Sonification of EEG for Anomaly Detection

By

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Abstract

The EEG is a technique which is utilized to monitor the electrical action of the brain. The communication between brain cells is through these electrical signals. An EEG is used to detect the possible issues which are associated with this electrical activity because normal activity makes decipherable patterns. One of the most important uses of EEG is to identify seizure, because seizure causes the abnormalities in the EEG wave forms. EEG is the one of basic investigative checks for seizure. It moreover plays a vital job in investigating other brain problems. EEG is the visualization technique of electrical action of brain, which is the simplest way to make information understandable to humans. An alternative way is sonification. We have done the sonification of EEG signal to differentiate between seizure and non seizure. Sonification gets the data as input and generated audio signals. It is the process in which data is converted into sound, which provides an auditory option instead of visually analyzing the data, which will be very helpful even for that listener which doesn't have any training or knowledge about the seizure detection. We assumed that humans can easily distinguish among seizure and non seizure by listening the sound of EEG created using our algorithm. Our algorithm reads the data done the processing and creates and plays the created sound immediately. Real time EEG data is used for this system obtained from CHB-MIT website. We used data of single channels as well as of multiple channels and tested the potential of our algorithm. Our system will work effectively for real time EEG monitoring, neuro-feedback etc

Key Words: *EEG, epilepsy, sonification, real time system, signal processing*

Table of Contents

Acknowledgements……………………………………………………………………………………………..vi

Abstract viii

Table of Contents……………………………………………………………………………………………….ix

List of Figures……………………………………………………………………………………………………x

List of Tables...xi

CHAPTER 1:Introduction……………………………………………………………………………...1

1.1 Background, Scope and Motivation 1

1.1.1 Why Audio..1

1.2 Sonification And Its Applications..3

CHAPTER 2: EEG Sonification…...6

2.1 What is EEG……………………………………………………………………………………...6

2.2 Applications of EEG Sonification…………………………………………………………………...7

2.3 Sonification Techniques……………………………………………………………………………..9

2.4 EEG Sonification Techniques………………………………………………………………...…13

CHAPTER 3: Literature Review……….……………………………………………………………..17

CHAPTER 4: Methodology and Results ……………………………………………………..…...21

4.1 Data Sets………………………………………………………………………………………….21

4.2 Sonification Algorithm………………………………………………………………………...23

4.3 Our Approach……………………………………………………………………………………..25

CHAPTER 5: Conclusions and Future Work.……………………………………………………......…...34

5.1 Conclusions…………..…………………………………………………………………………….. 34

5.2 Future Work…………………………………………………………… ………………………...34

Refrences……..…………………………………………………………………………………………35

List of Figures

Figure 2.1: Standard EEG Electrode names and position 6
Figure 2.2: Picture of presented EEG Electrodes and their respective location along with the data sequenc…..……7
Figure 2.3: Sonification based BCI system 8
Figure 2.4: Application areas that uses EEG Sonification(real and offline) 9
Figure 2.5: One to One Mapping 10
Figure 2.6: One to Many Mapping 11
Figure 2.7: Many to One Mapping 11
Figure 2.8: 19 x 19 distance matrix for spectral vectors for 3 succeeding frames 14
Figure 2.9: Representation of temporal and spatial organization of acoustic events in differential sonification 14
Figure 2.10: Bump Sonification System……………..15
Figure 2.11: Multi Channel EEG Sonification 16
Figure 4.1: Standard EEG Electrode names and position 21
Figure 4.2: Flow Chart of EEG Sonification 25
Figure 4.3: EEG with No Seizure 26
Figure 4.4: EEG with Seizure 27
Figure 4.5: EEG of Fz-Cz channel with No Seizure 28
Figure 4.6: EEG of Fz-Cz channel with Seizure 28
Figure 4.7: EEG of FT10-T8 channel with No Seizure 29
Figure 4.8: EEG of FT10-T8 channel with Seizure 29
Figure 4.9: EEG with No Seizure of multiple channels by taking their arithmetic mean 30
Figure 4.10:EEG with Seizure of multiple channels by taking their arithmetic mean 30
Figure 4.11: EEG with No Seizure of multiple channels by taking their minimum value 31
Figure 4.12: EEG with Seizure of multiple channels by taking their minimum value 31
Figure 4.13: EEG with No Seizure of multiple channels by taking their maximum value 32
Figure 4.14: EEG with Seizure of multiple channels by taking their maximum value……………...32
Figure 4.15: EEG with No Seizure of multiple channels by taking their weighted average using Fz-Cz channel 33
Figure 4.16: EEG with Seizure of multiple channels by taking their weighted average using Fz-Cz channel 33
Figure 4.17: EEG with No Seizure of multiple channels by taking their weighted average using FT10-T8 channel 34
Figure 4.18: EEG with Seizure of multiple channels by taking their weighted average using FT10-T8 channel 34

List of Tables

Table 4-1: Channels in EDF files 22

Chapter 1

Introduction

With the advancement in the imaging technique, we got many ways to monitor the brain activities like (EEG) electroencephalogram, (fMRI) functional magnetic resonance imaging, (MEG) magneto-encephalography and (PET) positron emission tomography [1].

Electroencephalogram (EEG) is the standard technique to monitor the brain activity and for the diagnosis of seizure. These all techniques provide data which can only be visually examined for evaluation and diagnosis. But there are many limitations and challenges in examining such data like we need a trained person to read the waveforms and to identify the characteristics patterns of the disease. And it also takes many hours to analyze the data of one day recordings of a single patient. The other big issue is that visual techniques are unable to provide the differentiation level between the health and disease. Or maybe the information is available but is invisible to human eye. And also there are very large diagnostics inconsistencies upon visual inspections of medical data.

For all these reasons, scientists are trying to find alternative methods and techniques for the representation of data so that the accuracy as well as consistency of diagnosis can be improve. The most effective way is to hear the data obtained from EEG instead of visually displaying it.

So the sonification is the most effective alternative of visual display .Sonification is the process in which data is converted into sound which will act as an alternative to visual display. It is the transformations of data into sound which for the purpose of communication and interpretation. Data sonification is an analogous audio technique to data visualization in which data is converted into sound in order to communicate complex information efficiently and clearly.

We designed a sonification algorithm to aid in diagnosing the patients with seizure.

1.1 Background Scope and Motivation

1.1.1 Why Audio

Auditory display has number of advantages like the resolution of human hearing system is much greater than visual setup in chronological aspect. The complexity of the auditory system of the human being is comparable to the complexity of the visual one [2]. The capability of the human hearing system to differentiate between multiple instruments and voices from surroundings noise

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makes it fine personalized to processing the sonified EEG. In certain conditions the auditory display is the main process which is being used for transmitting the information through which the user or receiver have the better understanding of information. In this section we described the different ways how the auditory display is very useful for the human beings.

Auditory display developed a lot after the foundation of ICAD (International Conference on Auditory Display), 1992 [3]. In the recent years audio display is widely accepted method of data display along with the visualization.

Auditory displays are being used in numerous areas like biomedicine, data mining and interfaces for disabled people, chaos theory etc. This is the one of most complicated areas to learn because for the successful implementation, several fields and disciplines like Physics, Acoustics, Computer Science must be understood and mastered. Human auditory system can process multiple data in parallel unlike that of visual setup that serially process the data.

Also human aural processing deals with very high complexities because human have the power to differentiate the multiple voices simultaneously even in the noisy environment and this is very good feature to use the music or sound for multi parametric data like EEG.

Human ears can easily and accurately distinguish two different rhythms. If there are many pieces of information and they are mixed and combined in a single stream, human ears can easily recognize the individual information and individual piece easily.

If we have changes in sound due to changes in data especially if the changes are very rapid, these changes can be read and felt immediately. For visual display it usually took more time to respond. To explain the response time difference between visual and sound perception we have the best example of ‘LAG’ .The response time of visual display lags with the response time of auditory display. It is very interesting and comfortable to listen to the music instead of staring at the screen.

Auditory displays are designed to be used globally. Gaver and Mountford suggested that "sound exists in time and over space while the vision exists in space and over time." Which means that information provided using sound will show the fluctuations over time and on the other hand visual displays are less transitory and can be supposed at exact point in space.

Sound is alerting and omnidirectional, which tells us that sound can be use to provide information over visual display.

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1.2 Sonification and its Applications

As discussed above the basic concept behind the sonification is that to create a nonverbal sound that represents numerical data and also to provide support for information processing methods of several different types [4]. And also sound had few natural characteristics that are very advantageous as a source for information display. In our daily life we have many examples in which we used auditory modality for the representation of the data. We explained some of the functions that Sonification might perform.

