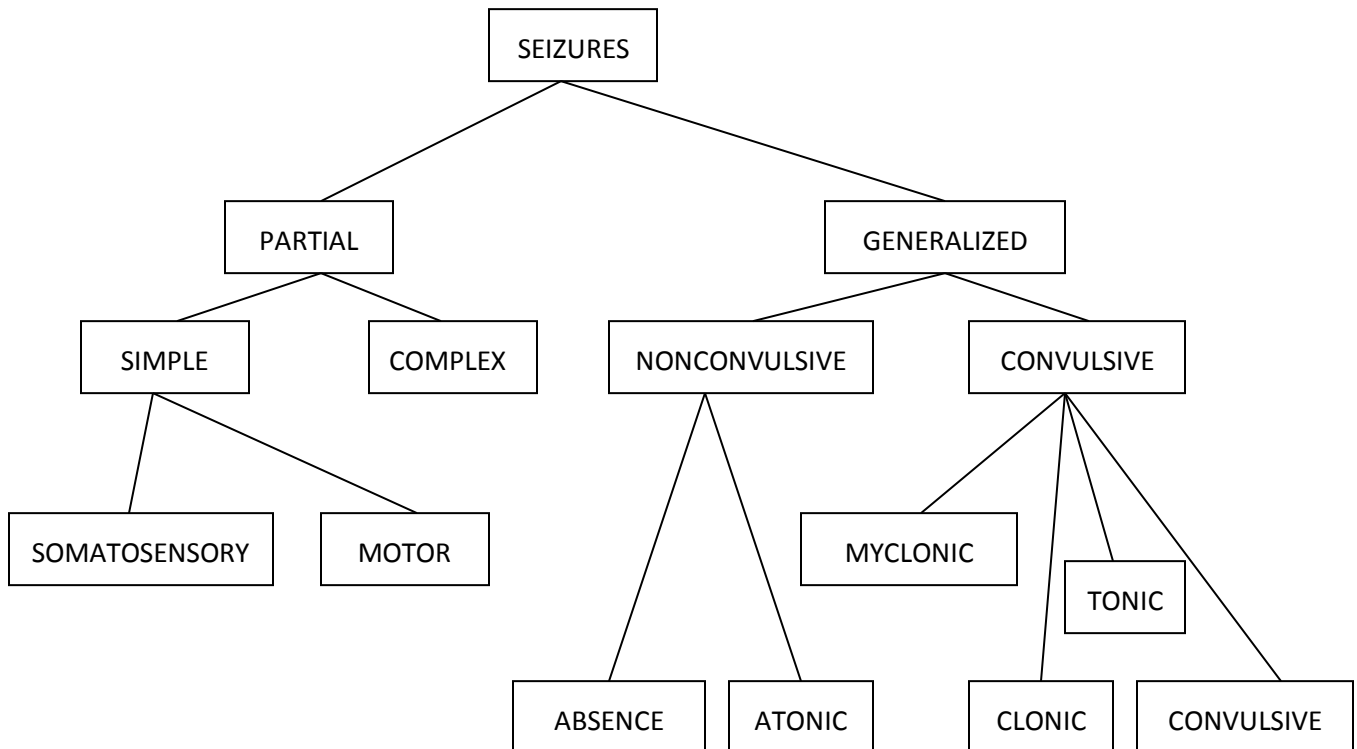


Figure 1.10: Classification of Seizures

Classification of seizure is shown in figure 1.10.

### **Partial seizures** (Non-convulsive seizures)

Affect only one area of one side of the brain.

#### ➤ **Simple Partial Seizures**

Simple partial seizures do not alter consciousness, but temporarily impair an individual's sensory or motor systems. A simple partial seizure that originates in the somatosensory area of the brain is called a *simple partial sensory seizure*, while one that originates from the motor cortex is called a *simple partial motor seizure*. Individuals typically experience simple partial seizures for less than a minute, and are able to recall events that occurred during the episode. It may involve uncontrolled movement, emotions, or sensations. The person does not have convulsions.

#### ➤ **Complex Partial Seizures**

Complex partial seizures result in the impairment of consciousness. They are often preceded by auras that include an unusual smell or sensory illusion and are typically accompanied by an automatism such as snapping fingers, picking at clothes, walking aimlessly, mumbling, or lip smacking. After the conclusion of a complex partial seizure, which lasts between 1-3 minutes, individuals will experience a period of confusion lasting several minutes. Can progress into chewing movements, picking at or fumbling with clothing, mumbling and performing simple, unorganized movements over and over again.

### **Generalized Seizures**

Affect both sides of the brain. Produce a loss of consciousness. Generalized seizures whose clinical manifestations include spastic muscle activity are classified as *generalized convulsive seizures*, while those that don't are classified as *generalized nonconvulsive seizures*.

### ➤ **Generalized Convulsive Seizures**

The nature of involuntary muscular activity and the individual's state of consciousness during generalized convulsive seizures allows for the further subdivision of this class of seizures into the *myoclonic*, *atonic*, *absence* and *tonic-clonic* types.

#### **Generalized Tonic Clonic Seizure** (Also known as a grand mal seizure)

- Usually lasts 1 to 3 minutes.
- Begins with stiffening of the limbs
- Followed by jerking of the face and limbs
- Wetting or soiling of clothing may result from the seizure

#### **Myoclonic Seizures**

- Usually lasts 1-2 seconds
- Rapid, jerking movements of the body that are often confused with a person being clumsy
- May occur singularly or in groups

#### **Atonic Seizure** (Also known as drop attacks)

- Usually last less than 15 seconds
- Sudden loss of muscle tone causes an individual's head to drop and loss in their posture. The student may fall to the ground.
- Injury is more common; a helmet may need to be worn to protect the head.
- This seizure occurs singularly/rarely in groups.

#### **Absence Seizures** (Also known as Petit Mal)

- Usually last less than 10 seconds but can last up to 20 seconds.

- The most difficult seizure to recognize.
- The student will look like they are daydreaming but if you try to get their attention they will not respond.

Not everyone that has a seizure has epilepsy. There are other medical conditions that cause someone to have a seizure.

### ➤ **Generalized Nonconvulsive Seizures**

Absence seizures are generalized nonconclusive seizures that result in the loss of consciousness, eye blinking, staring, and other minor facial movements. These seizures last between a few seconds and a minute and can occur very frequently over the course of a day. Absence seizures are most common in childhood. Atonic seizures are generalized nonconclusive seizures that do not lead to a loss of consciousness. However, the sudden loss of tone in postural muscles that accompanies atonic seizures leads to dangerous falls that result in serious fractures and injuries to the head.

## **1.10 Hippocampal formation**

The **hippocampal formation** (Ammon's horn) is a curved cortical structure in the medial temporal lobe of the brain. There is no consensus over which brain regions are encompassed by the term, with some authors defining it as the dentate gyrus, the hippocampus proper and the subiculum, and some closely related cortical areas in the parahippocampal gyrus, including the subicular complex (which itself is divided into the subiculum, presubiculum and parasubiculum) and the entorhinal cortex, are together referred to as the hippocampal formation [3]. The hippocampal formation is thought to play a role in memory, spatial navigation and control of attention. The neural layout and pathways within the hippocampal formation are very similar in all mammals.

Ammon's horn and the dentate gyrus can be recognized quite early in embryonic development, where they form a thin band along the medial edge of the pallium. The dentate gyrus is the most medial component of the hippocampal formation, and it lies along the "free edge" of the cortical mantle during early embryogenesis, since it is bordered along its medial aspect by the tela

choroidea of the lateral ventricle caudally, and the septum ependymale and lamina terminalis rostrally. As development progresses, caudal (temporal) parts of the hippocampal region undergo considerable enlargement, whereas rostral (septal) parts develop little and come to form the indusium griseum dorsal to the genu of the corpus callosum. As the cortical mantle expands during development, the hippocampal region remains medial, and its main body comes to lie along the medial aspect of the inferior horn of the lateral ventricle in the temporal region. However, because of tremendous cellular proliferation, Ammon's horn folds back upon itself along the hippocampal fissure, as does the DG, which eventually forms a wedge-shaped structure. As a result, the hippocampal formation is perhaps best viewed as a series of adjacent cortical stripes that begin laterally at the rhinal fissure and consist, in order, of the lateral and medial entorhinal areas: the parasubiculum, presubiculum, and subiculum; fields CA1, CA2, and CA3 of Ammon's horn; and the dentate gyrus.

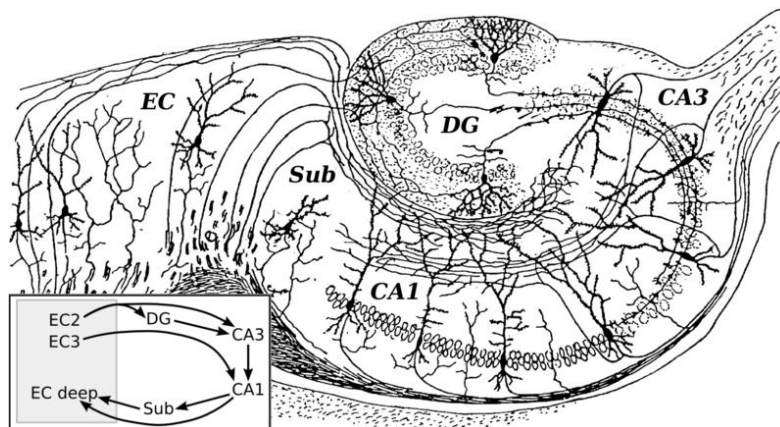


Figure 1.11: Hippocampal formation

## 1.11 Epileptogenic zone

The **epileptogenic zone** is an area of cortex that is necessary and sufficient for initiating seizures and whose removal (or disconnection) is necessary for complete abolition of seizures [4]. Localization of epileptogenic focus is most important step in screening patients with medically intractable focal epilepsy for potential surgical cures. The locations of epileptogenic zones are found using the clinical criteria produced by the sum of noninvasively acquired findings, such as clinical semiology, EEG, Magnetic Resonance Image (MRI), Positron Emission Tomography

(PET), and Single Photon Emission Computed Tomography (SPECT). Surgery is the only option in these situations and requires a previous precise localization of the epileptogenic zone [5].

## **1.12 Treatment of EPILEPSY**

Once epilepsy is diagnosed, it is important to begin treatment as soon as possible. Research suggests that medication and other treatments may be less successful in treating epilepsy once seizures and their consequences become established.

### **Medications**

Medications used to prevent epileptic seizures are called antiepileptics (AEDs). There are over 30 different antiepileptic drugs, but they do not all treat the same types of seizures. Often times obtaining seizure control through antiepileptic drugs is a matter of finding the combination, schedule, and dosing of medications that is right for the individual. If a person is seizure free for several years, a physician may reduce or even stop the person's medication. However, epilepsy is a lifelong condition, and there is no permanent cure.

### **Surgery**

If treatment with medications does not work, some individuals with epilepsy may be candidates for brain surgery. To be eligible for the surgery the person must have seizures coming from one area of the brain that can be removed without causing damage to the person's ability to function. If a defect in the brain (such as a scar) can be identified as the cause of the seizures and is confined to a small area, surgically removing that area can eliminate seizures in up to 80% of people, or at least reduce the severity and frequency of seizures.

### **Vagus Nerve Stimulator**

The Vagus Nerve Stimulator is a device that is implanted in a person. Electrical stimulation of the vagus nerve can reduce the number of a certain type of seizures by more than one half in some people. This treatment is used when seizures continue despite use of AEDs and when surgery is not a possibility.

The vagus nerve is thought to have indirect connections to areas of the brain often involved in causing seizures. A device that looks like a heart pacemaker is implanted under the left collarbone and is connected to the vagus nerve in the neck with a wire that runs under the skin. The device causes a small bulge under the skin. The operation to implant the device is done on an outpatient basis and takes about 1 to 2 hours.

When people sense that a seizure is about to begin, they can activate the magnet mode of their device to deliver an on-demand dose of stimulation. Otherwise the device is programmed to deliver intermittent stimulation to the vagus nerve. Vagus nerve stimulation is used in addition to AEDs. Side effects of this device include hoarseness, cough, and deepening of the voice when the nerve is stimulated.

### **Ketogenic Diet**

The ketogenic diet, which is very high in fats and low in carbohydrates, was first developed almost 80 years ago. It makes the body burn fat for energy instead of glucose. It has a success rate of 75%, stopping seizures in 50% of individuals and further reducing seizures in 25% of cases. It is a strict diet, and takes a strong commitment from the whole family. The ketogenic diet is not a do-it-yourself diet. It is a serious form of treatment that, like other therapies for epilepsy, has some side effects that have to be monitored. More research is being done to learn about the underlying reasons for the diet's positive effect.

## CHAPTER 2: LITERATURE REVIEW

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Human brain is the most complex organ in the human body. The nerve cells of the brain generate electrical impulses that fluctuate rhythmically in distinct patterns. Epilepsy can be defined as a disorder of the central nervous system that results in recurrent seizures due to chronic abnormal bursts of electrical discharge in the brain. This chapter reviews the different methods proposed by the researchers for the detection of Epileptic activity using EEG.

The early methods of epilepsy detection were based on a Fourier transform for processing EEG automatically. For the representation of the signal is basically done by using Fourier transform. EEG spectrum contains characteristic waveforms that fall basically within four frequency bands. Such methods have been proved beneficial for various EEG characterizations, but fast Fourier transform (FFT) suffer from large noise sensitivity. A parametric method such as autoregressive reduces the spectral loss problems and gives better frequency resolution. Since the EEG signals are non-stationary, the parametric methods are not suitable for frequency decomposition of these signals. The classical Fourier Transform (FT) analysis is able to achieve infinite frequency resolution, but it does not provide temporal localization information. Proper description of the

EEG often requires simultaneous localization in both time and frequency domains. Hence, for such transient signals, analysis and representation in time–frequency domain is highly desirable approach.

Themis P. Exarchos et al. in 2006 originate Association Rules. The association rule is a technique which provides high precision and interpretation which performs automated detection and classifies different types of transient events in EEG recordings that is: epileptic spikes (ESs), muscle activity (EMG), eye blinking activity (EOG), and sharp alpha activity (SAA). The methodology based on a four-stage schema (Fig. 2.1) for the transient event detection and classification. In the first stage, pre-processing of the EEG signal is implemented in order to identify the candidate transient events. In the second stage, the transient events are clustered and feature extraction takes place. In the third stage, the continuous valued features are transformed into discrete ones via a discretization technique. In the last stage association rule mining is applied to create association rules, which are used to form the final transient event classification model [6].