One of the first known example and implementation of Sonification is the Mesopotamia in which we detect anomalies in relation of commodities. For the audiofication of heart rate, breathe, blood pressure etc the device stethoscope is used. One of most popular device to incorporate an auditory display is Geiger counter. This device transforms ionizing radiation into clicks while the pulse depends on the amplitude of radiation. This Geiger counter is firstly used with the responsive telephone was integrated in the electrical circuit with the aim of hear the audiofication of electrical impulses because of the ionization of the gas in the tube of the counter [5].

In late 20^{th} century, creating and recording of sound has improved the life of blind persons greatly. One area of research that has allowed blind persons to access the digitized data is sonification [6].Sonification gives blind persons an innovative way to understand the data and sense their surroundings if data from sensors and videos are used for sonification. Sonification enhances screen readers and accelerates their contact and their job with the computer.

For the persons having impaired sight auditory display is good solution for interaction between the person and system. Visual display is very difficult to perceive or read in some unacceptable environments such as low light, making the system less efficient.

Sonification gives a real time environment to observe the data .Sonification helps that person who is required to observe a big and complicated network or have to manage an ICU in the hospital by providing an eyes free way which becomes a backdrop stream that gets the user awareness when there are significant changes in the input data.

As far as computers are concerned, various sounds are already used in the computer for example when we delete something crushing sound is produced but there is not much information available. But if for example by deleting a large file creates a complex sound and deleting a small file creates a simple sound, this would instantly increases the user's attention and sonification helps very much in creating such systems.

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Sonification helps a lot in the environment where visual sense is highly loaded to give extra information. Consider an operation theater where surgeon is required to pay attention on the injury and cannot notice the visual display regularly.

Specifically a good application of Sonification is the Exploratory Data Analysis in which we need to explore a large and high dimensional data and we need to obtain multiple views of data in order to discover the hidden structures of data. Certain structures are simply analyzed by listening instead of seeing, e.g. changes in regular patterns are detected easily by analyzing them auditorily.

During different phases of a life cycle of business process we have different processes like design, simulation, operation, analysis etc. For all these phases especially like design and simulation we have GUI (graphical user interface) and visualization methods are broadly used. But now as visualization techniques reached their limits. As an example in design and simulation process we have large number of events which are very difficult to analyze visually. Also during operations and evaluation, we have thousands of running instances and it is very difficult to find deviations from regular route using only visual methods [7]. Data sonification can be used as an enhancement to visualizations that might be very helpful to tackle some of the above challenges.

The sounds created using sonification may be use for alert and notifications. Sounds for alert and notifications indicate that something has happened or near to happen, or the listener should instantaneously concentrate that something happened in the surroundings like in the hospital when a patient’s blood pressure has exceeded a certain limit. The information delivered through alert or notification is very little but this little information contains the details of incident. Like microwave beep shows that the set time has expired irrespective of food is fully cooked. Alarms and warnings are the alert or an announcement that delivers the happening of an event that requires immediate attention. Warning signs created using auditory modality automatically gets attention better than visual warning signals. An alarm contains more information than a simple alert but still the information about the event is limited. Think of a fire alarm, it gives the information about the fire that needs attention but the alarm does not show the site where fire had started. Complex alarms try to encode more information into audio signals. So that the listener hearing the warning signal immediately and effectively reacts to the signal [8].

When an auditory alarm is carefully built and when all the suitable factors or inputs are satisfied the alarm output i.e. Sound rises quickly. A good alarm should be loud enough that can be heard

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in the noisy environment. The alarm is that which is used to distinguish the anomaly in the data. Like think an alarm system using daily temperature of a year. When the temperature falls or increase then the threshold then the listener get aware of this change still he is not giving full concentration to the sound or alarm full time. It is the biggest advantage of audio display as contrast to visual display.

Some scenarios need a presentation that provides extra details regarding the data represented with sound. Auditory display has been used as a basic where we need to represent the present or ongoing condition of a procedure to a human listener. The audience has ability to monitor the small changes in the auditory display and taking advantage of this thing status and progress indicators are built so that the user or listener can easily detect the small changes and the user eyes are free for any other tasks. For example we need such indicators to monitor the factory process states or to a patient suffering from blood pressure etc.

Sonification can help a lot in the data exploration functions where we need to encode and deliver information about the whole data set. This type of sonification differs from status or process pointers because in data exploration we use sound to provide a extra holistic representation of the data in the scheme rather than condensing information to capture a quick state such as with alerts and method pointers.

Computing systems have evolved the capability of sound production. In addition to generate warnings, sonification can be use for the basics of musical compositions. Through these sonifications, composer tries to convey something which is not the pure purpose of information delivery. Sonification of human EEG data, Concert of sonification at the Sydney Opera House to global economic and health data is examples of such type of sonification.

Sonification can be use to give information related to temperature. In this we did the audiofication of data, which is played as a sound stream. A simple audiofication of such type of system results in noise, but the quality of noise tell us about the temperature. For lower temperatures, sonification remains silent. And in hot temperature, the sound is rather homogeneous, because in a hot system we have a lot of Brownian movement which results in noisy sounds.

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Chapter 2

EEG Sonification

2.1 What is EEG

EEG (Electroencephalography) is the physiological method which is used to trace the electrical activity of the brain, which is used as a test to find the problems related to brain. EEG is a test that calculates and records the electrical activity of the brain, and is widely used in the recognition and investigation of epileptic seizures [9].This recording is done using electrodes positioned on scalp surface.EEG measures the electrical activity created by the thousands of neurons in form of milli volts. It also provides best time resolution which allows detecting any abnormality. As these fluctuations are very small, the recorded data in amplified and then this data is displayed as a sequence of voltage values. The EEG data was recorded with 19 scalp electrodes position in relation to 10-20 positioning system calculated against the averaged signal of both ear lobes. This system defines the standard physical position and designations of electrodes on scalp. The head is divided into relative separation from major skull landmarks i.e. nasion, preauricular points and inion to give sufficient exposure of whole brain. Label 10-20 assigns proportional distance in percents between ears and nose where points for electrodes are selected. Electrode positions are named according neighboring brain areas: F (frontal), C (central), T (temporal), P (posterior), and O (occipital) [10].

Figures gives the over view of existing electrodes and their respective position.

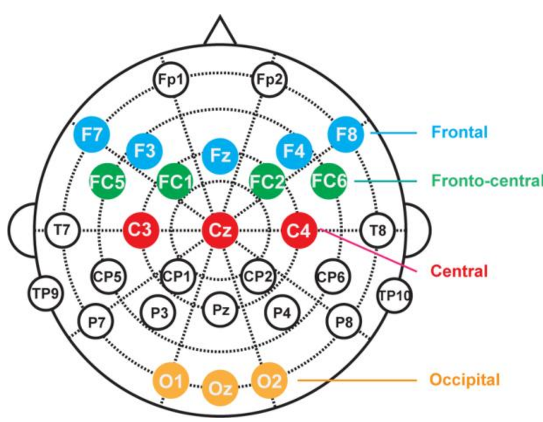

Figure 2.1: Standard EEG Electrode names and position

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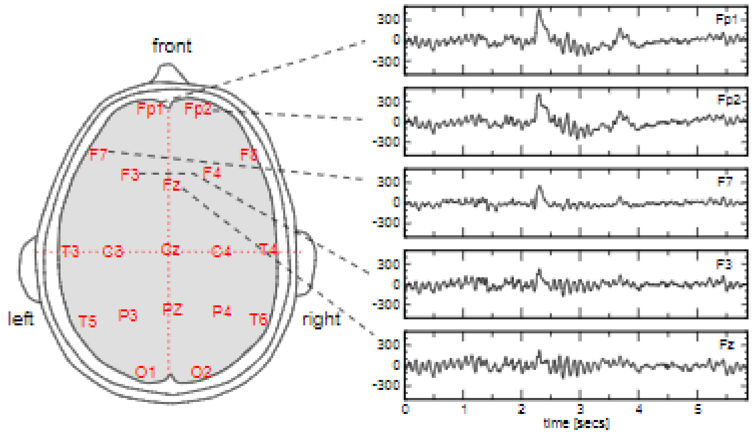

Figure 2.2: Picture of presented EEG Electrodes and their respective location along with the data sequence

Before the investigation, the signals are filtered using band pass filter having frequency from 0.3 Hz to 35 Hz and then digitized using a 16 bit quantization process and the sampling rate is 256 Hz.

2.2 Applications of EEG Sonification

Besides of real time constraint, we have many applications in which we use EEG sonification for the data representation. We have different application areas of EEG sonification which can be differentiated on the basic of data input real time or offline.

Based on the objectives and validation we have many applications of real time sonification of EEG like to monitor the EEG of a patient in real time will inform the care taker about the patient condition like an anesthetist during surgery. Or to update the user himself like an air traffic manager being warned for his serious fatigue level.

The next purpose of EEG sonification which is being classified as offline application is for diagnostic purposes which will allow fast recognition of major changes like different sleep stages [11].

Another important application of EEG sonification is neuro feedback target learning about the user own state and important aim is to observe the altering the state like for post stroke rehabilitation.

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The next important domain is Brain Computer Interface feedback and communication in which sound is used for teaching the power of brain activity **.**This interface provides a novel communication channel between the computer and human brain. Patients having severe trauma, spinal injuries and motor impairments can make use of this BCI system which is based on EEG and this system provides an alternative way of communication using brain activity. The basic principle of this interference is the analysis and classification of EEG. These classification results of EEG may be related to some human actions like limb movement. Sonification is being done of different frequency parameters like alpha, beta, gamma etc present in EEG. The below figure illustrates the BCI system based on sonification [14].

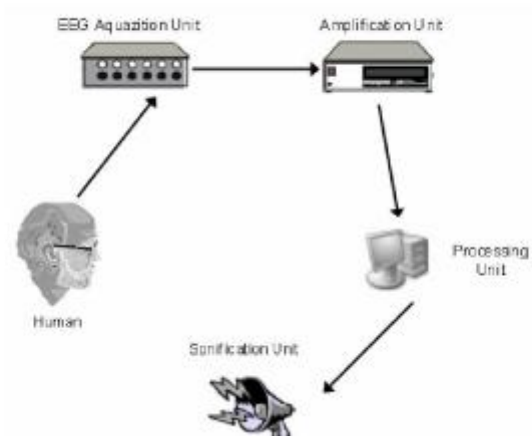

Figure 2.3: Sonification based BCI system

Also the searchers are performing the EEG sonification for creating brain controlled musical instruments, which read specific brain patterns and change them directly into music [11].

EEG sonification can also be used for the music generation. Like Stephen Barras performed many experiments in which the EEG, EOG and ECG signals of music performers are captured using wearable enbio and then the captured signals are mapped into sound and then these sounds are played in the real time. One more usage of EEG sonification for music creation is developing a system using EEG signals to guide generative regulations to create and perform music. Different EEG characteristics like activation of frequency bands are used in generative rules and can also be use to control tempo and loudness of the act.

Summarizing all the above mentioned applications has different objectives and different validation methods. The main way to differentiate between sonification approaches is that how

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the end results are judged i.e. quantitative and qualitative. Like in BCMI, only by listening to the sonification output is sufficient to explain that system is working. But in BCI the user can adjust the amount to which the interface permits the musically essential degree of control. But both of these areas are more related with the aesthetics of the resultant sonic composition than any other type of validation. The condition is very dissimilar for diagnostic and neuro feedback uses of real-time EEG sonification, where the informational and perceptual value of generated sounds is of primary significance and finds the functionality of the application.

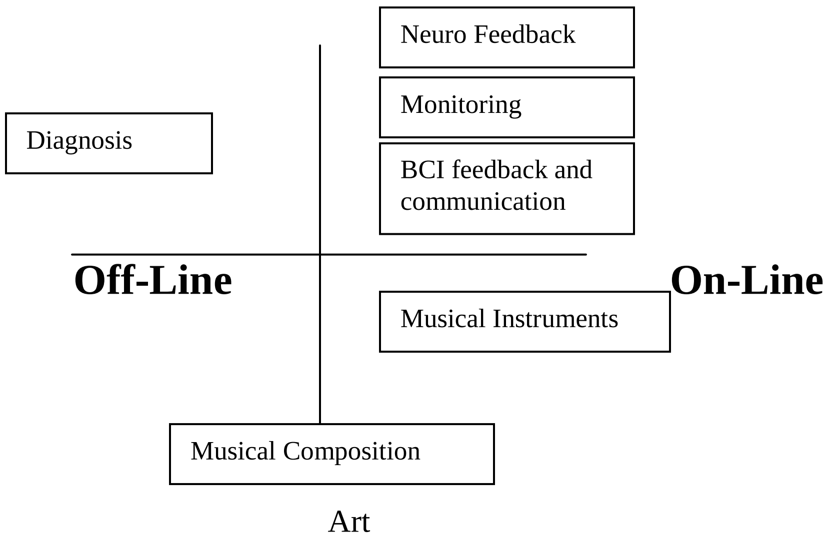

Figure 2.4: Applications areas that use EEG Sonification (real time and offline)

2.3 Sonification Techniques

Since 1990, we have many sonification techniques which are been elaborated and formalized. For the purpose of Sonification many methods have been presented. Among of all, the most important and widely accepted by the researchers are:

Audiofication: It is the simplest and the most direct technique of sonification. Audiofication is the straight translation of records into audio or sound [13].In this process data streams are directly changed to sound with little processing for the signal to become clear that can be easily heard [5b]. Processing involves the time compression and scaling of the data which should be waveform like. It may be related as a sonification technique that have uniformly spaced metric in at least one dimension. However this is usually not a good method because the audio might be too small to be played or it may be very noisy [15].

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Parameter Mapping Sonification: Parameter mapping is the relationship of information with auditory factors for the point of data display .This is most widely used sonification technique for the representation of multidimensional data [13].Another benefit of this technique is that it has potential to communicate information in the continuous manner [5b]. In this technique different dimensions of data are plotted to sound parameters either to physical parameters like (frequency, amplitude), or psychophysical parameters (pitch, loudness) or perceptually coherent complexes (timbre, rhythm) [13].A trend in the data is represented during the mapping of a parameter of data to sound. For example to represent the trends in the market share prices etc. The parameter which is to be selected for the mapping should be selected so carefully because the wrong selection results in instability of whole system. Parameter mapping sonification is further divided in to three main categories.

a) **One to One mapping**: This is the most direct and simplest type of parameter mapping. In this method one parameter of the data is coupled with one parameter of sound. For example during the mapping of temperature to sound the trends in temperature mapped to pitch of audio.

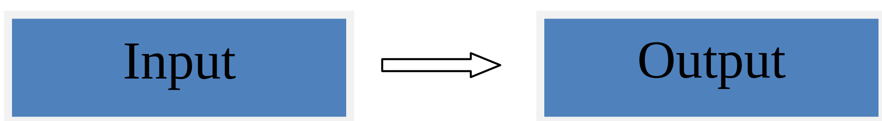

Figure 2.5: One to One Mapping

b) **One to Many mapping**: This type of mapping is also called divergent mapping. As name indicates in this type one data parameter is mapped to several synthesis parameters. This type is usually used when we have some key values in the whole data which may show the qualitative change. For example we have continuous number from 1 to 10 and let's say when the values are between 3.4 and 7.9 shows the special case. If we map this order to sound, we need to design two different notifications. One for normal scale and other for special scale.

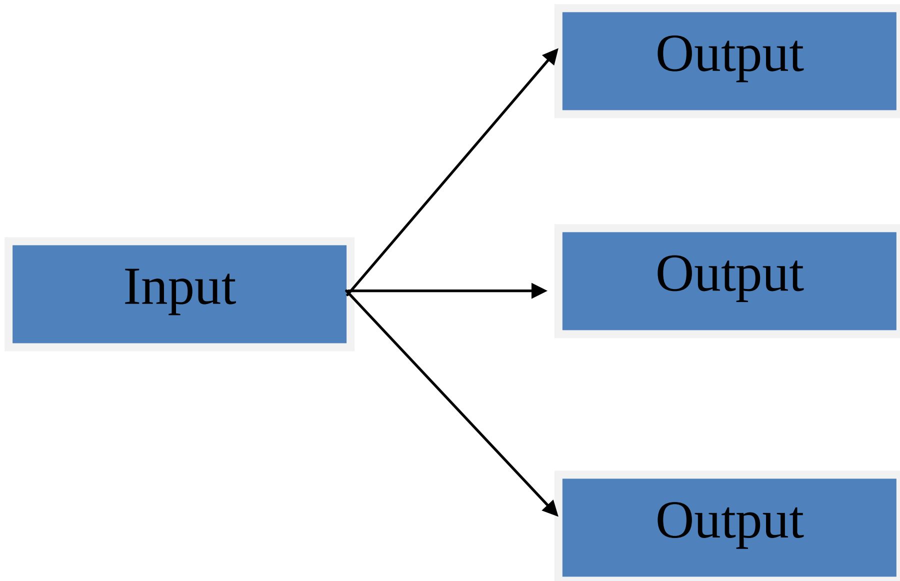

Figure 2.6: One to Many Mapping

c) **Many to One mapping**: This is the last type of parameter mapping which is also known as convergent mapping. This type of mapping is used where we have several inputs but we need only one output. This type of mapping is commonly used in the musical interfaces because sound parameters are normally controlled by many human inputs like pitch of violin depends on many parameters like finger position ,bow pressure and vibrato modulation.