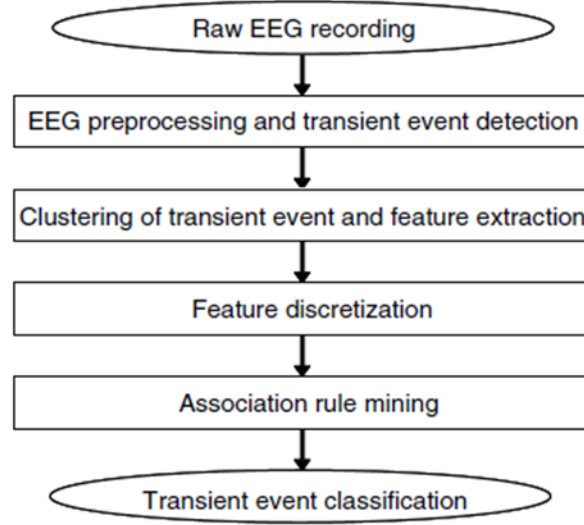


Figure:2.1 Flowchart of four-stage methodology

Alexandros T. Tzallas et al. in 2009 presented time-frequency analysis of EEG signals by Short-Time Fourier Transform (STFT) and  $t$ - $f$  distributions (TFDs). Time-frequency analysis is mainly effective for representing various aspects of non-stationary signals for example trends, discontinuities, and repeated patterns where other signal processing approaches fail or are not as effective. The ability of the time-frequency ( $t$ - $f$ ) analysis to classify EEG segments which contain epileptic seizures. Most of the classifiers used in the analysis of EEG signals apply the statistical features obtained by the time-frequency analysis of EEG signals. Short Term Fourier Transform (STFT) and various Time-Frequency Distributions are used for the  $t$ - $f$  analysis. For STFT, the signal  $x(u)$  at an instant of time  $t$ , the Fourier transform is calculated for each instant of time  $t$

$$STFT(t, f) = \int_{+\infty}^{-\infty} x(\tau)h(\tau - t)e^{-if\tau} d\tau \quad (1)$$

where  $h(t)$  is a short time window. Using  $t$ - $f$  analysis, the Power Spectral Density is calculated of the signal, which represents the distribution of the energy of the signal over the  $t$ - $f$  plane [7].

Mousavi et al. method of epilepsy detection is based on autoregressive (AR) estimation of EEG signals. The optimum order for Autoregressive (AR) model is determined by Bayesian Information Criterion (BIC) and then autoregressive (AR) parameters of EEG signals and their sub bands are extracted by discrete wavelet transform. These parameters are used as a feature to classify the EEG signals into normal and epileptic by multilayer perceptron classifier [8].

Hyunchul Kim et al. in 2010 presented a training free (on line) epileptic seizure detection algorithm for implantable device utilizing Autoregressive (AR) model parameters is developed and studied. Pre-recorded (offline) epileptic seizure data are used to estimate the internal parameters of an AR model prior and following the seizure Principle Component Analysis (PCA) is used for reducing the dimension of the problem while allowing only the salient features representing the seizure onset to be saved into the implantable device. The implantable device estimates the AR model parameter in real time and compares the saved features of seizure onset with feature from the incoming signals using cosine similarity. The proposed approach can be extended to multi-channel approach using Multi-Variant Autoregressive (MVAR) model which enables seizure foci localization and the sophisticated seizure prediction [9].

Mirzaei et al. in 2010 was based on Wavelet-Spectral Entropy Based Detection. Discrete wavelet-spectral entropy (SEN) method is presented for epileptic seizures detection through the analysis of EEGs and EEG sub-bands. DWT is appropriate for analysis of non-stationary signals. Entropy was the parameter considered. The spectral entropies basically use the amplitude of the power spectrum of the signal as the probabilities in entropy calculations. This is a method for epilepsy detection by analyzing EEG and EEG sub bands based on determining discrete wavelet-spectral entropy. The EEG signal is decomposed by discrete wavelet transform into its sub-bands by high pass and low pass filtering to different levels as shown in Figure: 2.2 and is then characterized by spectral entropy determining approach.

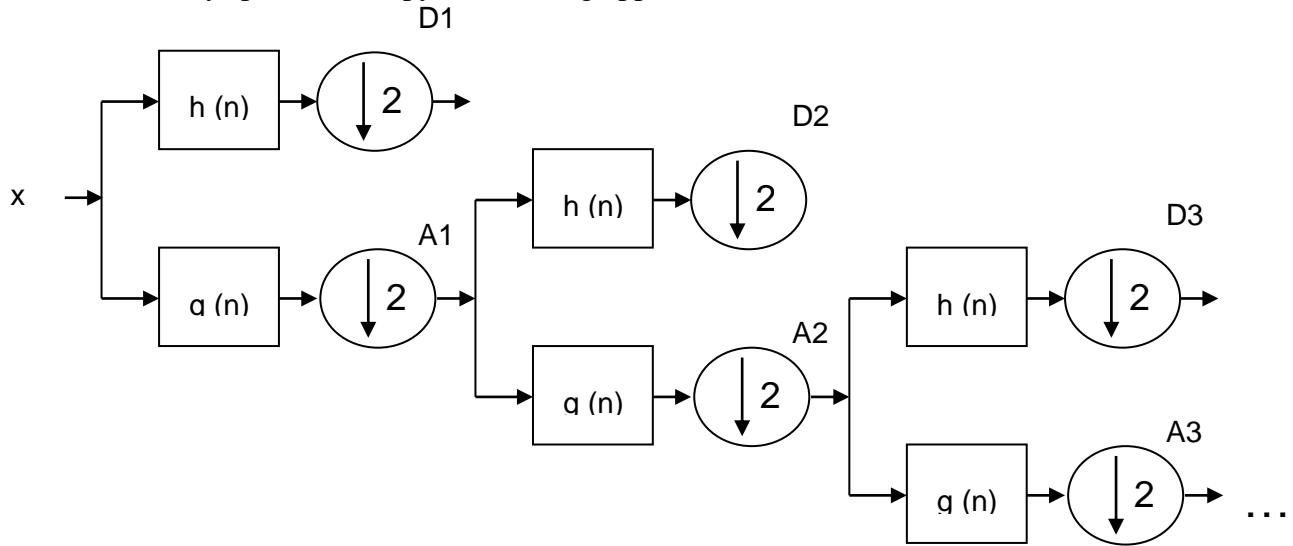


Figure 2.2: Discrete Wavelet decomposition of signal

$$Entropy, (e_i) = -\sum_{j=1}^n D_{ij}^2 \log(D_{ij}^2) \dots\dots\dots (2)$$

This method was applied to three different groups of EEG signals: 1) healthy, 2) epileptic during a seizure-free interval, 3) epileptic during a seizure.

Spectral entropy is used which differentiated between these three states and their sub-bands. Then statistical approach is applied to determine the measure of distinguishing between different subjects. This method can discriminate between epileptic and non-epileptic subject of alpha sub-band (8-12 Hz). Also there is an approach using wavelet transform where first the pre-processed signal is decomposed into a wavelet packet tree. Then features are extracted from standard frequency pattern i.e. from obtained sub-bands. These features are then fed to neural network classifier for detection of seizure activity or normal result [10]. The whole technique is explained through this Figure 2.3 shown below.

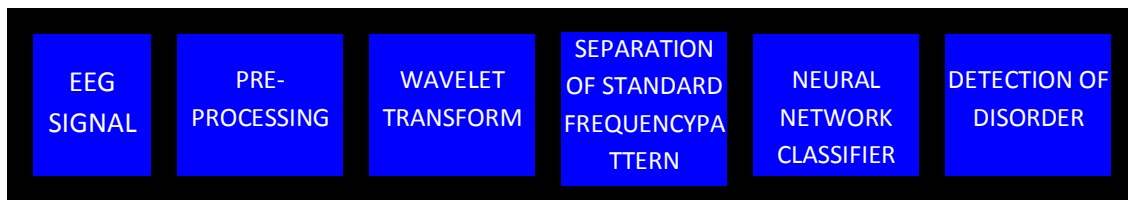


Figure 2.3: Detection using wavelet transforms method

The Equal Frequency Discretization based probability density approach can be used for detecting epilepsy from EEG signals. These signals are decomposed by using the Discrete Wavelet Transform (DWT) into its various sub-bands, the coefficients in each sub-band are then discretized to several intervals by Equal frequency discretization method, and the probability density of each sub-band of each EEG segment is computed according to the number of coefficients in discrete intervals. Then, two probability density functions can be defined by means of the curve fitting over the probability densities of the sets of both healthy and epileptic patients. EEG signals are then classified by calculating the mean square error (MSE) of these probability density functions. The result of the classification of epileptic subjects is evaluated by Orhan et al in 2011[11].

K.A. Helini Kulasuriya et al in 2011 presenting wavelet transform and artificial neural network. EEG is signal records of electrical activity of brain neurons. EEG, which is a compulsive tool,

used for diagnosing neurological diseases such as epilepsy, beside of techniques such as magnetic resonance and brain tomography (BT) that are used for diagnosing structural brain disorders. It describes novel approach for forecasting epileptic seizure activity, by classifying these EEG signals. The extracted features are applied on wavelet transform and then on artificial neural network model, which is supervised learning based algorithm classifier, used fir signal classification. Wavelet transform is an effective tool for analysis of transient events in non-stationary signals, such as EEGs. The performance of the ANN classifier is evaluated in terms of sensitivity, specificity and classification accuracy. The obtained classification accuracy confirms that the proposed scheme has potential in classifying EEG signals [12].

## CHAPTER 3: PROBLEM DEFINITION

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In 1980 a powerful method called the discrete wavelet transforms (DWT) was introduced.

Since early days work done for frequency sub-band separation of EEG signal for epilepsy detection is based only on decomposition of the signal to certain levels. This is followed by feature extraction from these sub-bands. The major tasks that need to be undertaken are briefed below:

- The decomposition of EEG signal does not generally include that peculiar frequency range as defined in Delta, Theta, Alpha, Beta, Gamma sub-bands. To get this frequency band is still a challenge for the researchers. A passing reference about the technique is made by Shantha Selva Kumari et al. [13]; however, the methodology for obtaining the signal in this band is not given explicitly. Only decomposition method is described, which alone is not capable of the getting the required frequency band.
- After decomposition of EEG signal into sub-bands: delta (0–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz), and gamma (>30Hz) using discrete wavelet transform, extracting features out of all statistical parameters that can be used as a feature vector for distinguishing between an epileptic and normal EEG is itself a challenge. For identifying the epileptic and normal EEG, it is required to examine subject for selected features extracted from the sub-bands of EEG. It is probable that none of the features show a non-overlapping range. Thus a simple threshold based two class classification is not possible. In order to achieve two-class classification and multi-class classification using the features extracted we propose an ANN based classifier.
- Considering EEG signal to detect epileptic cases using appropriate features extracted from various sub-bands, none of the non-overlapping range is found such an efficient system is developed. This system shows several accuracy. There is a need to develop a system which is tolerant to these accuracies and is flexible enough to give high detection rate in practical situations.

## CHAPTER 4: METHODOLOGY

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### 4.1 Data Used

The EEG data considered for this work was obtained from EEG database of University of Bonn. It contains three different cases: 1) healthy, 2) epileptic subjects during seizure-free interval and 3) epileptic subjects during seizure interval. The complete data set consists of five sets A-E. Each data set contained 50 single channel EEG signals. Each segment is of 23.6 sec duration which contains 4096 samples. Set A and Set B both are for the healthy subjects, whereas Set C and Set D both are for epileptic subjects with seizure-free interval and Set E epileptic subject with seizure interval. Sets A and B recording was obtained from the surface of EEG recording that was carried out on five healthy volunteers using a standardized 10-20 electrodes.

Set A is for healthy volunteers who are in awake-state with eyes open while Set B is with eyes closed. Recordings in set C were from the subjects with the hippocampal formation of opposite hemisphere of the brain and set D were from the epileptogenic zone. Both Set C and D were measured during seizure free interval. Set E only contains seizure activity. All signals were recorded with 128-channel amplifier system, using an average common reference. After 12 bit analog-to-digital conversion, the data were written continuously onto the disk of a data acquisition computer system at sampling frequency of 173.6 Hz. Band pass filter settings were 0.53-40 Hz. In this work, we use all the five data sets A-E [14].

### 4.2 Discrete Wavelet Transform

There are no general methods of EEG analysis. Usually time and frequency domains have been considered for analyses of EEG signals. In both time and Frequency methods, an EEG signal is considered as a realization of a random process features of signal are: means, variances, power spectral density and skewness. It may have a high degree of complexity and only a description of statistical terms may be justified.

The discrete wavelet transform (DWT) is an active tool for Time-Frequency analysis of signals. Discrete wavelet transform (DWT) is a spectral analysis technique used for analyzing non-stationary signals, and provides time-frequency signals. Wavelet transform is a spectral estimation technique in which any general function can be expressed as an infinite series of

wavelets. The decomposition of the signal results in a set of coefficients called wavelet coefficients. Decomposition of the signal analysis is depending on the high-pass and low-pass filter. Wavelet transform uses a different window size, which allows the wavelet to be stretched or compressed depending on the frequency of the signal. The important property of DWT is that this technique is used for analyzing the non-stationary signals like EEG signals. DWT analyzes frequency bands with different resolution by means of multi-level decomposition into a coarse frequency band. This results in excellent feature extraction from sub-bands of the non-stationary EEG signals.

The decomposition of the signal into different frequency bands is obtained by low-pass and high-pass filter of the EEG signal. Here the study has adopted multilevel decomposition of DWT, in order to filter the signals. A model of this multi-resolution decomposition procedure is shown in figure 2.2. Each stage of the process consists of two filters and two down samples by '2'. The first filter  $h(n)$  is high-pass filter and  $g(n)$  is low-pass filter. The output of first high-pass and low-pass filter gives the detail D1 and the approximation A1. The first approximation A1 is further decomposed and this process will continued until the particular level will not be reached by the user [10].

### **4.3 DWT Analysis**

DWT successfully analyses the multi-resolution signal at different frequency bands, by decomposing the signal into approximation and detail information. The method for frequency band separation for epilepsy detection is implemented in MATLAB 2011a.

Data is first pre-processed by removing dc component from the signal thereby achieving different levels of decomposition for Daubechies order-2 wavelet with a sampling frequency of 173.6 Hz on each signal of 4096 samples. Figure 4.2 shows the decomposition of the EEG signal  $x(n)$  at Nyquist frequency which is the maximum useful frequency i.e. half of sampling frequency 86.8 Hz. Signal is subjected to six level decomposition where each stage of this scheme consists of two digital filters.

The first filter,  $h[n]$  is the high pass filter or it is the discrete mother wavelet and the second,  $g[n]$  is low-pass filter. After the first level of decomposition, the EEG signal (0-86.81Hz), is

decomposed into its lower resolution components, CA1 (0-43.4) Hz and higher resolution components, CD1 (43.4-86.81 Hz).

Likewise six level of decomposition is done. The approximation and detail coefficients are shown in diagram by  $CA_i$  and  $CD_i$  where  $i$  is 1, 2, 3.... at each level of decomposition. The data after decomposition to various levels has approximation and detail coefficients at each level of different frequency resolution. These frequencies are to be then recombined in order to achieve subbands delta, theta, alpha, beta, gamma at their perspective frequencies. The delta band is of frequency range 0-4 Hz so lower resolution components i.e. approximation coefficients CA7 (0-2.7 Hz) and CA8 (2.7- 4.05 Hz) are to be recombined. But the problem arises when the number of samples of CA7 and CA8 mismatch. CA7 has 128 samples while CA8 has 64 samples. For this up-sampling of CA8 is done to 128 samples and then the DELTA band is reconstructed successfully by recombination of CA7 and up-sampled CA8 through Inverse Discrete Wavelet Transform using Daubechies order-2. Similarly THETA sub-band is of frequency range 4-8 Hz so CA9 and up-sampled CD8 are recombined.