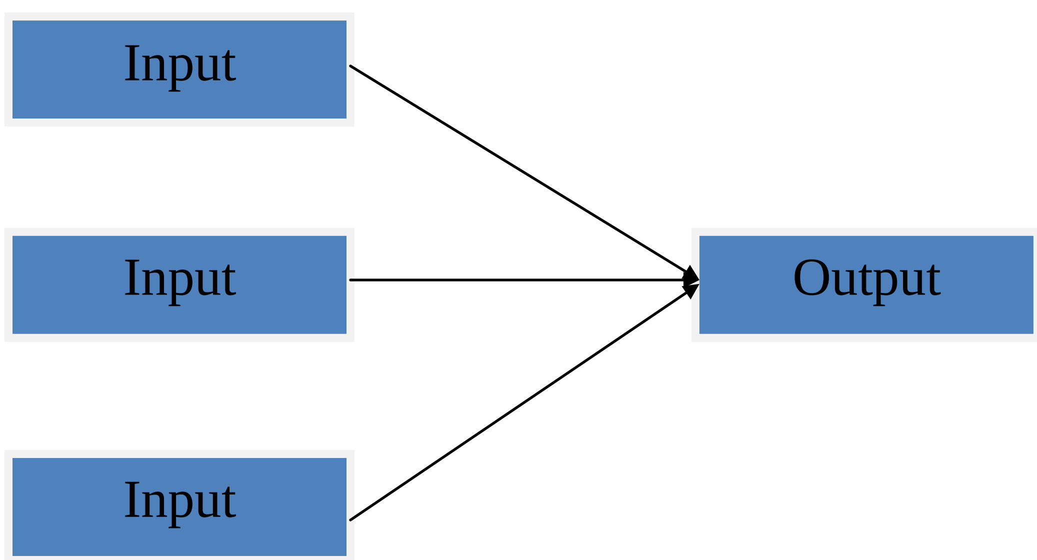

Figure 2.7: Many to One Mapping

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Model Based Sonification: This type of sonification was introduced by Herman and Ritter [5b]. As its name implies, this type of sonification creates a physical representation based on data. In this process a variable of data which is required to be sonified is allotted to some structural properties of the part of the model [13]. This method is associated with the human ability to interpret the sound and its properties and associate its characteristics with the source generating the sound. For example based on the sound and spectral characteristics produced by the new and a broken tennis ball when hit on the ground we can differentiate between them. The sound produced by the crushed ball usually has a high centroid. The model based sonification follows the physical laws through which data is converted to sound when data is injected into the model. The main difference between the parameter mapping sonification and model based sonification is that in parameter mapping data acts like a "score" through which instrument is played while in latter the data itself forms the instrument which to be played by the user. The same model is applicable where data is coming from different areas, structurally different and dimensionally independent. The sound of the data coming from different areas shows the different instruments while similar data sets represent the same instrument with different characters. Model based sonification has many applications like musical gesture analysis, data exploration, augmenting human computer interaction, process monitoring etc. This is very valuable and applicable to the data which don't have the time ordering. In such situations parameter mapping finds difficulty to form the data into fixed sequence which to be played in time but model based sonification utilizes the data complication which is helpful in the formation of complex model

Auditory Icons: This type of sonification is used for the creation of sound which gives details about an event in the data, which indicates that we are using non speech sounds to perform as a related event for the representation of desired data. A very simple example of this type of sonification is that when an event occurred we make use of short sound effects like when we turned a page in electronic book a same sound is produced when two papers are rubbed with each other in real time. By listening this sound users realized that what is occurring. An auditory icon is usually used in graphical interfaces with pioneering interfaces like wearable devices. This method is widely use in ubiquitous computing by providing multisensory feedback.

Earcons: This type is the representation of an incident as well. But this type doesn't have direct correlation with the event like the auditory icon. This point is good where it is hard to discover a

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sound which has close association with the incident. Like when the Microsoft windows start a famous startup song is played which is widely recognized by the people. This type is popular while composing an adequate auditory display.

Spearcons: Speech based Earcons: The working principle of the Spearcons is same as of earcons and auditory icons, but the spearcons worked in more efficient manner overall. Spearcons are generated automatically by changing the text of a menu item i.e. Export File to speech using text to speech and then after this speeding up the final audio clip to that point from where it is no longer comprehensible as speech [16].

We had explained different techniques of sonification. Each type has its own application and works in their corresponding areas. First two techniques (audiofication and parameter mapping) are best to be use in time indexed data. For simple or short notifications and alarms we make use of Auditory Icons and Earcons. Model based sonification works when we have complex data. As a group all these methods shows the flexibility of interactive sonification which is one of the most dominant tool available for researchers who want to analyze data.

2.4 EEG Sonification Techniques

Now we will talk about the different approaches and techniques of EEG sonification. We have different approaches like

Spectral Mapping Sonification: The simplest way to obtain the audio illustration of EEG data is audiofication. Audiofication is the straight playback of data [15]. In audiofication the voltage measurements of EEG are translated into sound. This translation allows the detection of outliers, flowing and pitched models in the raw signals. But during audiofication we have a problem of noise. The sound created using audiofication is very noisy and is free control over playback speed and also its pitch is very hard. In spectral mapping sonification we extract the parameters like Power band, Frequency Magnitude etc from EEG data and the specific activity of spectral band is explored. This technique is generally used to observe the EEG data which is spectrally resolved and it permits comparing the data differences of dissimilar channels.

Distance Matrix Sonification: The above mentioned technique allows the user to track spectral activation of the brain, this technique is based on a less straight and more conceptual variable i.e. in this technique we perform the synchronization of different areas of brain as function of brain.

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This type of Sonification focuses on the coherence of diverse brain areas as a function of time [7]. Now the question arises that how information proceeds in brain in terms of information flow. The hypothesis to this question is that the electrodes having a same spectral activation profile over time will perform same information processing tasks. This information explained in the shape of time dependent distance matrix as

$$D_{ij}[m] = ||S_i[m]-S_j[m]||$$

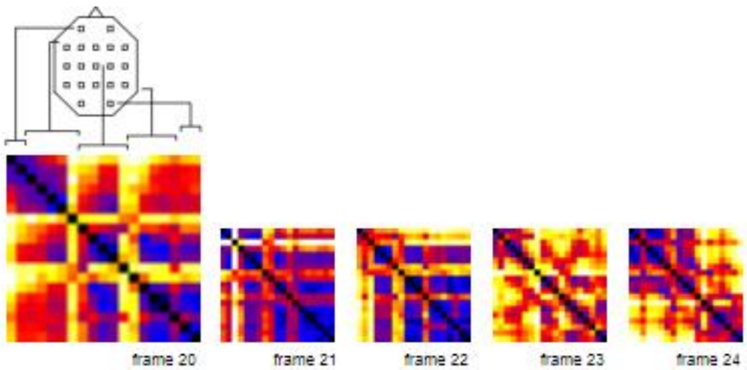

Figure 2.8: 19 x 19 distance matrix for spectral vectors for 3 succeeding frames

This sonification allows searching the variety and power of couplings among dissimilar channels, although this is not possible to describe the cause of coupling from the sound.

Differential Sonification: This technique of EEG sonification is used to compare the EEG data recorded for one person under diverse conditions with the purpose of speed up the recognition of attractive channels and frequency bands with the situations that causes systematic differences. In contradiction of previous techniques here the time axis is used to differentiate the electrodes position, scanning the brain from frontal side. This type of sonification helps to use sound in more abstract way. To make this sonification further better we may use timbre, timbre evaluation and controls for amplitude.

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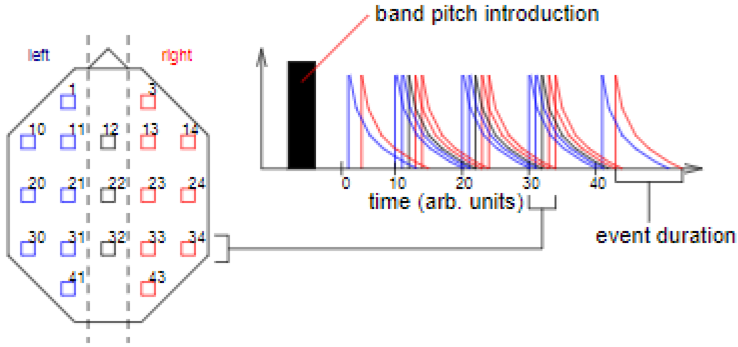

Figure 2.9: Representation of temporal and spatial organization of acoustic events in differential sonification

Bump modeling: EEG data obtained from multi channels is used to perform the bump sonification. For bump sonification we have following three steps [7].

a. Preprocessing of data that includes removal of artifact and dimensionality reduction of data using BSS (Blind Source Separation) or ICA(Independent component analysis)

b. The next step is Sparse TF representation

c. The last step is music generation in which midi files are created

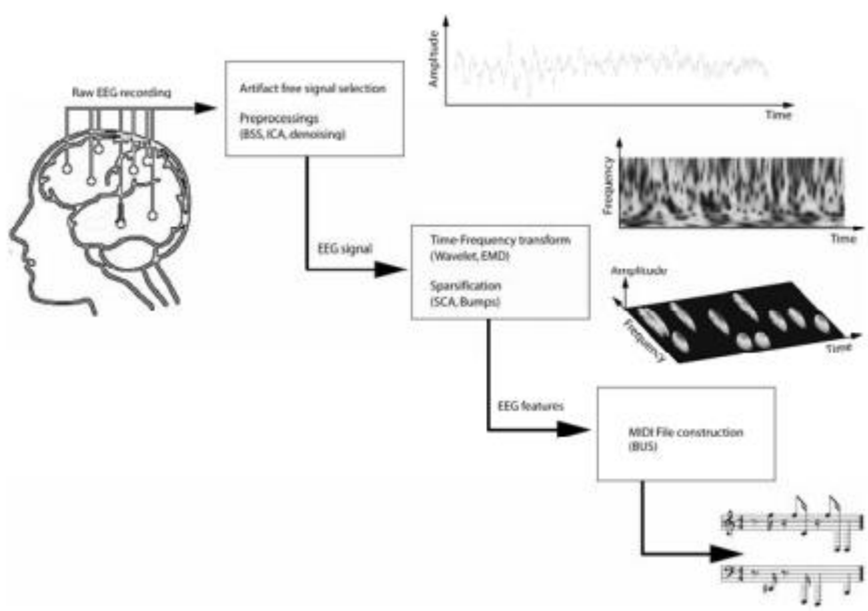

Figure 2.10: Bump Sonification System

Multi Channel Sonification: When we need to investigate more than one channel like we want to investigate global EEG dynamics. For this requirement we have described an approach in which the areas whose functionalities are close to each other the sound of these areas should be close to each other and on the other hand the areas whose functionalities are remote these areas should be represented by the sounds which are easily differentiable [7]. So for multichannel EEG representation we have following parameters for bumps like

a) The velocity(loudness) of note to be played should be equal to the amplitude of the bump
b) The electrode position should be the pitch of note. For example in midi format C4 note=pitch 60.Remote electrodes have different pitches while we have close pitches for closed electrodes.
c) Onset and duration of the note came from position and width in time respectively.

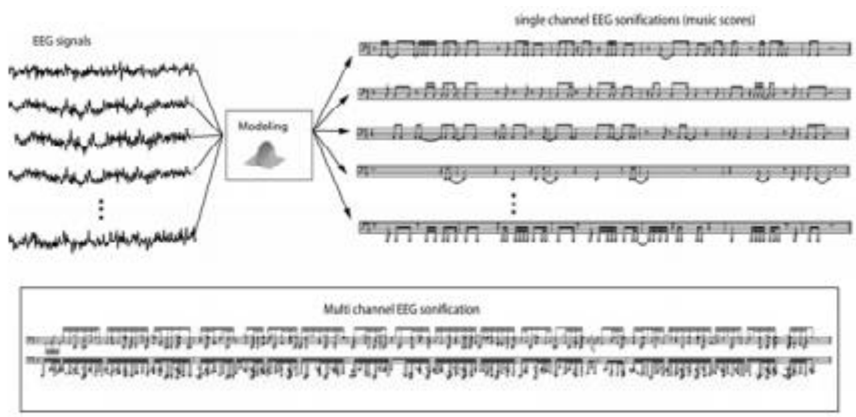

Figure 2.11: Multi Channel EEG Sonification

Techniques to sonify EEG signal remains comparatively exclusive as some have developed means but no technique has exposed extreme value in contrast to any other.

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Chapter 3

Literature Review

The process of sonification depends on data input as well as on data on sound process. As the EEG is in the form of time voltage readings this type of signal can easily be translatable into sound. In this section we will talk about the different approaches and procedures of different authors and researchers for EEG sonification.

Hermann, Baier and Hinterberger are the most important authors who explore the techniques for human EEG sonification for the diagnosis of epileptic seizures. In diagnosis of epilepsy, the extrema (min and max) in time series are the natural parameters for events. This technique provides an efficient way to differentiate between normal and abnormal rhythms.

When we done the simple audiofication or sonification that come out using the general acoustic wave formula which shows some periodicity in the sequence, then we should need to differentiate between the significant data and noise. In such cases we need an algorithm that will perform the filtering of irrelevant noise for optimal sonification [12]. Herman also works on event based sonification to find the auto and cross-correlations of multidimensional data. Event based sonification is an efficient way to deal with multivariate time series data of spatio temporal physiologic patterns. A major issue while using event based sonification is the latency. Because while using event based sonification EEG data need to be buffered till some significant event occurs [11].

Hinterberger in his recent work (2011) developed a neuro feedback environment named as Sensorium which allows the persons to visually and auditorily experience the signals from their body processes. This setup is based on parametric orchestral sonification using the parameters like rhythm, pitch and amplitude of the data. Rhythms and frequencies are estimated as sounds.

Hinterberger and Baier have explained that the parametric orchestral sonification (in which we can use the data of multiple channels) that be able to be use in the real time, applying a sample rate of 0-40Hz which is being separated into six frequency bands (named as alpha, beta, gamma, theta and delta) which are allocated to individual tones in the MIDI (musical instrument digital interface) device [12].

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Khamis search shows that non experts with the limited training were able to identify seizures from audified EEG at a speed similar to experts using visual displays of EEG. His sonification procedure needs the compression of EEG data over time. Using this algorithm authors successfully demonstrated that the non experts can easily detect the seizure from audified EEG with minimal training. But as he is performing the time compression this technique poses challenges to be use in real time [12].

In contrast to Khamis work (time compressed sonification), Baier explained a process of EEG sonification for seizure detection in real time and this process does not requires compression of data over time. He explained event based sonification technique whose working principle is to suppress surroundings noise and emphasizing on both pathological and normal patterns. Seizure detection was achieved by developing the amplitudes of waveforms and inter maxima intervals to activate certain sonification factors like tone duration, volume etc. This work depends on stereotyped EEG beats and need to be adjusted from patient to patient and this effort can be used in real time [12].

Sonification of the spatial data is another application area of sonification. Spatial data contains the information about the position. The position may either be referred to exact location in physical world or in abstract virtual world. And sound is also spatial, means that the sound source can also be located. There is a synergy between sonification and spatial data. Many researchers like Tooba worked on strategies for the representation, exploration and what spatial interfaces and device developers has used to relate with the sonification [17].

Some researchers had developed the complicated parameter analysis prior to the data is put into the algorithm for sonification. For EEG sonification one basic and common parameter is time-frequency dimension and researchers have constructed special ways to control this parameter. Like some researchers like Arslan has introduced a sliding window technique in which data is examined with addition of few milli seconds but this is not good for real time because this add latency and delay into the system [12]. Also it looks that high order processing is involved in defining the parameters of human brain that represents emotional or perceptual processes of human. A midway step to use the high order processing of EEG is the representation of brain activity of different regions of brain. As an example Cichocki and his colleagues used the bump sonification to reveal time frequency structure. The most recent trend of sonification is to sonify

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the affective states of users. Real time sonification may be use directly for emotion regulation and for essential research on affective chronometry [11].

Another sonification parameter which can be used is amplitude. Because this parameter of the EEG shows the firing rate of neurons, this parameter plays an essential role in sonification of EEG. While estimating the quick variation of different situations of user, we need an accurate and fast representation of amplitude [11]. During EEG monitoring and neuro feedback the level or amplitude of a particular parameter is of extreme interest like alertness of the person is reflected by frontal alpha power [11].

Another important method used in neuro feedback is to distinguish when a parameter go beyond a certain value or threshold or a zero crossing. But the threshold selection depends upon the application and is very significant for its success [11].

During normal brain activity we have high level of noise like during jaw clenching or head moving we have intense spiking in the brain waveforms. Some groups like Väljamäe worked on linking the extreme maxima and minima values to differentiate them from normal brain activity [12]. For the representation of mental state, Wu et al suggested a method to translate EEG signals to music. During different sleep stages different music parameters like note, tempo, rhythm and tonality are created from EEG and evaluated [18].