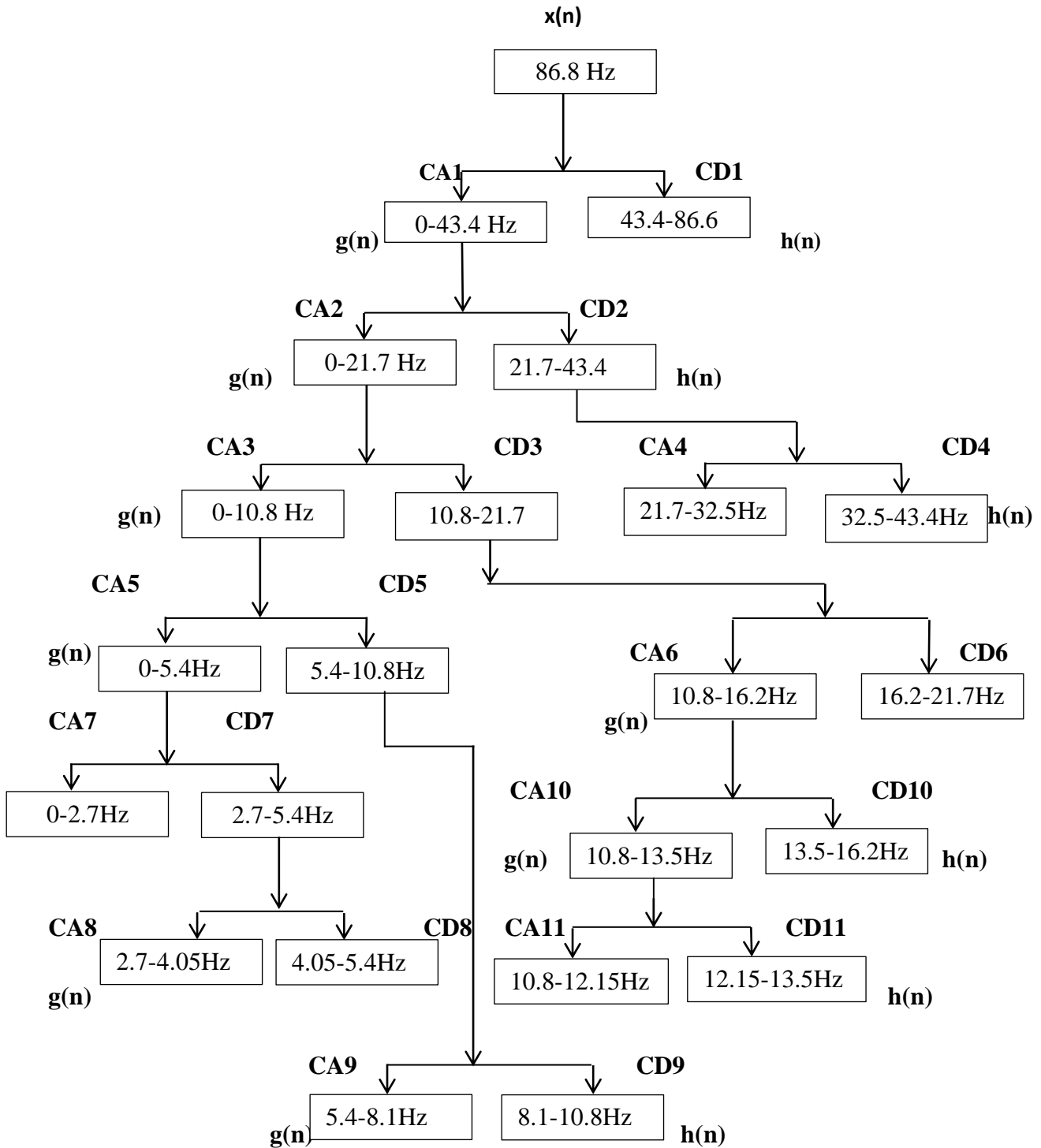


Figure 4.2: Decomposition of Signal into its approximation and detail coefficients.

After recombining all coefficients falling in their respective sub-bands, delta, theta, alpha band with 256 samples and beta with 1024 and gamma with 4096 samples are achieved as shown in Table 4.1.

Table 4.1: Sub-bands with their frequency range, recombining coefficients and no. of samples

<b>SUBBAND</b>	<b>FREQUENCY</b>	<b>COEFFICIENTS</b>	<b>SAMPLES</b>
<b>DELTA</b>	<b>0-4 Hz</b>	<b>CA7, CA8(up-sampled)</b>	256
<b>THETA</b>	<b>4-8 Hz</b>	<b>CD8(up-sampled), CA9</b>	256
<b>ALPHA</b>	<b>8-12 Hz</b>	<b>CD9, CA11(up-sampled)</b>	256
<b>BETA</b>	<b>12-30 Hz</b>	<b>CD11(up-sampled), CD10, CD6, CA4</b>	1024
<b>GAMMA</b>	<b>&gt; 30 Hz</b>	<b>CD4(doubly up-sampled), CD1</b>	4096

EEG segment is decomposed to 6 levels discrete wavelet transform and then inverse discrete wavelet transform is used to recombine the various frequency band to form delta (0-4)Hz , Theta (4-8)Hz , Alpha (8-12)Hz , Beta (12-30)Hz, and Gamma (>30)Hz. The delta, theta, alpha band have 256 samples and beta have 1024 and gamma have 4096 samples. The required frequency and the actual frequency achieved after decomposition and recombination is given in Table 4.2. Thus the recombined sub-band frequency closely matches with the required frequency in Delta, Theta, Alpha, Beta and Gamma sub-bands as shown. The sub-bands can actually and accurately be used further to detect features that can distinguish epileptic EEG signals from non-epileptic EEG signals.

Table 4.2: Required frequency and achieved frequency of each sub-band

<b>REQUIRED FREQUENCY</b>	<b>FREQUENCY ACHIEVED</b>
<b>0-4 Hz</b>	<b>0-4.05 Hz</b>
<b>4-8 Hz</b>	<b>4.05-8.1 Hz</b>
<b>8-12 Hz</b>	<b>8.1-12.15 Hz</b>
<b>12-30 Hz</b>	<b>12.15-32.5 Hz</b>
<b>&gt; 30 Hz</b>	<b>&gt;32.5 Hz</b>

The sub-band decomposition of the EEG signals as explained is applied on all the data sets of normal subjects (SET A and SET B) and epileptic subjects (SET C, SET D and SET E) of 50

subjects each. Each segment in SET A-E is composed of 4096 samples at sampling frequency of 173.6 Hz. The discrete wavelet transform is used as a primary computational tool for extracting features of the epileptic EEG signals at different resolutions [15]

#### 4.4 Feature Extraction

The parameters derived for the epilepsy detection are: variance, energy, max power spectral density (PSD), min power spectral density (PSD) and entropy. All these parameters were extracted by using MATLAB R2011a and Microsoft Office Excel and used for epilepsy detection [16].

(1) **Variance:** Variance is defined as a measure of the dispersion of a set of data points around their mean value.

$$y^2 = \frac{\sum(X-\mu)^2}{n} \quad \dots (1)$$

where  $\mu$  is the mean value of the set X and n is the number of samples.

(2) **Energy:** The energy of the signal is defined as the sum of squared modulus of the sample values of any signal.

$$E = \sum_{n=0}^{N-1} |X|^2 \quad \dots (2)$$

where X is the samples values in each sub-bands and N is the total number of samples.

(3) **Power Spectral Density (PSD):** The PSD is the amount of power per unit frequency as a function of frequency. PSD is computed by squared modulus of the Fourier transform of the time series of the signal.

$$\max(\omega) = \frac{1}{n} |X(\omega)|^2 \quad \dots (3)$$

The Maximum and minimum values are estimated from the PSD of each EEG subbands can be considered as feature for classification.

(4) **Entropy:** Entropy is a numerical measure of the randomness of a signal.

$$(e) = -\sum_1^n X^2 \log(X^2) \quad \dots (4)$$

Entropy can act as a feature and used to analyze psychological time series data such as EEG data. Entropy is a strong feature for epilepsy detection.

These features extracted from the five sub-bands of EEG signals are tabulated in table 4.3.

1. Variance of the coefficients in each sub-band.
2. Power Spectral Density (max) of each sub-band.
3. Power Spectral Density (min) of each sub-band.
4. Entropy of wavelet coefficients in each sub-band.
5. Energy of the wavelet coefficients in each sub-band.

Table 4.3: Features of sub-bands and their nomenclature

<b>Sub-bands</b> →					
<b>Feature</b> ↓	<b>DELTA</b>	<b>THETA</b>	<b>ALPHA</b>	<b>BETA</b>	<b>GAMMA</b>
<b>Variance</b>	y1	y2	y3	y4	y5
<b>PSD max</b>	Max1	Max2	Max3	Max4	Max5
<b>PSD min</b>	Min1	Min2	Min3	Min4	Min5
<b>Entropy</b>	e1	e2	e3	e4	e5
<b>Energy</b>	E1	E2	E3	E4	E5

Using these 25 parameters 50 each for normal subjects and epileptic subjects taken from database described before are analyzed. None of the features had non-overlapping range. Thus a simple threshold based two class classification is not possible. In order to achieve two-class classification using the features extracted we propose an ANN based classifier.

## 4.5 Matlab Functions

Matlab functions used in the study are summarized in the Table 4.4.

Table 4.4: Matlab functions

FUNCTION		USE	SYNTAX
1.	DWT	DISCRETE WAVELET TRANSFORM	[CA1,CD1]=DWT(s,'db2')
2.	IDWT	INVERSE DISCRETE WAVELET TRANSFORM	A=IDWT(CA1,BD1,'db2')
3.	WENTROPY	ENTROPY	e1 = wentropy(DELTA,'shannon')
4.	VAR	VARIANCE	y1= var(DELTA)
5.	WENERGY	ENERGY	[Ea1,Ed1] = wenergy(C1,L1)
6.	PERIODOGRAM	POWER SPECTRAL DENSITY	[Pxx1,w1] =periodogram(DELTA)

This work aims at achieving four different types of classifications:

- i. To classify normal subjects and epileptic subjects (two-class classification).
- ii. To classify normal subjects with eyes open and eyes closed (two-class classification).
- iii. To classify non-seizure subjects and seizure subjects (two-class classification).
- iv. To classify non-seizure subjects with hippocampal formation and epileptogenic zone (two-class classification).

From the 25 features extracted, it was observed that:

- i. For 100 subjects in normal class and 150 subjects in epileptic class, none of the features had non-overlapping range. Thus a simple threshold based two class classification is not possible.
- ii. For 50 subjects of normal eyes open and 50 subjects of normal eyes closed class, none of the features had non-overlapping range. Thus a simple threshold based two class classification is not possible.
- iii. For 100 subjects in non-seizure class and 50 subjects in seizure class, none of the features had non-overlapping range. Thus a simple threshold based two class classification is not possible.

- iv. For 50 subjects of non-seizure hippocampal formation and 50 subjects of non-seizure epileptogenic zone, none of the features had non-overlapping range. Thus a simple threshold based two class classification is not possible.

In order to achieve two-class classification using the features extracted we propose an ANN based classifier.

## 4.6 ARTIFICIAL NEURAL NETWORK

A neural network consists of hidden neurons arranged in layers, which convert an input vector into some output. Each neuron takes an input, applies a function to it and then passes the output on to the next layer, this show in figure 4.3. Generally the networks are defined to be feed-forward: a unit feeds its output to all the units on the next layer, but there is no feedback to the previous layer. Weights are applied to the signals passing from one unit to another, and these weights are modified to bring the network input-output behavior into line to adapt a neural network to the particular problem at hand [17].

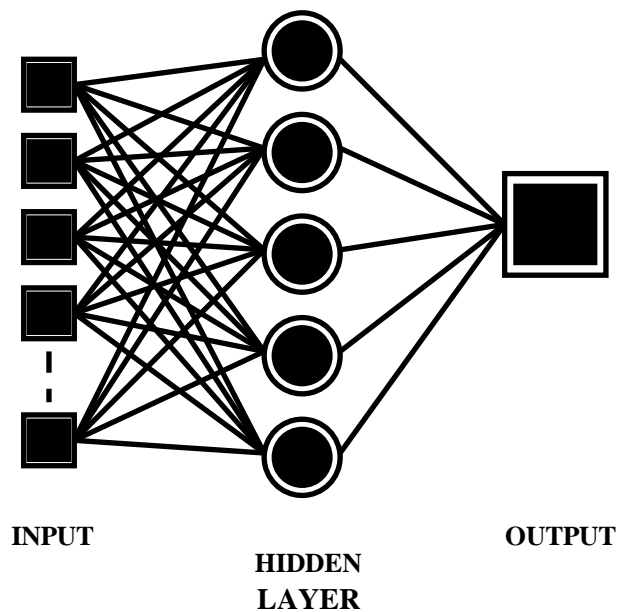


Figure 4.3: Artificial neural network architecture

The complete classification system is described in figure 4.4. From the decomposed EEG signal, the features are calculated for each sub-band. Total 25 features are considered for the classification. Neural network is designed with 25 input nodes, one output node and one hidden layer. We chose transfer function in all the layers as tansig. Further we chose 70% of the subjects

for training, 15% for testing and 15% for validation. Since this is a two class classification, the target values are determined as 0 and 1. The topology chose is Feedforward back propagation neural network. Of 25 input parameters, combination of 10 input parameters are selected which gives good accuracy, sensitivity and specificity. This is done to keep the neural network light and computationally effective.

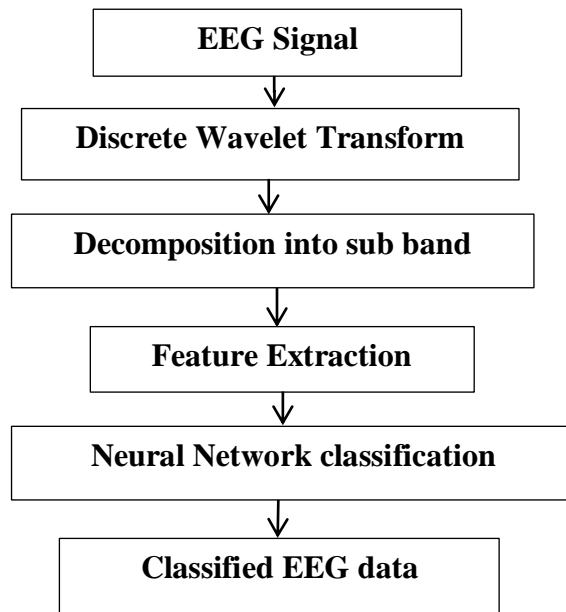
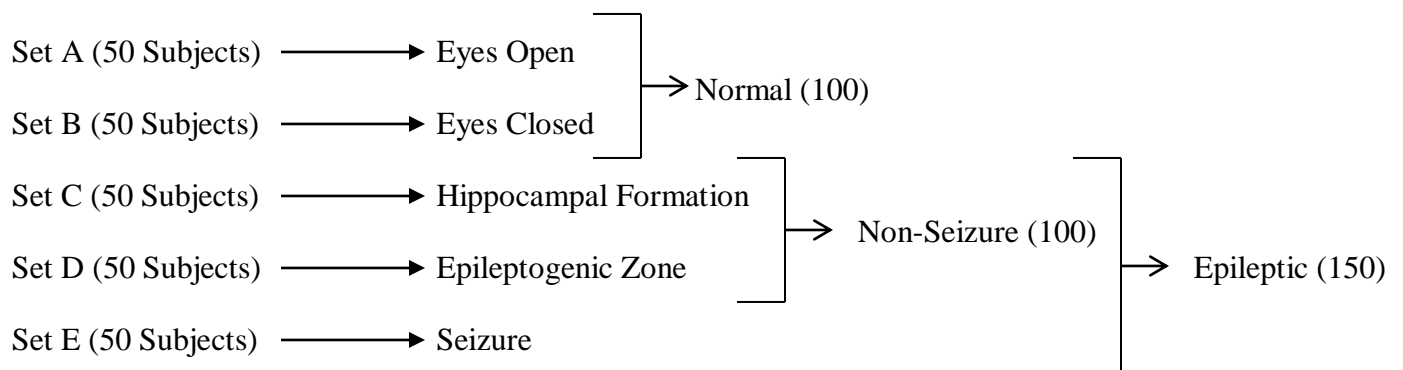


Figure 4.4: Classification of system

The data under analysis is as described below:



In this the classification of normal subjects and epileptic subjects described in phase-I. Sub-classification of normal subjects into eyes open and eyes closed is done in phase-II. Classification of non-seizure subjects and seizure subjects in phase-III. Sub-classification of non-seizure subjects into hippocampal formation and epileptogenic zone is done in phase-IV.