Fernandes proposed a new method for the transformation of parameters acquired from sleep EEG into music. This method takes the EEG signal as an input and returns the chain of words produced from set of symbols like (d, t, s, a, b).Each symbol matches to most relevant frequency bands of EEG like(delta, theta, alpha, sigma, beta). All these frequency bands corresponds to different sleep states like delta is interpreted as deep sleep, theta and sigma frequencies are common for sleep. Alpha and beta frequencies are meant for wakefulness EEG. Beta frequency is meant for highest awake state [18].

One more factor for EEG sonification is that the brain have specialized regions for different tasks like sensori motor cortex is the most important and prominent for neuro feedback and BCI application. Due to this many brain operations rely on network of neurons working with each other. That’s why electrodes position is very important in the measurement of specific cognitive operation. Also the usage of multiple electrodes allows the detection of brain activity which provides a number of space related characteristics for sonification. The number of electrodes used depends varies application to application. For diagnosis and treatment purpose few channels

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are used. While mostly author's used 20 channels and also 32. There are many projects that use channel correlation as an input for sonification [11].

A. Sanchez and M. Valderrama proposed a new concept of translating EEG recordings into music. This process is based on the basic concepts of musical composition to different time frequency properties of brain electrical signals that give information of different mental states. Basically normalization and thresholding methods are applied to wavelet transforms to examine the data to extract the amplitude and frequency parameters. Then these parameters are mapped to different natural and artificial sounds following basic musical composition structures. This concept provides a new viewpoint about the brain activity which will not only help in long term monitoring in clinical perspectives like epilepsy but also provides a new tool for self understanding of different human body processes controlled by the brain [19].

One approach for seizure detection is the use of differential operator. Differential operator has been used with great access to detect significant changes in image and signal processing. Kaushik Kumar Majumdar and Pratap Vardhan in their work shown that differentiation can improve certain characteristics of brain signals, which are contaminated with noise, artifacts, and acquisition defects, leading to efficient detection of those changes. For seizure detection, windowed variance method has been very successfully used. The authors had combined the both above mentioned methods and named this technique as differential windowed variance (DWV) to automatically detect seizure in real time, in continuous ECoG (depth-EEG) signals of epileptic patients [20].

The epileptic seizure detection is controlled by non-invasive analysis of EEG signals and its classification. Morteza Zabihi in his work proposed a patient specific detection algorithm. This algorithm picks up the optimal characteristic subsets and trains a dedicated classifier for each patient in order to maximize the classification performance. His algorithm uses frequency domain, time domain, non linear feature and time frequency domain. After this he used Conditional Mutual Information Maximization (CMIM) as the feature selection method and then optimal feature subset is chosen over which the Support Vector Machine is trained as the classifier. In his research he makes use of data sets downloaded from CHB-MIT website [21].

A linear Support Vector Machine (SVM) classifier is built to sense and categorize seizures in EEG data. This algorithm is based on some simple features like variance, mean, mean power spectrum and dominant frequency. This classifier is tested on benchmark EEG database. The

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prescribed classifier uses a few simple features is computationally efficient to be deployed in a real-time seizure monitoring system [22].

Another approach for seizure detection and analysis is based on phase slope index scheme which uses the data of multi channel EEG. This scheme classifies the increases in spatio–temporal interactions among channels which will clearly differentiate seizure from normal brain activity. We prepared a global metric of interaction between channels and then evaluate this metric to a threshold to detect the presence of seizures. The threshold is selected based on a moving average of current activity to accommodate dissimilarities among patients and slow changes within each patient over time. These metrics are very effective, computationally efficient and suitable for real-time application [23].

Summarizing we have different approaches of different authors having their own applications and importance. We are trying to make our sonification esthetically pleasant because as the sonification system will be implemented in the public place like nursing home or hospital and the sonifications that are unpleasant are not desirable. And secondly listening to the pleasant sound will help the non experts to listen the variations that will correspond to seizures and the stranger sonification will make it harder for the listener. As the seizure detection is the central goal of our study that's why esthetically pleasant sonification will serve the clinical goal. Therefore our goal is to create and analyze an algorithm that can be used in real time EEG sonification that will provide an esthetically pleasant perceptual practice which will be helpful in the diagnosis of the seizure.

CHAPTER 4

Methodology and Results

4.1 Data Sets

For our work we used the EEG data that was downloaded from CHB-MIT (Children's Hospital Boston-Massachusetts Institute of Technology) scalp EEG data base. This data is recorded from patients suffering from epilepsy with intractable seizures. The international 10-20 system of EEG electrode position was used for the recording.

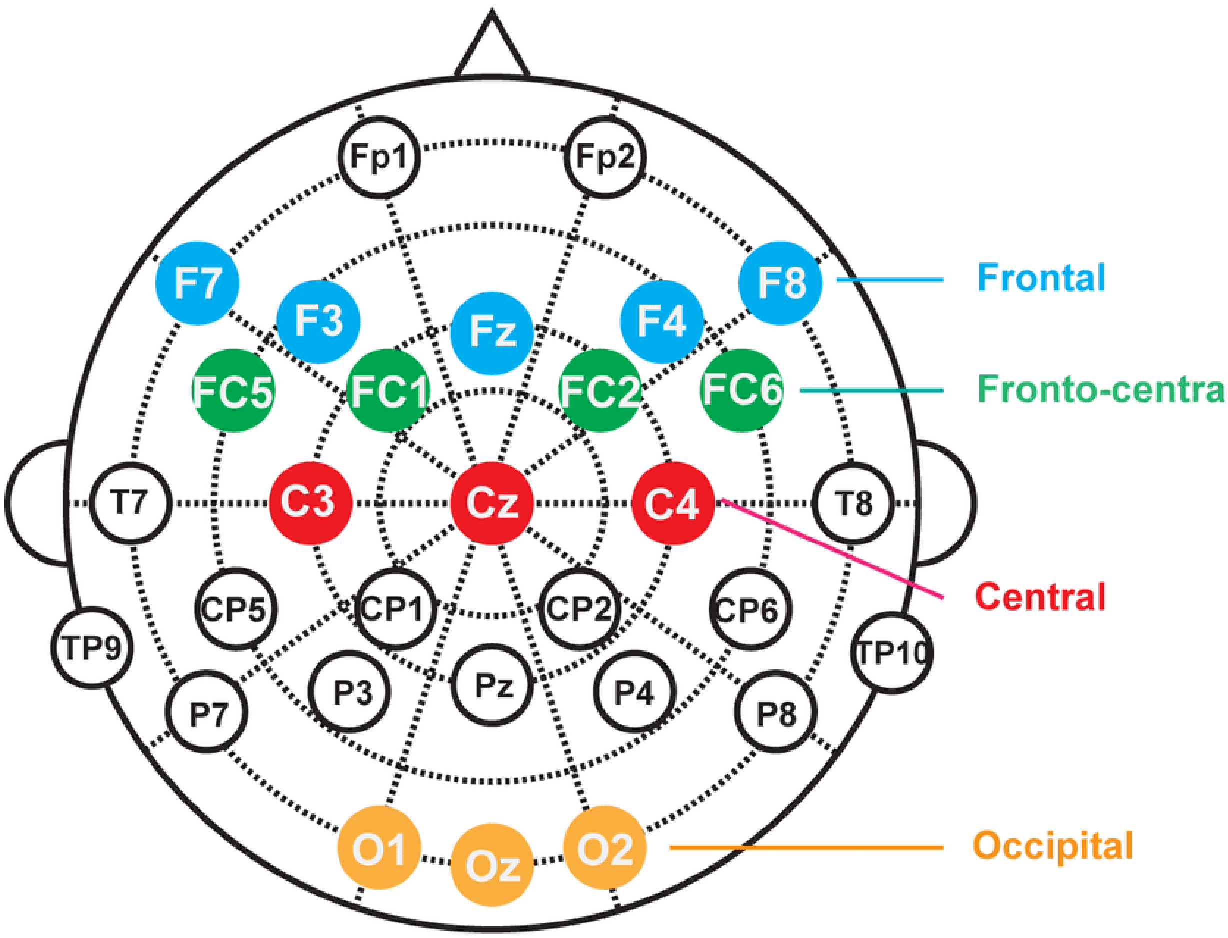

Figure 4.1: Standard EEG Electrode names and position

All this data have sampled at a rate of 256 Hz along with 16 bit resolution. The nomenclature of the channels is also according to international 10-20 system.

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Channels in EDF files:	
Channel No.	**Nomenclature**
Channel 1:	FP1-F7
Channel 2:	F7-T7
Channel 3:	T7-P7
Channel 4:	P7-O1
Channel 5:	FP1-F3
Channel 6:	F3-C3
Channel 7:	C3-P3
Channel 8:	P3-O1
Channel 9:	FP2-F4
Channel 10:	F4-C4
Channel 11:	C4-P4
Channel 12:	P4-O2
Channel 13:	FP2-F8
Channel 14:	F8-T8
Channel 15:	T8-P8
Channel 16:	P8-O2
Channel 17:	FZ-CZ
Channel 18:	CZ-PZ
Channel 19:	P7-T7
Channel 20:	T7-FT9
Channel 21:	FT9-FT10
Channel 22:	FT10-T8
Channel 23:	T8-P8

Table 4-1: Channels in EDF files

All this data is collected from 22 subjects, out of which 5 are males having age between 3 to 22 and 17 are females having ages between 1.5 to 19 years. All the values of data set are spanned from -800 to 800 mV. All this data is available and downloaded in the form of EDF (European data format). The data downloaded from the website also contained the information weather the recording contains seizure or not. And also if seizure is there what is began and end time (in seconds).

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4.2 Sonification Algorithm

EDF files read and converted in to text files using matlab command ‘edf read’. This is the general command for edf read**: [hdr, record] = edfread (fname).** This command reads the all records of file in edf format. Header information is saved in hdr, and the signal waveforms and their associated records are saved in data variable.

For the purpose of sonification we selected the 10 sec epoch for both seizure and non seizure from the data. As the frequency of recordings is 256 Hz so we have a total of 2560 points. After the selection of the data we did the scaling of the data using the ‘scaledata’ command of the matlab. The general command is **outputData = scaleData (inputData, minVal, maxVal).** This command scales the input data between the given minimum and maximum values and saved the data in variable outputData. We set the minimum and maximum value as 1 and 40 respectively. The next step is to fit the scaled the values to adjacent particular integer value which corresponds to a major pentatonic scale in the key of C. Pentatonic scale is a musical scale which has five notes per octave. Pentatonic scale have scale degrees up to 40 i.e. 0, 2.4, 7, 9, 12, 14……40 are saved in the separate list and the scaled valued are compared with this list. A value let’s say 2 will remain 2 as it equivalent the scale degree but the value let’s say 11 will be rounded and outputted as 12. As the frequency of the data is 256 Hz but to play the audio in matlab the frequency should be equal to or greater then 1000Hz. To increase the frequency we used the interpolation. Interpolation is the method in which new data points are built within the range of known discrete data sets. The interpolation command is **inter=spline (t1, input ,t2);** where t1 is the total number of points and t2 is the final number of points that we need as an output. In the next step these values are changed as an audio file in matlab. This data is saved as audio file using the ‘audiowrite’ command in matlab. **audiowrite (filename, input, Fs).** This command writes the audio file named as filename and Fs is the frequency.

And this file is played using the ‘sound’ command. The general command for this is **sound(y, Fs)** where y is the data and Fs is the frequency. This all processing is done for 10sec. Next this algorithm reads the next 10 sec data (2560 points) and done all the processing and write and played the audio file and carry on still the end of data.

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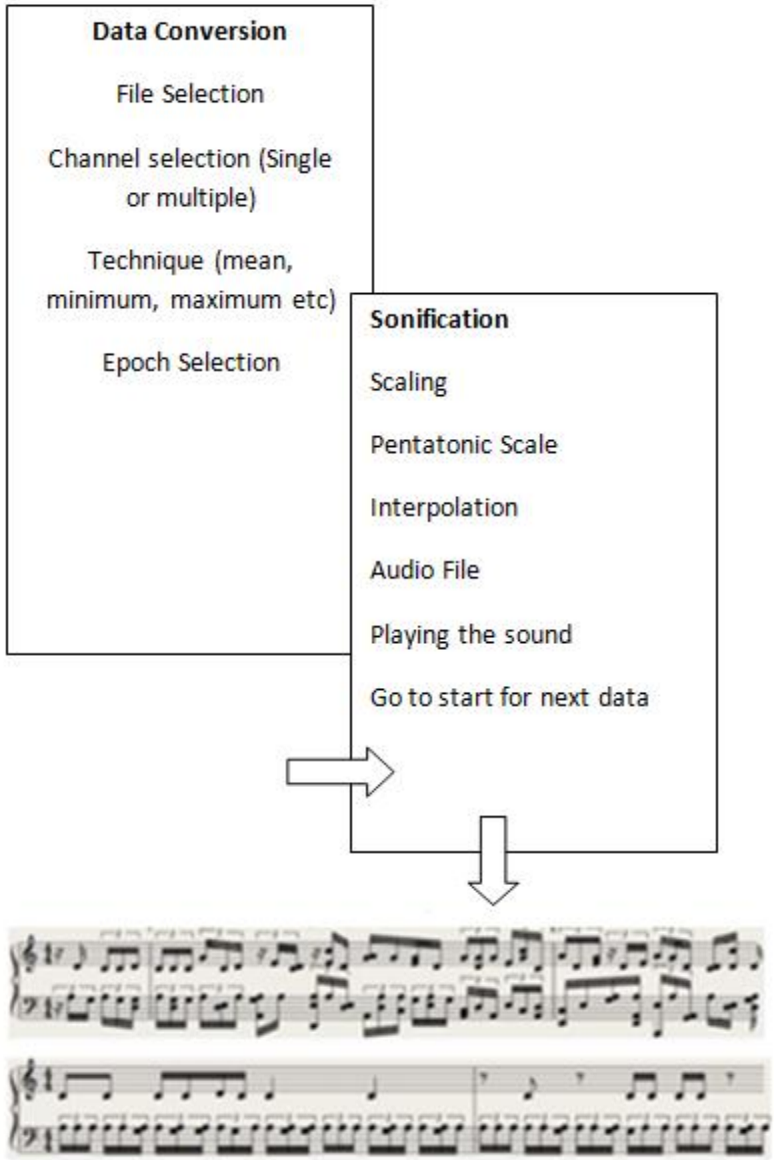

Figure 4.2: Flow chart of EEG Sonification

4.3 Our Approach

As discussed earlier we have many applications in which sonification of EEG are very helpful. On the basic of this we selected and done the sonification of EEG for anomaly detection. As an example we selected the problem of seizure. Seizure is basically caused by the abnormal activity of the brain. During seizure we have too much electrical discharge of neurons, which frequently build up synchronously and occurs suddenly in the central nervous system [24].Seizure is uncontrolled and sudden electrical disturbance of the brain, which causes changes in behavior, feelings, movements and level of consciousness. It badly affects 1% or so of the world population [25].