**Phase-I:** Classification of normal subjects and epileptic subjects.

As described earlier, we have 100 normal subjects and 150 epileptic subjects. For optimizing the accuracy of ANN, we tried various possible combinations of extracted features from all five sub-bands, with different number of neurons in the hidden layer. The result of this exercise is given in appendix A.1. It is found that ANN with seven neurons and 10 inputs, namely variance and entropy from all the five sub-bands gives maximum accuracy. This accuracy is 99.2% and is quite satisfactory.

**Phase-II:** Classification of normal eyes open and eyes closed subjects.

As described earlier, we have 50 eyes open subjects and 50 eyes closed subjects. For optimizing the accuracy of ANN, we tried various possible combinations of extracted features from all five sub-bands, with different number of neurons in the hidden layer. The result of this exercise is given in appendix A.2. Here it is found that many possible combinations give 100% accuracy. Fortunately the topology and input vector chosen for phase-II, i.e. ANN with seven neurons and 10 inputs, namely variance and entropy from all the five sub-bands also gives accuracy of 100%.

**Phase-III:** Classification of non-seizure subjects and seizure subjects.

As described earlier, we have 100 non-seizure subjects and 50 seizure subjects. For optimizing the accuracy of ANN, we tried various possible combinations of extracted features from all five sub-bands, with different number of neurons in the hidden layer. The result of this classification is given in appendix A.3. It is found that ANN with seven neurons in hidden layer and 10 inputs, namely variance and entropy from all the five sub-bands, gives maximum accuracy. This accuracy is 98.7% and is quite satisfactory.

**Phase-IV:** Classification of non-seizure hippocampal formation and epileptogenic zone subjects.

As described earlier, we have 50 hippocampal formation subjects and 50 epileptogenic zone subjects. For optimizing the accuracy of ANN, we tried various possible combinations of extracted features from all five sub-bands, with different number of neurons in the hidden layer. The result of this exercise is given in appendix A.4. It is found that ANN with seven neurons and 10 inputs, namely variance and entropy from all the five sub-bands gives maximum accuracy. This accuracy is 100% and is quite satisfactory. It may be maintained explicitly here that 100% accuracy was also obtained in some other combinations. The choice of seven neurons in hidden layer and variance & entropy in features is made to have consistency in the structure of ANN used.

## CHAPTER 5: RESULTS

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EEG signal of each patient acquired by placing 10-20 electrode system, is decomposed into five EEG subbands: delta (0–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz), and gamma (>30Hz) using discrete wavelet transform. Each EEG signal is sampled at 173.6Hz. From each segment 4096 samples are used for evaluation. The subbands yield more accurate information about the neuronal activities of brain therefore; decomposition into subbands is a necessity. EEG segment is decomposed to 6 levels using discrete wavelet transform and then inverse discrete wavelet transform is used to recombine the various frequency bands to form delta (0-4)Hz , Theta (4-8)Hz , Alpha (8-12)Hz , Beta (12-30)Hz, and Gamma (>30)Hz. The delta, theta, alpha band have 256 samples and beta have 1024 and gamma have 4096 samples. The recombined subband frequency closely matches with the required frequency after decomposition in Delta, Theta, Alpha, Beta and Gamma subbands. For identifying the epileptic and non-epileptic EEG, the subject is examined for selected features extracted from the subbands of EEG.

Variance of the coefficients in each subband (  $y_1, y_2, y_3, y_4, y_5$  ), Energy of the wavelet coefficients in each subband (  $E_1, E_2, E_3, E_4, E_5$  ), Power Spectral Density (max) and Power Spectral Density (min) of each subband (  $max_1, max_2, max_3, max_4, max_5, min_1, min_2, min_3, min_4, min_5$  ) , Entropy of wavelet coefficients in each subband (  $e_1, e_2, e_3, e_4, e_5$  ) are determined from each subband. Of these 25 parameters analysed for 50 normal (eyes open and eyes closed) and 50 epileptic (hippocampal formation, epileptogenic zone and seizure) cases taken from database, it is found that none of the feature show non-overlapping.

Table 5.1: Features Extracted From SET A Containing Normal Eyes Open Data

y1	y2	y3	y4	y5	max1	max2	max3	max4	max5
11290	6981	3478	1399	97	37780	19154	13049	16068	1847
12336	7775	4979	2550	199	46124	21588	32463	17105	3590
14729	8523	3189	1863	115	48838	23608	6718	13652	1852
9747	5960	4808	2515	300	26466	15011	10604	8084	5122
13979	6768	2533	1744	133	48376	20102	7466	11428	1484
13383	6339	3374	1855	143	73606	14658	11386	8037	1836
10377	7782	4893	1912	222	39636	14707	10013	6980	2855
6108	3150	1649	1106	85	30887	5684	6765	5997	1165
9072	2207	1976	441	49	33879	6123	5342	3404	708
20255	3537	2157	845	72	90523	16604	6255	4140	1481
11239	4472	3674	760	74	31244	14650	15316	3635	1547
12938	4489	4101	688	60	62601	13208	10610	2517	1802
8138	3321	2768	507	43	22882	11744	9314	3380	696
18409	4060	2140	805	54	63478	10958	5094	4299	977
6879	1649	1051	440	49	24437	7169	3167	1735	1178
19124	5439	3187	1456	113	105443	16751	11157	4773	1289
7376	2850	1996	471	42	18213	7496	7059	1726	1190
25506	6613	4064	1645	203	206825	17485	9624	5439	3666
5281	1467	1424	495	65	17859	2390	2709	2157	1107
7874	2128	1043	502	52	18176	4250	1780	2853	844
7428	2119	1601	487	43	45334	6168	3547	1830	1044
1844	6224	4569	1757	233	76678	14311	11658	8283	3403
5598	3815	2233	1287	273	12236	22382	8230	3681	4019
23340	5294	3166	1976	141	244344	12059	8920	10305	2931
24365	7048	5402	1961	321	71505	23969	13624	8230	6681
5727	2781	3523	1505	380	18430	5784	12566	6290	10708
9908	2575	1628	827	63	42703	7105	5941	4713	1572
10764	3992	3340	1699	266	43136	9958	8523	5411	3712
14503	5585	3978	2627	585	95936	8487	14658	13778	12113
5902	2881	2120	476	45	16401	6078	9461	2352	1479
4569	2370	1389	521	66	12299	5794	4808	2015	1544
10507	5542	2896	2060	297	28094	12986	6328	7203	5665
13109	3808	3469	1487	209	63938	7287	8713	9136	2559
32743	6366	2094	1773	95	194499	22534	4299	10178	1462
18369	6795	3535	1713	157	8376	12537	8616	8645	1795
16459	4780	2306	1981	137	80708	8391	4940	9534	2334
2675	1563	1171	487	71	7472	3572	2355	1731	1321
31198	7585	2703	1723	97	106267	16848	5320	9283	1201
6819	3077	2070	964	162	18350	7949	3791	3408	2374

17866	7594	3874	1272	106	76268	18913	12352	12307	1437
3419	1383	1115	544	67	11414	3617	2561	1832	1434
4705	3506	2159	984	92	17136	10427	5912	3317	3290
12840	5532	4265	1654	162	34701	14350	11611	8697	2070
11902	4722	2961	1228	125	45302	8488	7648	8456	1867
12696	3948	1616	1307	100	50445	7745	4570	5845	1293
14038	5584	3124	1328	98	70558	9921	8214	6959	1419
12421	5900	3383	1651	134	36186	12139	7903	7620	2820
5552	3005	2492	977	104	14782	7660	8641	3962	1674
20226	6319	4495	1724	145	93836	15387	8678	8027	2283
7350	2869	2597	480	41	64159	8548	6460	3566	1250

Continued....

min1	min2	min3	min4	min5	e1	e2	e3	e4	e5
0.003	0.6	0.9	0.0001	0.0009	13644225	-8523680	-4336469	-5987492	-997190
8.8	0.7	2.2	0.02	0.0005	15435727	-11119225	-6395894	12655058	2640082
7	7.2	3.9	0.004	0.0009	20453927	-10053625	-3732486	-7818744	1444381
6	1.8	2	0.1	0.0007	13510767	-4929692	-5193688	11455945	4187585
6	1.8	1	0.07	0.001	21065288	-10894998	-3231707	-7298725	1410389
11	5	0.6	0.006	0.0002	18679111	-8780924	-3.38E+06	-7782037	1835101
11	2.6	27	0.05	0.004	14883835	-10396429	-5622311	-7795433	3026940
5.8	1.2	1.2	0.009	0.00002	-7257059	-3831532	-1779422	-4354648	1093302
0.001	0.4	0.05	0.003	0.00001	11133801	-2230101	-2341982	-1530183	-473402
4	3	0.5	0.0003	0.0002	30917684	-4728366	-2999189	-3565422	-736283
4	3	2	0.002	0.0004	13248956	-4500516	-4632863	-2702335	-811556
11	3	4	0.004	0.00008	17067422	-6724671	-3710770	-2660971	-661463
0.8	2	1	0.002	0.00002	10503682	-3949048	-3433296	-1910256	-397229
7	0.5	0.9	0.01	0.0001	28509488	-4875909	-1587179	-3050412	-640555
1.6	1	0.05	0.03	0.001	-7496702	-1705871	-979763	-1640506	-472906
1.6	15	2	0.03	0.0008	24893394	-7776680	-4201788	-6275019	1281963

6	5	0.2	0.009	0.001	-9298094	-2376811	-2094699	-1821473	-390882
					-				-
4	8.8	1.7	0.02	0.001	39446379	-6692315	-4592136	-6731435	2522651
2	0.2	0.7	0.006	0.0002	-5492716	-1263466	-1211236	-1855049	-651158
5	1.9	0.8	0.01	0.0001	-9730089	-1736132	-1384787	-1992721	-561925
0.6	0.6	2	0.005	0.00003	-9552710	-2554157	-1651613	-1792301	-362810
					-				-
33	3	0.7	0.1	0.0007	23971847	-5079504	-8134397	-6580533	2986760
					-				-
2	1	0.1	0.02	0.02	-6914489	-4078951	-2399361	-5326053	3473295
					-				-
0.7	0.02	0.1	0.06	0.0006	29816964	-5371102	-4460949	-8891020	1725256
					-				-
2.9	1.9	3	0.1	0.002	34500762	-6888817	-6826923	-9487018	4043717
					-				-
7	6	2	0.02	0.001	-7097919	-3294151	-3343364	-5772070	4788951
					-				-
5	3	0.2	0.0002	0.003	12981862	-2599308	-1043503	-3382918	-701420
					-				-
2	0.6	7	0.1	0.007	14376901	-4509172	-4639796	-8543833	3435564
					-				-
4	6	0.2	0.2	0.003	21469036	-7762911	-4341180	12301453	8159139
5	8	0.7	0.00009	0.0002	-7191689	-3825515	-2411638	-1622485	-480460
4.8	1	0.03	0.01	0.0008	-4872560	-2640084	-1486488	-1972259	-551300
					-				-
0.9	0.4	3	0.1	0.001	11816661	-6789059	-2367481	-8795061	4429728
					-				-
8	2	5	0.1	0.001	19534156	-5087760	-4020004	-6038038	2853549
					-				-
10	4.8	1	0.001	0.0004	52498160	-6840020	-2466416	-7275596	-968407
					-				-
1	32	0.9	0.01	0.0001	24357511	-11673331	-4678719	-7009304	1716323
					-				-
0.03	2.9	0.4	0.02	0.001	20604176	-5511128	-2690417	-9556128	1699971
0.07	1	0.02	0.01	0.001	-2854658	-2006322	-1413208	-1758627	-668150
					-				-
4	1	0.8	0.02	0.005	41686841	-9380124	-3660303	-7071134	1068211
					-				-
1	2	1	0.03	0.003	-8550150	-3636558	-2635483	-3494727	1666180
					-				-
49	5	0.4	0.05	0.0004	23213873	-10203239	-3653821	-4881741	1150525
0.4	0.8	0.6	0.03	0.001	-4132462	-1534390	-1184062	-2041251	-792701
					-				-
1	3	0.9	0.1	0.001	-5702155	-3608728	-1906672	-4048670	1051425
					-				-
1	0.07	1	0.01	0.002	15886326	-5657125	-4735017	-6708841	1679348

1	0.5	3.9	0.01	0.0007	16190724	-5088814	-2966660	-5170323	1438947
0.6	1	1	0.001	0.001	17064528	-4403638	-2121790	-5880747	1255191
1	0.4	0.1	0.006	0.001	19313560	-7462875	-3234128	-5418675	1190224
9	3.7	2.7	0.006	0.0008	14726661	-7934705	-3822774	-6916164	1823495
2	0.3	0.4	0.03	0.002	-6397890	-2846201	-2632269	-3931060	1254164
0.7	0.2	7.2	0.0007	0.0003	29920722	-8216726	-4634554	-6863761	1925612
0.002	6.8	0.1	0.001	0.0004	-9171423	-2782384	-3313712	-1852243	-376791

Continued...

E1	E2	E3	E4	E5
60	36	52	15	83
51	28	49	18	84
60	43	41	13	83
49	26	37	25	78
68	28	44	13	80
71	28	46	18	84
59	25	32	26	84
58	34	55	12	83
59	59	54	25	78
72	57	45	24	84
58	67	62	24	79
54	60	57	30	80
40	62	58	23	81
63	58	57	24	82
65	55	38	25	79
67	58	40	22	80
59	63	40	25	76
70	54	33	25	83
61	48	49	30	79
60	60	44	23	80
57	50	41	26	80
63	52	51	26	77
47	57	39	33	71

74	52	38	19	85
59	40	45	27	79
43	37	53	42	87
67	49	55	21	84
52	41	44	25	73
68	38	27	39	69
49	54	67	25	81
60	46	49	29	79
53	46	41	34	75
50	39	41	25	75
76	44	42	13	84
68	47	47	21	82
66	34	52	23	84
44	46	33	29	79
64	42	39	12	82
58	43	44	26	77
73	48	49	18	80
50	40	42	28	79
50	58	53	27	79
52	51	56	23	81
61	48	41	23	82
60	34	53	20	78
66	43	45	21	80
59	43	43	25	85
47	40	50	26	82
73	31	42	26	85
58	64	56	21	81

Table 5.2: Features Extracted From SET B Containing Normal Closed Open Data

y1	y2	y3	y4	y5	max1	max2	max3	max4	max5
17589	9710	3136	2082	127	53122	22616	6919	16626	4183
13048	9311	3500	2329	120	50735	27981	11086	32486	1544
22619	9902	4418	3486	156	66074	41946	14618	26386	3006
23361	15610	5797	4939	204	80807	65567	11257	34580	2280
11613	15107	3265	4507	199	34153	77677	7184	75067	5438
12000	11050	3802	3374	169	64100	45278	9756	45063	2291
63702	23906	5878	4995	174	335287	53148	26418	89316	2378
15534	10467	2702	2525	130	50811	58652	5622	19506	1407
34138	12160	3001	3250	127	144988	49899	9388	43899	1516
15967	48432	7696	13772	450	48523	289888	19427	312202	12246
18832	60891	9500	18576	559	39374	593057	25518	246021	20121
6153	7103	3189	3431	225	25193	31014	8492	41763	3724
8372	14653	3334	5052	233	26550	10542	6653	62664	3789
14517	51094	7936	17284	567	47358	588716	13844	396806	16311
15227	66128	7966	13551	508	42448	581208	19946	366613	17118
8466	6817	3139	1882	146	37987	31511	9682	14654	1829
13085	64040	9319	1088	611	44627	652068	18441	448555	25581
9719	9551	4727	3312	394	25556	76773	7904	51977	11358
10562	38277	7625	7717	237	40052	121118	18573	49355	3362
8727	24161	6433	5020	175	26914	77198	24090	46741	4147
13935	19272	6450	4034	185	52179	50025	35565	18876	4384
9197	29648	8232	5813	222	17025	104917	23358	37289	3638
5446	12746	3512	2670	128	15717	76102	10024	18017	2677
12376	33430	6802	6372	233	70320	154616	20476	59123	4632
11710	28084	5128	5073	218	48258	65776	15099	30139	3264
3820	12326	2908	3060	141	9506	57218	7852	27160	2106
7915	32328	4106	6786	231	31503	179585	8544	88024	48191
9456	9858	3564	2352	141	23358	25574	7755	13084	2385
7121	7422	2426	2090	119	22638	23717	6790	9411	2379
12751	18008	6483	3986	165	42036	46532	17375	18834	2407
8262	8263	5116	1842	101	20973	29829	13134	13063	1825
5977	6334	3517	2106	182	16884	37043	8409	16618	2283
9096	8842	4420	2787	456	39811	33757	16563	27476	8802
18435	14882	6436	4213	326	86763	57019	16880	53885	6101
17228	47169	6194	1240	476	88480	346204	15721	218789	12352
8101	8108	2616	3068	164	41235	55894	68958	33663	2100
20772	53253	6918	16577	519	71605	309834	15464	258487	11657
15917	50285	7874	17095	552	46051	401734	14845	234321	10300
17897	50501	7203	11924	476	37547	552575	18213	284462	15648

10803	21812	3207	6074	265	40448	194823	9937	143969	9212
14676	45523	7785	19551	542	47329	363256	28000	561379	24653
2536	5216	1933	1224	95	7893	18507	5933	5941	1472
3577	6247	2629	2032	131	10627	13206	6398	16896	2457
4587	7522	2470	2336	124	17392	27899	4400	23316	3207
9205	36480	5299	9363	245	35894	123976	17292	115440	4450
11343	29074	5318	5721	187	47690	117876	17217	38839	2462
6630	5542	3507	1647	137	16036	19795	7725	10514	2524
10550	15391	7169	3390	157	45316	38252	22824	20708	2446
10800	8941	4410	1882	88	44009	18372	13479	9089	1784
5300	7357	3126	2045	103	14365	25446	7818	17536	2123

Continued...

min1	min2	min3	min4	min5	e1	e2	e3	e4
1.7	13	1.7	0.005	0.000006	-26390158	-11511997	-3581157	-9810358
0.9	1	0.7	0.04	0.0007	-16356066	-8680670	-3690707	-10697037
34	29	5	0.04	0.0004	-25451743	-13163424	-5520547	-16451949
1	4	11	0.001	0.003	-33554460	-20567230	-6539583	-24212351
0.008	8	0.2	0.001	0.002	-11424746	-21652696	-3654187	-22470228
2.5	1	0.9	0.01	0.001	-16994903	-14154480	-5844228	-16242610
33	0.9	8.8	0.06	0.004	-106001111	-36518692	-5860684	-24674488
2.9	0.3	0.8	0.009	0.0007	-21016471	-12070597	-3478991	-10769699
7	1	5	0.04	0.001	-46436712	-18647999	-4592735	-15771429
28	2	0.3	0.02	0.001	-22418045	-78804037	-11148061	-73936630
25	18	10	0.04	0.004	-21911253	-92095810	-11845527	-103595332
1	0.1	0.3	0.02	0.0004	-8509411	-9871530	-3876810	-16650497
0.2	0.4	13	0.003	0.001	-11243540	-18095941	-3490060	-25375415
0.7	3.6	10	0.02	0.001	-20309835	-68307715	-9362304	-99456631
4.7	2.5	3	0.08	0.001	-23710512	-97367099	-11513936	-76712577
1.7	1.7	0.1	0.002	0.001	-11117013	-8035696	-3891511	-8410543
1	2	8	0.0006	0.00007	-18352686	-88990729	-8973257	-98159604
2.9	1.8	6.7	0.01	0.0009	-13405292	-13287212	-4993226	-14780469
10	70	0.01	0.002	0.0008	-14103881	-52547264	-9685576	-41672568
1.5	10	2.9	0.01	0.0003	-11236774	-34571292	-7176060	-25397679
6	25	5	0.01	0.0001	-20276444	-28575142	-7777620	-20328647
28	7	3	0.01	0.0009	-12703525	-45560662	-11596681	-31651358
0.2	5	4	0.004	0.00001	-5797758	-18249320	-4627347	-13487531
15	6	2	0.006	0.0001	-13753444	-50798037	-9243915	-32441737
0.3	19	6	0.09	0.0001	-15039454	-42165058	-6877029	-24823710
5	0.04	7	0.0006	0.0002	-4454793	-16110342	-3227355	-13724636
0.03	10	1	0.001	0.001	-9457730	-40994228	-4380841	-34102286
0.6	4	0.2	0.006	0.0005	-12142673	-11899384	-3794147	-9560190

0.1	6.9	0.1	0.01	0.00007	-8479409	-9326685	-2447779	-9204862
0.3	7	0.7	0.02	0.001	-17365841	-27156323	-7676302	-20429081
0.05	4	3	0.001	0.0001	-10433569	-9965647	-7281277	-8310879
8	16	2	0.002	0.0009	-8015742	-8136853	-4750700	-10167419
0.5	4.7	15	0.0009	0.001	-11408319	-13267375	-5793105	-12799749
2	1.7	7	0.05	0.00003	-22149389	-24270275	-8877543	-21257777
2	35	0.5	0.04	0.0004	-26039610	-67688081	-6712290	-71779801
0.5	2	11	0.01	0.0006	-11608318	-10807294	-3458086	-14134740
10	33	6.9	0.03	0.002	-36625684	-71963999	-8090398	-97786548
1	0.9	7	0.004	0.0001	-23783071	-77584472	-11111518	-93241784
1	11	1	0.02	0.001	-19114950	-70166306	-7983477	-60333173
11	0.6	2	0.004	0.0008	-14529620	-28309214	-3031197	-31908031
1	4.6	1.6	0.01	0.0007	-21342915	-64694333	-6898977	-110672129
0.05	4	0.001	0.008	0.00008	-2647608	-5810285	-2268446	-5010359
1	7	0.09	0.002	0.0003	-4275151	-7628979	-3071681	-8534707
0.5	16	4.6	0.006	0.0001	-5553509	-9991176	-2871800	-10384343
1.7	1	9	0.01	0.0004	-11098707	-52788302	-6331214	-50579652
0.3	1	3	0.007	0.0005	-13198293	-42357272	-6432183	-30940168
0.01	14	2	0.05	0.00009	-8701099	-6454515	-4036208	-6886857
2.5	0.4	0.2	0.03	0.0004	-15177104	-19134023	-9235544	-17884422
25	5	0.8	0.006	0.0004	-14201566	-13485926	-4967678	-8420826
4	0.5	0.4	0.01	0.0005	-5563747	-10804803	-3905901	-9113244

Continued....

e5	E1	E2	E3	E4	E5
-1302393	58	31	52	10	82
-1242900	60	36	45	9	84
-1744499	68	30	47	8	84
-2414379	63	19	48	7	85
-2504994	62	8	41	8	87
-2201645	67	23	46	9	80
-2143848	64	44	51	7	85
-1292647	63	31	42	11	83
-1556125	69	24	45	8	84
-6823844	48	7	46	5.8	85
-8331991	65	6	42	4	87
-2575570	54	16	34	13	85
-2919894	59	10	38	9	84
-8219094	52	6	44	4	87
-7332545	64	4	36	5.9	85
-1497010	61	20	43	13	84
-9234474	44	6	39	3.9	87

-5152829	62	16	27	21	86
-3088718	57	6	31	7	86
-1988630	56	7.8	23	9	86
-2479906	52	17	40	15	85
-3305750	43	10	25	12	86
-1362755	59	11	33	16	86
-3653152	67	4	19	8	86
-3102792	66	5	27	11	87
-1794164	44	6	31	16	86
-3000623	56	4	35	7	86
-1574184	47	28	32	19	83
-1259009	52	19	33	18	85
-2212962	60	9	29	12	85
-1221428	51	22	47	18	83
-2209951	49	18	53	16	85
-8087871	58	20	41	28	86
-4877503	65	14	48	14	85
-6946961	60	7	38	5	86
-2054685	49	15	37	9	85
-7131923	66	6	43	4	86
-9393115	49	8	43	4	87
-6172573	74	4	46	7	86
-3470571	60	7	39	5	86
-7696036	49	6	45	3.9	86
-938680	40	9.4	33	26	85
-1995317	40	18	37	19	86
-1492227	66	21	40	13	87
-3027331	50	5	28	5	87
-2566884	66	5	34	6	85
-1480861	48	37	44	22	84
-1632771	61	17	38	13	86
-959713	58	21	48	13	82
-1240652	60	17	34	11	85

Table 5.3: Features Extracted From SET C Containing Epileptic Hippocampal formation Data

y1	y2	y3	y4	y5	max1	max2	max3	max4	max5
21709.5	9504.98	6082.63	511.62	19.75	42446.36	38612.95	25221.81	2657.058	271.79
45753.7	13624.8	8181.2	801.6264	37.37597	156725.7	76669.57	32233.02	4242.51	
19019.12	7411.056	4791.28		33.045	71257.06	39425.87	17501.59	3169.676	480.12
22755.16	5385.81	3787.46	510.4	28.394	70029.39	23595.18	12165.11	6515.89	508.147
140659.5	40497.09	23268.81	8648.8	723.14	432364.5	125833.4	50110.12	41824.64	10079.5
36982.17	7851.099	4961.011	603.593	26.31	97763.51	27049.07	17570.99	3016.33	324.14
	5907.57	2229.51	346.503	26.751	82731.65	18971.46	6445.78	1566.89	1203.145
17105.5	3518.82	1744.59	288.289	18.163	76627.66	11220.86	6692.55	1748.51	691.87
39009.2	13903.85	5776.89	960.56	59.84	80202.93	54788.29	13981.92	4037.32	682.09
13439.02	3424.07	2059.23	339.222	21.102	46423.3	9957.05	9033.26	1247.24	273.604
5699.81	1106.16	932.5	121.74	8.9001	15209.19	6235.16	3573.37	365.05	494.9
33011.65	13067.18	6527.74	855.86	36.278	94989.91	39141.35	35467.28		1199.47
14922.98	3670.39	1703.53	211.59	9.449	53714.21	19532.41	4760.91	759.76	129.88
12544.91	3121.1	2644.49	422	23.283	37759.38	9544.25	12463.32	1524.86	315.38
47041.46	14831.73	9115.76	1755.1	166.8	162853.1	48235.68	29064.78	6103.97	2000.4
19847.27	5792.7	3242.62	404.3	22.608	115703.9	25386.19	16512.96	1295.43	991.54
39819.48	12284.77	9373.42	2144.29		107279.3	44274.09	26124.4	8145.72	2863.93
8590.83	3669.76	4584.18	371.37	14.91	19086.99	13188.71	12896.05	1804.82	170.85
37657.62	6179.97	4433.86	548.15	27.54996	138311.8	20832.01	22428.49	3445.32	734.54
11996.48	3647.14	3212.97	343.77	15.60356	35897.01	10361.51	10962.35	1911	650.16
31438.71	8063.64	3980.89	513.13	32.83653	134769.8	31223.26	19548.78	2178.16	1051.16
21642.9	10997.63	5721.37	532.23	22.17	61239.39	91752.43	21729.35	1976.03	238.13
8432.94	1753.82	727.46	135.38	11.71445	49099.73	6557.98	2440.25	421.06	125.05
49300.4	11122.11	6199.06	1131.63	74.22999	149190.5	61667.97	19264.4	6109.56	1791.19
15911.55	5234.26	6169.2	480.58	14.36034	41052.27	17647.63	20366.02	3563.61	572.17
7165.32	1966	913.33	110.9	6.606317	19068.05	8015.76	4518.14	704.79	82.462
7202.29	2669.88	1883.68	227.3	10.57277	16487.2	10475.4	7111.06	1154.96	756.83
3385.27	1128.98	716.84	71.548	5.140001	11222.25	5641	2424.32	513.15	228.53
37965.94	6188.07	2920.58	419.77	28.2406	254901.6	25231.46	11035.11	1885.06	291.12
33311	5696	2399	426	26	207002	21595	10660	2176	348
15719	5252	7451	534	11	36889	16136	23685	6245	336
14933	3566	1975	297	18	38940	12298	6820	1113	268
50435	13214	4965	442	28	251017	102768	18311	1823	482
57415	8895	3258	498	23	329710	36795	9880	2395	498
17375	4443	4284	415	17	39914	18109	13018	6096	544
41351	12417	4974	360	12	147512	47797	12211	1612	134
27173	9603	4421	742	45	152906	32220	14521	2506	1135
24909	4586	1989	439	30	116079	22798	8479	1615	578

37546	8937	5328	1105	77	105583	31950	17860	5708	1461
34837	8800	4264	480	27	103030	36794	15229	2107	400
10216	1705	945	130	11	45271	7732	2372	631	188
58404	12016	7113	1251	77	210802	64068	20728	5280	1678
47516	10899	5611	1265	83	162966	37895	19700	5151	1349
22252	5908	3226	426	23	86680	18487	16786	2562	385
16061	7786	4885	394	17	49151	46959	18647	1957	324
10337	2471	895	155	13	58717	9868	2463	566	428
37789	18750	8213	1176	73	102086	60518	28179	4727	746
16647	10184	4759	2469	199	49879	17930	13894	10090	2518
15426	5003	3620	603	36	63218	15695	10345	2522	467
99508	21203	11517	2929	284	457545	57602	29113	12595	3127

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min1	min2	min3	min4	min5	e1	e2	e3
9.025	8.989	0.66	0.0565	0.0001	27953363.75	-12577647	-5591550.1
26.22789	6.16523	0.065395	0.0144405	0.00028	66727050.65	-20542786	-7565884.3
0.803859	3.279504	1.021939	0.00311878	0.000061	-27234064.3	-9760044.8	-5417490.3
1.039576	0.14707	4.256335	0.0053175	0.0010196	37692822.61	-5698356.3	-4509026.1
9.072574	38.98655	7.683078	0.08303869	0.0340939	268632648.2	-60718546	-32114098
28.49209	0.209073	5.029183	0.00563202	0.0003	-43742527	-10286775	-5156795.2
36.27354	0.179154	0.062034	0.00112499	0.00014	42562632.17	-7993229.5	-2607579.4
5.420959	1.262724	0.055627	0.00079	0.000119	-19401183.4	-4377718	-941327.16
34.23041	0.173855	4.923249	0.03200835	0.002258	-60791935	-15537740	-6109787.6
0.129244	2.076124	0.772926	0.01463171	0.00021	-16894597	-4181122	-1499566
1.53953	2.142093	0.079424	0.00893941	0.0005	-6414052	-852378	-1180884
17.92903	1.799698	0.631446	0.00849619	0.00096	-43753681.7	-14345087	-6516810.8
4.883277	0.57169	0.031358	0.00088	0.000029	-19239112	-4387408	-1635888.4
4.072905	2.684086	0.286499	0.00083	0.00068	-14783044	-3947006.6	-2166473.1
4.741121	13.47638	1.499307	0.03955747	0.0073228	-70278238	-15685578	-10795193
0.531863	1.254482	1.2313	0.00174844	0.000144	-19204400	-6869312	-3628750
1.23E+02	0.286262	0.07016	0.05510531	0.0013416	-57765957.9	-12128900	-11125123
0.242432	3.008555	0.094182	0.00480306	0.000014	-10132966.7	-3732629.7	-4840799.4

9.182911	3.37206	1.526828	0.04582153	0.00041	-66743953.2	-7081887.9	-4990888.1
12.34273	0.847426	0.851849	0.00027	0.0002	-15600716.8	-3892373.6	-4696214.1
7.033346	4.816511	1.145423	0.00363978	0.00013	-40232984.8	-10115442	-4507612.6
12.06039	0.274222	1.42434	0.03390483	0.00007	-29425985.9	-10552990	-5807516.1
3.660284	1.220206	0.175481	0.00388871	0.00003	9377737.454	-2437927.1	-599961.05
38.18146	1.670591	4.095202	0.00339669	0.00036	-66830190	-21146518	-5633381.7
1.544154	3.369979	0.617436	0.00432321	0.00006	-20432103	-5964059.3	-5809314
0.118329	0.230498	0.421273	0.00553782	0.000002	-8960014	-1803712	-734302
1.94311	1.97902	0.023997	0.0000034	0.00007	-9802275	-3975457	-1622811
0.320571	0.563476	0.10385	0.00987113	0.00031	-3775671	-935672	-681256
30.10386	8.470685	0.079085	0.01560112	0.00024	-55061737	-6182453	-4723429
0.6	0.3	0.1	0.005	0.0009	-45707291	-6164591	-3577369
2.8	1.7	0.8	0.001	0.0001	-19772292	-6188189	-6836268
0.3	0.1	0.3	0.0006	0.00009	-19769476	-4167891	-1338220
0.6	1.7	1	0.006	0.00007	-89457099	-14775527	-5541715
11	0.9	1	0.01	0.00005	-85975504	-18030726	-3417439
1.6	1	0.0003	0.007	0.0003	-26335336	-4871066	-4677982
6	0.5	1	0.00001	0.0002	-58381013	-11396848	-6493525
2	8	2	0.02	0.0001	-34353766	-11215440	-6054663
22	1	1	0.02	0.00002	-30949468	-5679524	-1486401
6	12	5.9	0.009	0.002	-49131273	-8059086	-5637773
13	0.3	2.7	0.02	0.00007	-54124689	-10066082	-5270366
1	0.6	0.05	0.005	0.0002	-12803490	-1361264	-1000057
0.8	0.7	0.4	0.02	0.0002	-81508086	-24040743	-6858360
21	26	2.8	0.004	0.0006	-63867469	-9790893	-5839434
12	0.1	2.7	0.03	0.00002	-31251885	-7419813	-2760280
36	3.8	0.7	0.0002	0.000007	-22811934	-7435787	-4626650
3	2	0.06	0.005	0.0002	-11556498	-4261761	-999562
31	19	3	0.06	0.0007	-56915963	-19639060	-10216770
0.6	6	1	0.1	0.0001	-26523220	-14619911	-6210361
0.8	5	3	0.002	0.0003	-20773764	-5107046	-6136554
25	0.03	1.7	0.1	0.009	-160660794	-37129065	-13917764

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e4	e5	E1	E2	E3	E4	E5
-1980013	-157128.8	35.885	80.982	66.145	28.952	80.5
-2906598	-327221.4	37.484	79.92557	66.2544	23.43339	79.5
-2336932	-346504.6	54.36921	68.94405	57.20304	19.0972	78.65016
-1890445	-261459.7	54.02938	79.79574	61.81171	27.07537	74.77719
-46833050	-10228326	48.47767	68.5959	49.29115	30.92371	77.89494
-2228722	-222539.4	64.33894	76.18853	59.61708	26.67905	79.44361
-1292244	-216945.4	44.65571	87.0071	55.4723	29.72374	73.68261
-905390.6	-136640.9	70.72601	71.73101	48.8768	19.65064	72.87998
-3631896	-519069.1	28.55831	85.03699	44.7655	22.06444	79.81946
-1218449	-186024.6	45.22061	72.22457	58.52869	22.57438	82.19509
-318504	-50438.2	53.58016	81.69471	52.84506	24.87	70.66055
-3601825	-383658.5	82.56899	57.11514	26.97261	77.91123	
-630039	-57141.8	60.14225	82.22794	48.27647	19.13649	77.0778
-1569192	-190641.7	45.03232	67.92847	57.30556	24.84156	80.01906
-7197671	-1916540	50.86385	61.1364	61.01589	30.98283	71.39009
-1507139	-214142.8	47.99454	73.70203	57.20031	17.51517	76.54365
-9247843	-2312136	49.0155	61.32761	56.65056	26.1393	76.96188
-1391855	-115462.2	41.14507	69.29794	58.26416	18.87204	77.03495
-1998220	-257350.1	59.26149	84.99508	65.94907	27.01503	74.78619
-1207396	-123170.2	61.7966	68.30991	51.57495	22.65274	72.58869
-2012150	-352947.8	44.09065	72.81542	60.02623	16.01289	76.7436
-1781170	-163475.6	34.30614	83.92339	55.61461	27.4646	82.13369
-434684	-79598.6	63.35248	80.51687	60.46267	26.45402	62.63285
-4782069	-749872.8	54.72977	75.23654	67.08628	23.48606	79.56164
-1695777	-92020.6	33.71728	76.50003	59.59524	24.15886	75.3764
-316679	-35564.8	45.0064	82.48604	50.2025	22.55018	64.82115
-766030	-65826.1	45.27569	82.24607	51.92407	20.32549	72.72647
-200554	-23847.7	46.05476	80.61752	55.1695	21.39393	62.38523
-1493642	-252433.5	51.16734	71.59151	46.68964	21.10432	76.98598
-1449041	-200988	59	69	48	18	77
-1925886	-78658	31	72	56	21	75
-1115002	-154446	48	72	57	24	79
-1372072	-252366	52	90	58	28	78
-2003195	-225289	49	86	47	19	81
-1515734	-147791	45	77	61	26	73
-1229978	-83347	57	87	44	31	78
-2806154	-476067	56	78	51	24	78
-1632249	-263907	59	74	49	19	75
-3896867	-766061	56	70	53	22	78
-1649962	-227686	46	81	58	28	77

-381068	-88120	70	83	48	26	63
-5445479	-787810	53	69	66	22	79
-4648535	-822058	61	70	52	19	78
-1474598	-205184	55	79	62	19	75
-1286556	-126551	35	81	52	27	75
-502521	-82673	55	84	49	25	67
-4850359	-679654	35	81	67	23	81
-11637622	-2258847	34	45	44	19	80
-2417882	-331003	38	65	52	20	81
-13523272	-3672419	65	57	48	24	66

Table 5.4: Features Extracted from SET D Containing Epileptic Epileptogenic zone Data

y1	y2	y3	y4	y5	max1	max2	max3	max4	max5
9154	2003	942	195	15	34238	10268	2366	793	331
223612	22947	28626	2701	108	766422	87568	71971	9934	1206
52848	14691	7.77E+03	1668	75	389799	28785.04	25553.37	6798.26	1074.4
12054	5325	3815	334	16	47968.6	29923.7	16332.18	1560.4	195.9
52723	29063	16781	3026	260	157802.8	101960.6	68489.2	9871.1	4123.2
4931	966	1736	151	8.81	19858.8	2954	23059.17	1444.7	154.9
11956	4912	3657	646	51.04	36856.3	16617.5	12846.6	2270.2	794
132374	18018	13963	1609	57.53	401805	63656.8	58410	5085.7	787.7
2260964	415776	269353	32343	744.4	17506897	1434772	842521.5	123286.3	8142.5
236732	37418	17335	3452	150.3	815934.7	111996.5	60332.3	17630.7	2585
26290	17638	5464	644	20.43	137665.6	118769.5	24108.7	2417.5	298.31
13952	6676	5029	468	23.06	26387.07	29537.2	17057.7	1890.3	285.13
5074	1833	1623	224	11.69	20010.4	4967.1	3819.03	1060.2	598.78
7505	2268	2.71E+03	249	12.57	23062.1	9863.7	9017.9	2742.5	595.58
8925	1747	2241	235	9.26	36426.7	5587.8	32006.8	3186.2	158.79
24023	9837	5245	1146	77.9	42549.3	31500.6	16359	4299.6	843.77
9468	4469	6138	528	10.15	24632.6	11580.5	16338.5	7237.5	654.75
24210	17492	12435	2418	91.71	57837.5	48412.6	33732.7	19273.8	5459.7
8480	3103	2805	470	22.97	16508.7	8556.4	10640.7	1581.1	420.53
14069	6155	1972	309	16.63	74977.3	25923.4	4620.2	1773.3	698.7
182087	79524	22475	8466	677.7	695103	337065.2	61227.2	35477.8	15831.6
54442	12517	5325	1153	62.02	393946.2	34466.1	20883.6	3955.4	724.42
23659	18401	14576	2658	75.27	50507.9	44325.5	43992.4	23492	4282.2
45391	25799	13484	2080	148.66	139432.3	88365.6	40172	9841.5	11041.8
70059	39066	15978	2053	100.42	246615.8	149559.4	46641.2	8634.3	1331.7
3583	1558	874	146	11.02	9369.07	7179.1	2727.8	651.8	909.6
43823	11826	3459	507	51.24	297165.2	39496.8	14431.4	1534.8	782.75
13194	5672	4368	485	20.15	26534.3	24009.3	24800.8	1834.6	292.2
135278	19880	10695	1666	58.14	635656.3	68073.7	28067.8	6082.4	81024
257093	37227	18882	3742	213.41	2292687	150497.4	66181.3	12380.6	2512.1
56988	31166	19485	3777	382.8	167650	94967	78116	10860	4994
69501	16389	9001	2602	178.6	274428	67741	19609	11813	6064
14723	5630	4872	612	19.9	46640	20629	23647	2995	224.2
5144	1665	1804	195	9.5	20785	4263	5386.8	1.20E+03	226.6
11184	5478	8211.7	709	11	33028	12597	23538	9740	233
13228	3669	4091	362	10.1	51910	10740	9601	2226	586
15530	7258.5	6273.5	1491	89.9	67629	14718	22590	7370	11488
27179	11519	5207	831	36.5	111844	54405	15574	3762	697
41867	11998	4615	429	17	142408	51225.5	10941	1796.9	348

9387.6	2576.7	1343.8	316	19.5	42114	7782	3072	1734	257
61199	13097	13309	737	21	171824	65143	41364	3249	456
6896	2135	1123	230	14	29533	8600	3362	773	522
21091	17473	16189	2707	69	45546	41203	60307	21082	4386
20705	11353	6877	857.8	35	39706	49552	29933	4364	387
17394	7179	3401.9	963	64	55649	30388	10385	4297	1331
17676	7775	2906	1329	67	67372	21674	7196	7175	1362
27920	12684	6098	1270	92	65927	45815	22442	5164	1264
34113	15113	7693	1317	93	79686	47369	15741	5757	2289
17226	4489	2304	411.5	23	82364	17919	7284	1843	322
51760	13070	3533	478.9	18	187187	61859	15032	2040	571

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min1	min2	min3	min4	min5	e1	e2	e3
0.3	1	0.3	0.03	0.0002	-12003972.2	-2322453	-1071645
7	5	1.9448	0.032	0.00055	-496420901	-25212932	-58893571
7.2571	13.815	2.4133	0.0099	0.00029	-78057327	-20107734	-10483598
1.0078	2.487	0.8269	0.00005	0.00053	-15191584	-5268385	-3735045
1.3909	4.3537	9.826	0.0158	0.0035	-83531537	-40321508	-15164734
7.4725	0.0711	0.0618	0.0039	0.00029	-5865619	-1070131	-1649679
0.0536	106158	2.3211	0.0322	0.0016	-15919185	-6888176	-6083822
3.3601	13.8512	0.6987	0.0039	0.000036	-288793413	-22843366	-22800145
1492.6	208.96	40.3835	0.1457	0.0018	-7134943429	-878357626	-793255795
1.2465	37.5647	0.8067	0.0043	0.00026	-514452410	-64728818	-22891774
9.9512	0.0213	0.7967	0.0044	0.0013	-34467375	-22951883	-5727906
2.9505	1.9723	0.0463	0.0002	0.000074	-18324383	-7758836	-5855843
7.2215	0.3454	0.0616	0.0081	0.000006	-5846173	-2081154	-1708952
1.1094	1.1088	0.3513	0.0012	0.00017	-9630524	-2326129	-2990783
14.4209	0.152	0.1204	0.00056	0.000024	-11274769	-2065696	-2357166
30.356	1.1251	0.3744	0.0051	0.0024	-32503467	-14215961	-7868266
2.1802	0.2368	0.4723	0.003	0.00001	-11487445	-4618403	-7017539
1.6956	8.1528	2.8484	0.0038	0.0019	-33172794	-25374800	-14457851
18.6525	1.7444	0.1689	0.0019	0.0001	-8277349	-3051535	-2992408
0.125	12.2288	0.8077	0.00044	0.00033	-20067962	-4793237	-1823741
224.1	39.1079	2.5984	0.1824	0.0167	-290940017	-102451166	-39344224
12.2999	16.0041	0.6917	0.0042	0.00017	-80885947	-16882258	-6172419
32.9292	1.0332	1.9975	0.0248	0.000035	-31928531	-26003528	-17310910
0.7451	13.4984	7.6778	0.093	0.001	-66736911	-29033225	-20012835
148.0781	10.9131	2.6319	0.0057	0.0031	-112160442	-42587179	-24411074
0.9554	1.407	0.2618	0.0076	0.000017	-4508071	-1956070	-677570
20.5435	2.7013	0.4924	0.0456	0.0013	-65695180	-16597018	-3394117
6.1857	0.6007	0.038	0.00046	0.00034	-17908763	-5177443	-4608053

34.6964	0.4379	0.8924	0.0174	0.00032	-277736822	-19662713	-13710160
19.2875	44.248	2.701	0.0429	0.00014	-654837481	-55430392	-46397339
82.12	1.48	4.44	0.07	0.00007	-91008371	-42092241	-17717044
22.5	1.05	14.9	0.017	0.00003	-78401210	-24074690	-13898157
8.7	1.4	0.76	0.0032	0.00008	-21407837	-7458658	-4564937
0.58	0.85	0.38	0.0008	0.00008	-6306536	-1826168	-1800113
15	2.5	0.12	0.0005	0.00003	-13732151	-5913071	-9759213
9.5	1.7	0.1	0.0015	0.00016	-18139258	-4245769	-4498832
12.9	5.5	0.06	0.0015	0.0007	-21887516	-10450885	-9180525
0.03	1.5	0.9	0.03	0.00001	-40457260	-13829106	-6254575
0.00001	4.6	0.03	0.01	0.0002	-59735341	-22080294	-4910715
0.4	1.5	0.1	0.005	0.00007	-12707401	-2971892	-1256984
45	2.6	3.3	0.0004	0.0001	-104034213	-31154537	-16119054
3.4	0.07	0.004	0.007	0.0001	-9592543	-2551018	-785111
1.9	8.1	0.1	0.02	0.00006	-28565637	-24506054	-22013056
3.3	2.5	0.01	0.006	0.0004	-29427957	-13778252	-8801635
3.8	8.6	0.6	0.0004	0.0008	-25080262	-14555485	-3736092
4.2	6.5	0.5	0.01	0.00001	-24148586	-8621084	-3023432
14.7	10	0.008	0.03	0.0005	-37224241	-17357857	-8762534
20	0.7	3.3	0.02	0.001	-48507614	-18908108	-7168792
3.8	0.2	0.06	0.0008	0.0001	-23325678	-5243522	-2550103
13	1.7	1.3	0.008	0.00008	-75672240	-17539672	-3231085

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e4	e5	E1	E2	E3	E4	E5
-630340	-102609	41	75	53	21	72
-19689032	-1733882	57.13147	65.29569	44.84274	27.37874	85.7754
-7348950	-1077284	37.55194	54.03407	54.2881	14.90431	84.35145
-1043251	-136761	44.59411	82.34486	62.78872	23.90253	74.49213
-12512142	-4416874	34.5034	68.26886	54.80212	27.32605	84.61588
-431163	-52260	34.4513	59.6935	81.3886	23.1845	69.6304
-2464819	-553716	36.1386	63.1528	60.6532	23.7496	73.2469
-9837774	-804882	56.8875	55.6093	52.4667	20.8281	85.2982
-246209644	-13976697	60.1156	74.6721	50.2711	17.4628	81.5922
-22265771	-1236043	62.1254	74.8988	62.2408	25.0686	88.0813
-2308937	-207573	20.2663	88.1924	63.3575	23.7498	76.2002
-1704876	-189302	28.7044	81.496	66.8942	24.1107	79.5939
-692849	-77909	29.7791	67.3036	44.7948	24.2123	74.8347
-825917	-93824	24.5611	60.9127	56.7949	21.6999	76.0892
-715667	-57424	36.4117	58.2272	81.8756	19.8884	75.0034
-4659023	-920575	35.0395	71.123	57.3093	21.7748	77.2118
-1984142	-62074	33.9213	59.8203	52.2348	14.7745	75.7363

-11299839	-1095091	34.5565	43.1406	29.7441	11.4709	76.4066
-1728051	-363749	30.1127	64.0044	62.1445	23.1222	80.3631
-1039982	-127332	56.4371	79.6465	46.9395	19.7159	80.9751
-39715955	-12249886	58.3899	73.774	57.8565	20.4487	82.4134
-4635282	-840476	37.323	65.979	47.6128	17.4205	85.0528
-12792255	-875616	40.5473	32.0931	27.7446	11.2778	75.0227
-9074274	-1814466	31.382	75.5703	52.3684	22.5503	75.4508
-9483980	-1256591	53.9806	84.8215	59.78	23.7796	78.0526
-430198	-84071	41.8652	79.3423	59.4755	22.4892	71.7463
-1742934	-423704	58.2206	86.0754	60.5504	28.0919	72.813
-1672056	-158593	31.4186	81.1137	65.9924	26.6501	76.332
-9941494	-797736	61.6505	66.514	53.8456	25.2453	85.2798
-24345031	-3570032	64.9566	73.6624	47.2118	22.0248	86.8068
-16206100	-6792406	36.8	66.05	57.54	29.9	81.85
-11976177	-2952178	76.39	62.2	42.8	24.5	84.13
-2079333	-188128	32.9	67.8	70.8	19.9	77.4
-613715	-62214	27.7	65.7	54.6	22.2	71.8
-2777366	-71029	36.1	56.8	48.7	14.3	74.4
-1268511	-66445	65.2	65.2	65.2	65.2	65.2
-6403426	-936353	58.4	30.5	20.7	14.8	71.9
-3197989	-347384	50	76.9	55	18.8	79
-1612398	-155283	34	84	51.5	25	78
-1142439	-132436	59	68	47.8	26	79
-3001974	-202073	52.6	79	44	20	76.9
-691572	-105241	64.9	76.9	51	21.5	77.9
-12813683	-728244	43.6	23.9	23	11	74
-3579947	-242514	24.7	80	62	23.8	77
-3934708	-610728	57.7	62	44.5	17	76.6
-5646609	-643560	54.8	30	36.6	14.8	78
-5314532	-1170044	36.8	72	57	22.8	78
-5509709	-1011031	36.5	77	49.5	27.5	76.5
-1407740	-162095	64.9	71	49	18	81
-1625392	-138504	50.8	89	47	22	82

Table 5.5: Features Extracted From SET E Containing Epileptic Seizure Data

y1	y2	y3	y4	y5	max1	max2	max3	max4	max5
852854	989225	461273	264872	18878	1699523	3986849	1268427	1260345	289860
1338865	500985	579622	309123	25740	3337860	1816487	1605787	2131986	480293
323189	444760	261853	233779	20264	657222	1354336	650676	1393399	430577
97145	53773	165504	19713	933	446171	126037	947994	133509	25269
724394	399824	376415	57135	2795	2606269	1117888	1560272	470844	45254
83321	41909	81804	9534	405	370146	112330	415903	64333	5202
430821	114605	69838	57194	8753	2004999	349839	173762	207004	114649
563289	278589	1261677	128160	2971	2673946	748801	7628535	1523110	89960
481222	280459	594692	89538	3986	2727179	813415	3692950	475053	36190
326580	519821	601922	574335	67550	722574	1539736	926065	3724660	1219206
409839	426767	400169	157953	13591	1546968	1002167	865870	915120	185353
1094022	694398	1334512	128356	5085	13278520	1698153	6251703	620364	67810
1023967	720778	1396296	335547	15703	7154870	4092305	4901397	1514567	212216
144721	68140	49411	10086	790	306649	199260	175685	41186	12600
471615	111971	42494	22277	1144	2328770	300265	88710	119867	11148
136957	22722	73192	19647	167	570431	167793	20245	7117	3142
1733910	858620	955181	374264	35036	5003898	2660030	4631577	2754127	753223
180431	63007	35953	12204	1270	947008	226110	101149	39187	21721
854396	978196	800433	149187	6002	2920718	4918188	2297163	947044	62979
119128	78299	214670	36750	2236	729011	137024	1215469	355592	42015
94647	63318	47257	8625	565	248454	235294	155512	46461	8141
150150	126896	88080	45262	2935	332242	428117	195265	221263	48594
228194	194668	106600	41867	2778	431275	671524	305604	188035	42803
328880	360278	314043	79809	4246	1068165	652093	1045891	400935	52167
928746	533917	252264	79931	5902	2553114	2391032	960196	432441	127219
165256	103344	382766	34371	971	740072	326020	1849595	289087	15484
881103	871594	713155	432368	30042	1875561	2174423	1930567	2028649	513978
1275020	1040070	793040	119736	5102	3325702	4945067	2704610	559212	90495
328257	83947	21962	17513	19630	1221387	392643	70753	80386	34699
520625	757512	663065	314330	19266	1076577	2099605	1334579	2286393	235721
411974	102250	497870	52173	2628	2075055	203475	2289381	301584	27278
74800	45511	28650	6616	343	229809	132145	112383	25423	6106
759035	434449	523361	51936	1485	3382327	891900	2661491	251779	17393
482719	480662	499377	149461	13703	1061229	1227263	1832613	730503	163972
632810	519972	623536	532069	35063	1255351	2036029	2396748	2852413	894470
161751	72615	219355	25194	700	1259129	139688	1466851	188024	12153
1069851	1177033	874130	475203	39651	2889254	3053103	1871693	1887364	549873
207982	102349	66868	18926	607	645011	336150	345730	96160	7174
47426	23748	74958	75514	323	153788	59120	332792	51746	11181

417561	109579	31499	17096	1254	1642130	517395	71663	58330	14417
1180951	710456	276180	151015	14278	3739686	3275481	1011038	777175	184085
357048	295085	608670	102896	3960	1462138	654773	3147124	683640	67900
77627	39807	56199	5969	230	572582	90028	190405	29613	3358
656327	628615	605538	106423	3633	4061096	2182314	2394953	481682	46285
414687	91209	20901	13587	900	1753259	524668	60942	53708	13700
368310	317165	307327	58995	2419	1460109	600181	1014707	279488	34911
646807	773778	712045	628721	64444	1688275	2156170	1580956	4260346	1174277
350421	226934	247207	37960	1370	1217806	637429	850499	263862	15229
470192	937354	721678	340645	26109	1443559	2148693	1961975	1599497	348265
217389	164055	428172	77470	2769	972008	320917	1800076	356548	31215

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min1	min2	min3	min4	min5	e1	e2	e3
159	1180	105	0.0000003	0.1	-1481747707	-1984726226	-761189556
15	834	417	0.2	0.2	-2661148268	-1018136244	-821416946
271	5	272	0.5	0.04	-523512706	-670179504	-501514755
41	2	24	0.1	0.003	-166430698	-86744266	-293179886
22	126	0.005	0.4	0.007	-1413291528	-611643051	-672762614
2	5	6	0.02	0.002	-118003573	-49589027	-179143965
30	25	55	3	0.09	-656379914	-170489306	-128378731
896	16	55	0.1	0.01	-1093093962	-474202991	-2305641935
11	20	16	0.2	0.02	-841748302	-491790403	-1184527158
385	1015	239	0.6	0.01	-548450887	-835178570	-983499524
24	25	179	0.3	0.06	-781635805	-850190146	-731197462
431	169	456	0.01	0.01	-2054811084	-1378057692	-2757027218
128	52	759	5	0.1	-2014509993	-1262105872	-2885722822
0.9	61	25	0.1	0.02	-199249933	-97714367	-87201326
24	11	0.3	0.1	0.008	-903941608	-175514663	-74782710
2	2.9	3	0.01	0.002	-281288545	-30319327	-12441916
2085	919	837	28	0.02	-3437051211	-1957602415	-1009706792
67	12	0.6	0.05	0.004	-257255570	-114430670	-71662536
280	530	61	0.8	0.001	-1532079373	-1758649067	-1323988815
6	126	24	0.03	0.01	-191803064	-125265695	-365607371
91	32	18	0.01	0.0001	-171793298	-101530125	-86971893
26	125	6	0.4	0.001	-239615992	-254244709	-121198555
13	4	159	0.6	0.03	-389205406	-402434455	-135526427
10	1047	2	1	0.006	-545241361	-695649320	-615523843
389	442	251	1	0.02	-1683415583	-926190670	-354254115
90	7	7.9	0.02	0.0005	-276286594	-165012898	-620413327
632	769	310	2	0.3	-1460998349	-1717348663	-1439531777
303	251	5	0.5	0.01	-2364891808	-2008809708	-1322622470

17	23	5	0.1	0.004	-584027362	-120973597	-28329744
858	414	1769	0.9	0.1	-1039912448	-1526603114	-1186080700
23	41	10	0.3	0.001	-705843303	-168133381	-948421677
136	11	38	0.07	0.002	-116996976	-73244971	-44054601
335	396	0.6	0.08	0.004	-1365913558	-1027672575	-799281348
188	207	384	2	0.01	-854719455	-757437182	-1247394438
1054	652	236	2	0.005	-1107182007	-899730877	-1343888812
113	79	29	0.03	0.0009	-291463744	-116271899	-416278319
117	1923	293	9	0.06	-2020164028	-2419993620	-1716842258
73	17	1	0.09	0.002	-386543044	-139582926	-108463602
35	0.5	28	0.02	0.0008	-66661656	-34336065	-103521178
158	5	10	0.2	0.01	-823691673	-215501381	-46681369
256	540	32	0.3	0.02	-2215348462	-1151701554	-401105797
225	251	33	0.2	0.007	-589533860	-556509906	-1041767287
52	21	20	0.009	0.0003	-90940073	-58378032	-80614169
261	1161	0.003	0.08	0.04	-1183474228	-1157600618	-1243064349
83	6	8	0.09	0.01	-915806012	-131959262	-27401668
5	435	2	0.2	0.01	-731245111	-536799482	-594464735
25	17	64	15	0.002	-1104204486	-1381495280	-1324788869
62	23	3	0.01	0.00006	-689296864	-355730928	-441461172
295	1058	207	0.5	0.08	-735314038	-1652639887	-1059233851
56	84	94	0.03	0.001	-375145034	-242413881	-759364331

Continued...

e4	e5	E1	E2	E3	E4	E5
-1651177584	-379004433	13	68	43	23	88
-2352743634	-564427473	33	58	70	32	88
-1570175941	-409758861	13	62	38	30	89
-115208364	-14057048	8	43	79	22	88
-305648381	-62243205	16	63	69	28	83
-54084565	-6562339	18	52	83	23	85
-327322022	-239276743	67	50	19	36	80
-951261642	-59068145	28	39	73	15	85
-620493710	-71697376	13	18	87	14	86
-4161715678	-1691256773	20	40	32	42	89
-1211284167	-301503183	11	30	53	28	85
-991828181	-107120082	10	46	64	22	85
-2642234269	-331624935	17	13	57	19	87

-51970115	-10217829	35	60	58	24	85
-105989870	-24930444	52	51	43	15	87
-9571025	-2200298	58	80	44	31	85
-2337733369	-858834572	24	72	67	37	86
-69673409	-27536019	37	62	44	28	85
-1064920074	-91168999	22	64	37	14	88
-202292726	-38759395	6	28	72	17	86
-52085479	-6846970	27	69	66	25	86
-230179120	-56231331	10	59	59	25	88
-220576659	-54605006	6	68	53	27	88
-504905837	-100997609	16	41	68	21	86
-400915997	-128509680	24	68	52	24	87
-216902615	-13883580	12	51	70	20	86
-3007266616	-743054701	43	55	65	30	88
-820983857	-91708017	6	80	62	26	87
-121485051	-45346665	37	62	42	22	88
-2.34E+09	-356367848	26	15	37	21	87
-376479191	-43431922	3	32	83	24	81
-36402093	-4934997	30	61	56	14	84
-258948135	-24528002	9	63	72	23	87
-1049557271	-263654740	12	46	60	25	84
-3891327133	-839274646	41	59	55	30	87
-139211575	-11171015	18	42	76	16	88
-3283973928	-931682083	24	56	41	29	89
-113915564	-10917903	38	54	65	12	85
-40342543	-4693139	11	40	79	17	86
-100653945	-24749710	46	75	30	30	81
-1037536531	-304770237	15	66	55	27	87
-622178414	-76564857	15	25	74	14	85
-32111266	-2896008	47	54	54	16	81
-768489083	-62807555	10	60	56	18	88
-67473452	-13550322	57	77	39	30	83
-416983600	-40468111	27	36	65	17	87
-4408979603	-1500498714	25	52	37	36	88
-259479235	-24830245	30	47	70	15	86
-2459580927	-644379360	20	25	52	20	86
-573283449	-45537916	10	30	64	17	87

None of the features of dataset had non-overlapping range. Thus in order to achieve two-class classification using the features extracted we propose an ANN based classifier. All the datasets SET A-E should be normalized. Then those normalized data is used in single-class classifier. For optimizing the accuracy of ANN, we tried various possible combinations of extracted features from all five sub-bands, with different number of neurons in the hidden layer. The result of this exercise is given in appendix A.1, A.2, A.3 and A.4. It is found that ANN with seven neurons and 10 inputs, namely variance and entropy from all the five sub-bands gives maximum accuracy. Thus accuracy is 99.2% for normal and epileptic subjects, 100% for normal eyes open and normal eyes closed subjects, 98.7% for seizure and non-seizure subjects; and 100% for hippocampal formation and epileptogenic zone subjects.

We conclude that,

- (i) Variance and entropy from all the five sub-bands are optimum for classification of EEG signals.
- (ii) A hidden layer with seven neurons is best suited for two-class classification.

The result is further elaborated with general confusion matrix given in table 5.6.

Table 5.6: General Confusion matrix

		Predicted Class	
		Yes	No
Actual Class	Yes	TP	FN
	No	FP	TN

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}$$

$$\text{Sensitivity} = \frac{TP}{TP + FN}$$

$$\text{Specificity} = \frac{TN}{TN + FP}$$

TP = True positive

FP = False positive

TN = True negative

FN = False negative

For epilepsy detection, we ask is the subject epileptic? Answer may be Yes or No. Our results for the chosen ANN are given in table 5.7.

Table 5.7: Confusion matrix for normal and epileptic detection

		Predicted Class	
		Class	Yes
Actual Class	Yes	148	2
	No	0	100

$$\text{Accuracy} = [(148+100) / (148+100+0+2)] \times 100 = (248/250) \times 100 = 99.2\%$$

$$\text{Sensitivity} = [148 / (148+2)] \times 100 = (148/150) \times 100 = 98.6\%$$

$$\text{Specificity} = [100 / (100+0)] \times 100 = (100/100) \times 100 = 100\%$$

For eyes open and eyes closed detection, we ask is it eyes open? Answer may be Yes or No. Our results for the chosen ANN are given in table 5.8.

Table 5.8: Confusion matrix for eyes open and eyes closed detection

		Predicted Class	
		Class	Yes
Actual Class	Yes	50	0
	No	0	50

$$\text{Accuracy} = [(50+50) / (50+50+0+0)] \times 100 = (100/100) \times 100 = 100\%$$

$$\text{Sensitivity} = [50 / (50+0)] \times 100 = 100\%$$

$$\text{Specificity} = [50 / (50+0)] \times 100 = 100\%$$

For seizure detection, we ask is the subject has seizure? Answer may be Yes or No. Our results for the chosen ANN are given in table 5.9.

Table 5.9: Confusion matrix for non-seizure and seizure detection

		Predicted Class	
		Class	Yes
Actual Class	Yes	50	0
	No	2	98

$$\text{Accuracy} = [(50+98) / (50+98+0+2)] \times 100 = (148/150) \times 100 = 98.7\%$$

$$\text{Sensitivity} = [50 / (50+0)] \times 100 = (50/50) \times 100 = 100\%$$

$$\text{Specificity} = [98 / (98+2)] \times 100 = (98/100) \times 100 = 98\%$$

For hippocampal formation and epileptogenic zone detection, we ask is the subject having hippocampal formation? Answer may be Yes or No. Our results for the chosen ANN are given in table 5.10.

Table 5.10: Confusion matrix for hippocampal formation and epileptogenic zone detection

		Predicted Class	
		Class	Yes
Actual Class	Yes	50	0
	No	0	50

$$\text{Accuracy} = [(50+50) / (50+50+0+0)] \times 100 = (100/100) \times 100 = 100\%$$

$$\text{Sensitivity} = [50 / (50+0)] \times 100 = 100\%$$

$$\text{Specificity} = [50 / (50+0)] \times 100 = 100\%$$

The result is finally shown in table 5.11.

Table 5.11: Final result

<b>Case</b>	<b>Accuracy</b>	<b>Sensitivity</b>	<b>Specificity</b>
<b>Normal and epileptic classification</b>	99.2%	98.6%	100%
<b>Eyes open and eyes closed classification</b>	100%	100%	100%
<b>Non-seizure and seizure classification</b>	98.7%	100%	98%
<b>Hippocampal formation and epileptogenic zone classification</b>	100%	100%	100%

Work has been done on two-class classifier where accuracy achieved is very high. But the method is time consuming so further work can be done using a multi-class classifier for epilepsy detection. This classifier should be able to place the subject in one of the five classes, namely:

- (i) Normal eyes open,
- (ii) Normal eyes closed,
- (iii) Hippocampal formation,
- (iv) Epileptogenic zone and
- (v) Seizure.

A three layered feedforward back propagation multi-layer perceptron (MLP) has been used for classification. MLP is designed with 10 input nodes, 5 output nodes and one hidden layers. Since this is a five-class classification, the target values are determined [1 0 0 0 0] for eyes open normal subjects, [0 1 0 0 0] for eyes closed normal subjects, [0 0 1 0 0] for hippocampal formation subjects, [0 0 0 1 0] for epileptogenic zone subjects and [0 0 0 0 1] for seizure subjects. The topology chosen is Feedforward back propagation neural network. nstart pattern recognition tool from MATLAB has been utilized for this task. Though for two-class classification seven neurons in hidden layers gives best result. For five-class classification, we have to increase this number to twenty to obtain accuracy 88.7% which is reasonable shown in figure 5.1.

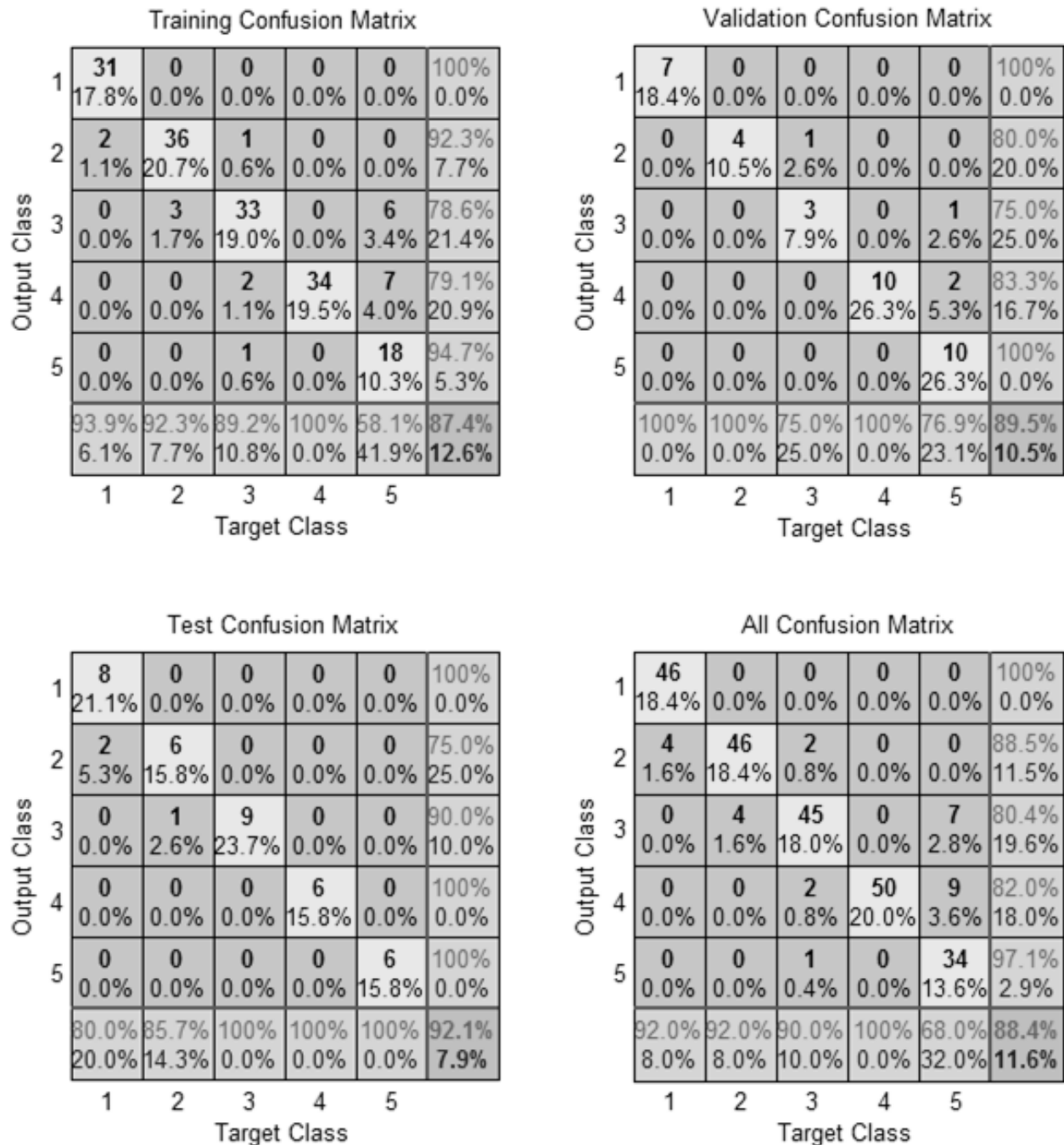


Figure 5.1: Final result in confusion matrix

The MLP shows the accuracy of 88.4%. The two-class classifier shows high accuracy, it is time consuming, so we use multi-class classifier.

## **CHAPTER 6: CONCLUSION AND FUTURE SCOPE**

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Epilepsy is a serious neuronal disorder that needs to be detected accurately. Electroencephalogram is a good non-invasive diagnostic tool that can be digitally analyzed to detect the epileptic disorder. Approximately 1% of the world's population suffers from epileptic disorder, a disorder of the normal brain characterized by excessive neuronal activity in the brain. Epileptic seizures are manifestations of epilepsy and are the result of sudden, usually brief, excessive electrical discharges in a group of neurons and that different parts of the brain can be the site of such discharges. The clinical manifestations of seizures therefore vary and depend on where in the brain the disturbance first starts and how far it spreads. They may be localized in certain area of the brain called partial seizures, which can be seen only in a few channels of the EEG recording, or may be involved the whole brain area called generalized seizures, which can be seen in every channel of the EEG recordings.

Classification of epilepsy can be done in two ways. One approach is to repeatedly use two-class classifier and the other is to use one multi-class classifier. Two-class classification is done for normal and epileptic subjects. Normal subjects are further classified for eyes open and eyes closed. Epileptic subjects are further classified for non-seizure and seizure, and non-seizure as hippocampal formation and epileptogenic zone. It is observed that the repeated use of two-class classifier give better accuracy i.e. in the range of 98.7% - 100%, but is obviously time consuming. On the other hand single multi-class classifier gives lower but reasonably good accuracy (88.4%). The work may be refined further to improve this level of accuracy.

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## LIST OF PUBLICATIONS

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1. Mandeep Singh, Harleen Kaur, “ANN based Epilepsy detection using EEG”,  
*International Journal of Information Technology & Knowledge Management*, Vol 7, No. 1, Dec 2013, [in press].
2. Mandeep Singh, Harleen Kaur, “ ANN based Sub-classification of Epileptic cases”,  
*International Journal of Information Technology & Knowledge Management*, Vol 7, No. 1, Dec 2013, [in press].
3. Mandeep Singh, Harleen Kaur, “ANN based Multi-class classifier in Epileptic cases”,  
*International Journal of Information Technology & Knowledge Management*, Vol 7, No. 1, Dec 2013, [in press].

## APPENDIX A

Table A.1: Accuracies Achieved For Classification of Normal and Epileptic Dataset

Parameter $\rightarrow$ Neurons $\downarrow$	Variance and PSD Max	Variance and PSD Min	Variance and Entropy	Variance and Energy	PSD Max and PSD Min	PSD Max and Entropy	PSD Max and Energy	PSD Min and Entropy	PSD Min and Energy	Entropy and Energy
2	86.40%	80.40%	97.60%	92.80%	66%	83.20%	94.80%	79.20%	91.20%	94.40%
3	82.40%	74.80%	98.80%	94.40%	57.20%	58.80%	92.80%	77.60%	92%	95.60%
4	76.80%	79.20%	98%	95.60%	68.80%	81.60%	95.60%	72%	93.60%	95.20%
5	84.80%	80.80%	97.20%	95.60%	78.80%	80.80%	93.60%	77.20%	94.40%	95.60%
6	82.40%	74.80%	98%	96%	64%	94.40%	94.40%	75.20%	92%	94.80%
7	84.00%	83.60%	99.20%	95.60%	64.40%	88%	94.80%	69.60%	96.40%	96.80%
8	86%	74.40%	96.40%	93.20%	67.60%	75.60%	95.20%	80.40%	93.60%	92.40%
9	84%	86%	94.80%	96.40%	71.60%	87.20%	95.20%	76%	94.80%	95.60%

Table A.2: Accuracies Achieved For Classification of Eyes Open and Eyes Closed Dataset

Parameter ↑ Neurons ↓	Variance and PSD Max	Variance and PSD Min	Variance and Entropy	Variance and Energy	PSD Max and PSD Min	PSD Max and Entropy	PSD Max and Energy	PSD Min and Entropy	PSD Min and Energy	Entropy and Energy
2	97%	97%	99%	98%	87%	100%	96%	86%	93%	96%
3	100%	97%	100%	67%	92%	100%	90%	52%	46%	56%
4	100%	96%	100%	98%	88%	100%	97%	83%	90%	95%
5	99%	92%	100%	97%	91%	100%	98%	72%	94%	95%
6	100%	96%	100%	100%	88%	100%	98%	73%	91%	95%
7	100%	99%	100%	99%	91%	99%	99%	96%	93%	95%
8	100%	99%	100%	99%	69%	99%	99%	87%	80%	98%
9	98%	95%	100%	99%	94%	100%	99%	93%	93%	95%

Table A.3: Accuracies Achieved For Classification of Non-Seizure and Seizure Dataset

Parameter → Neurons ↓	Variance and PSD Max	Variance and PSD Min	Variance and Entropy	Variance and Energy	PSD Max and PSD Min	PSD Max and Entropy	PSD Max and Energy	PSD Min and Entropy	PSD Min and Energy	Entropy and Energy
2	92%	87.3%	96.7%	98.3%	66.7%	87.3%	96.7%	81.3%	94%	95.3%
3	73.3%	77.3%	96%	73.3%	70%	68.7%	86.7%	80.7%	96.7%	92%
4	94%	70%	95.3%	90%	68.7%	84.7%	94%	87.3%	94%	94%
5	82%	78.7%	95.3%	84.7%	68%	82%	94.7%	85.3%	95.3%	92.7%
6	86.7%	82%	95.3%	89.3%	70.7%	80%	96%	90.7%	96%	95.3%
7	86.7%	77.3%	98.7%	80%	72.7%	84%	93.3%	75.3%	96.7%	95.3%
8	92.7%	82.7%	96.7%	94.7%	76.7%	68%	93.3%	67.3%	98%	95.3%
9	89.3%	76%	96.7%	85.3%	66.7%	86%	67.3%	85.3%	66.7%	96.7%

Table A.4: Accuracies Achieved For Classification of Hippocampal formation and Epileptogenic zone Dataset

Parameter → Neurons ↓	Variance and PSD Max	Variance and PSD Min	Variance and Entropy	Variance and Energy	PSD Max and PSD Min	PSD Max and Entropy	PSD Max and Energy	PSD Min and Entropy	PSD Min and Energy	Entropy and Energy
2	97%	94%	99%	97%	98%	98%	97%	88%	97%	80%
3	54%	54%	100%	68%	97%	99%	96%	47%	47%	71%
4	96%	99%	100%	96%	98%	100%	96%	92%	93%	85%
5	96%	98%	100%	93%	97%	99%	98%	95%	86%	83%
6	99%	98%	100%	97%	95%	98%	95%	94%	96%	92%
7	98%	89%	100%	96%	97%	100%	97%	97%	86%	82%
8	94%	95%	99%	83%	95%	99%	98%	93%	91%	89%
9	98%	97%	100%	94%	97%	98%	97%	84%	90%	92%