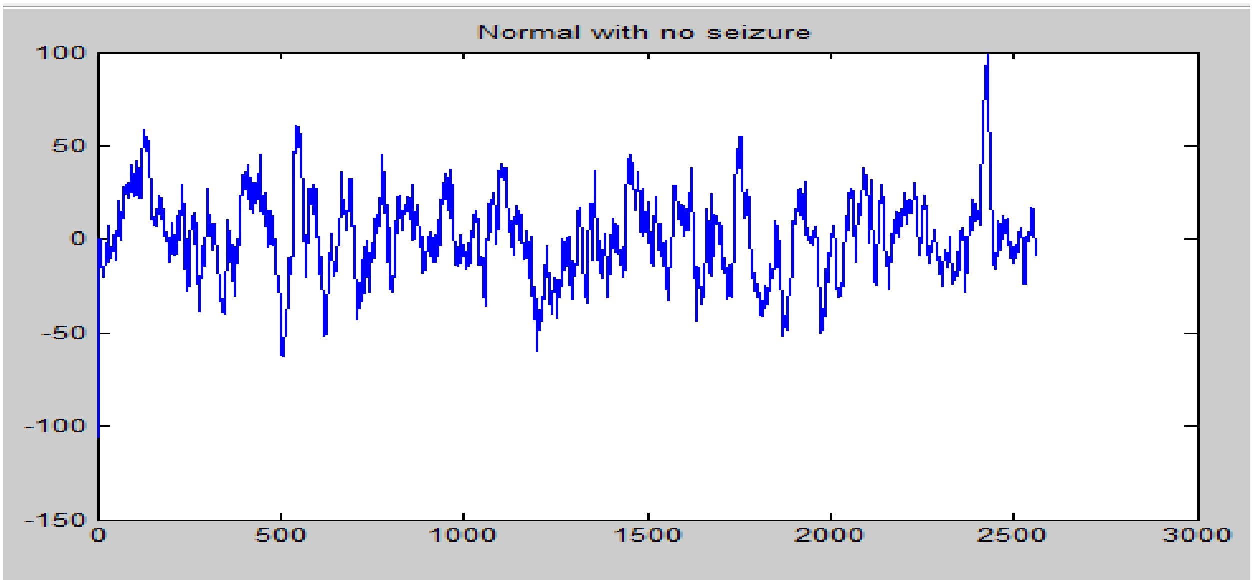

Figure 4.3: EEG with No Seizure

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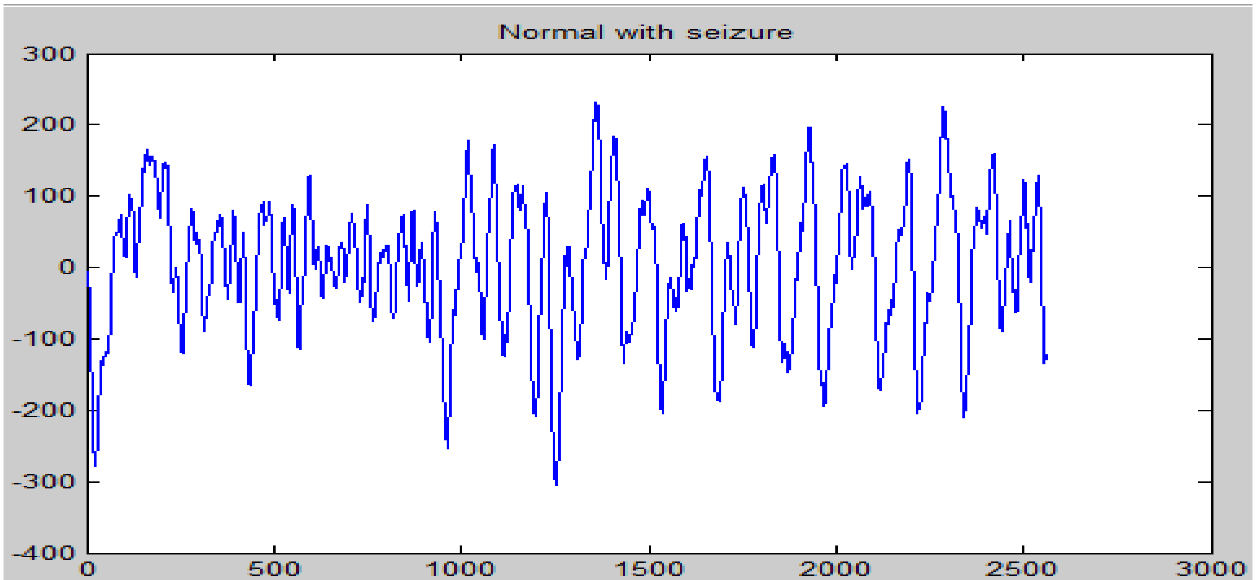

Figure 4.4: EEG with Seizure

The above figures are of EEG of a person. First figure is of normal person and other is of person having seizure. It can clearly be seen in the pictures that the normal EEG have low voltage peaks and almost all values are between -50 to +50 while in the other figure with seizure have the high voltage values and are between -250 to +200. On the basic of EEG we can easily distinguish between seizure and non seizure. That's why we constructed an algorithm that will also distinguish between seizure and non seizure on the basis of the respective generated audios.

Now we will discuss about the approach and method that we had selected for our work. Our work is different from Khamis in this way that we are creating sonification algorithm that don't need any compression of EEG data. Due to this, our algorithm can be applied and used for real time investigation. As seizure analysis is time sensitive that's why the skill to sonify the EEG data in real time is the vital goal of sonification.

We had done the audiofication of the EEG data in which data is converted directly into sound. Our work has two parts.

First Part: In first part we selected the most important channel of EEG data and done its sonification.

We have different views of authors about the important channel like Hinterberger and Baier recommends that for every EEG data, the Fz-Cz channel will be selected for the sonification

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because it was closed to Cz, which was the most general electrode location used for sonification purposes [12].

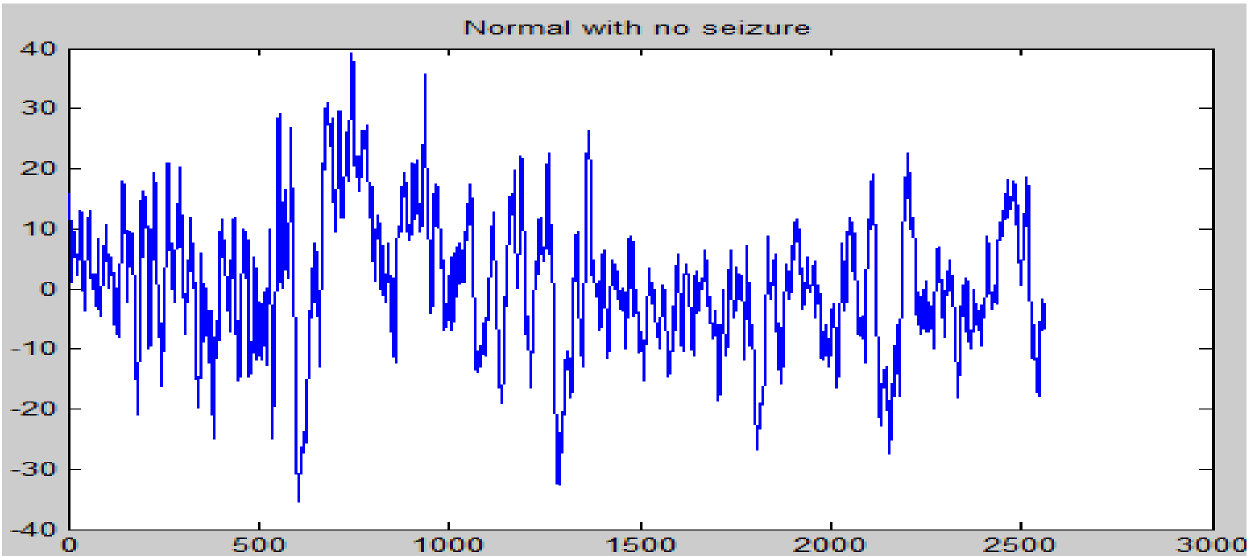

Figure 4.5: EEG of Fz-Cz channel with No Seizure

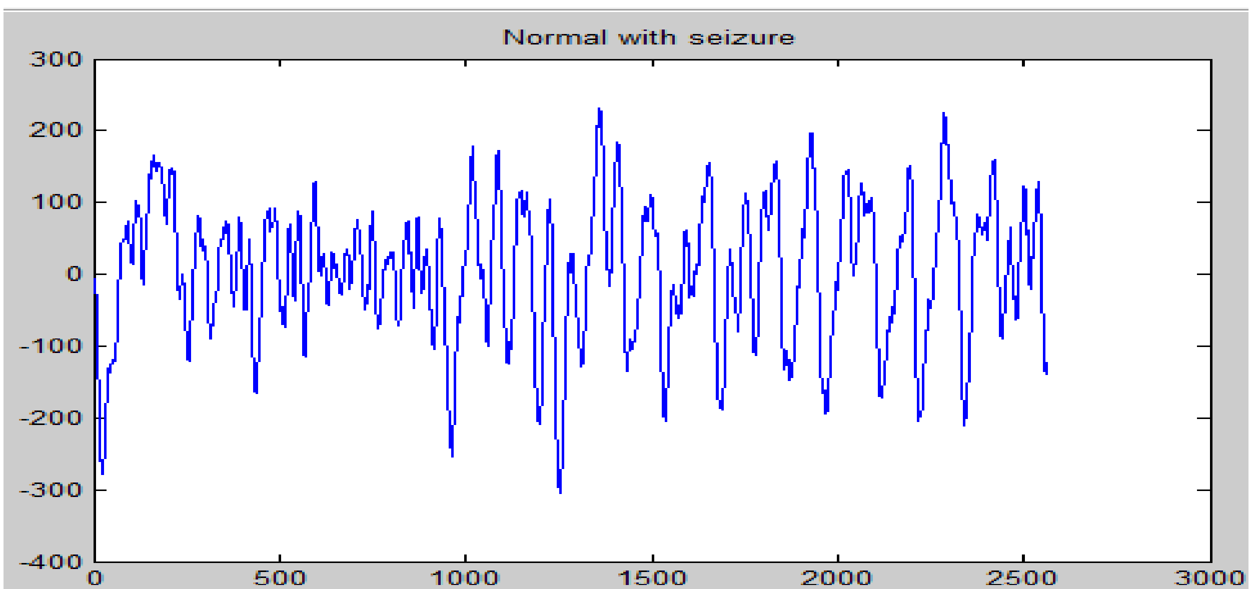

Figure 4.6: EEG of Fz-Cz channel with Seizure

The next most important channel for EEG sonification is FT10-T8 because this channel gives the difference between FT10 frontal temporal channel and temporal channel T8. This channel is the closest difference channel with reference to inner ear that's why this channel is also very important

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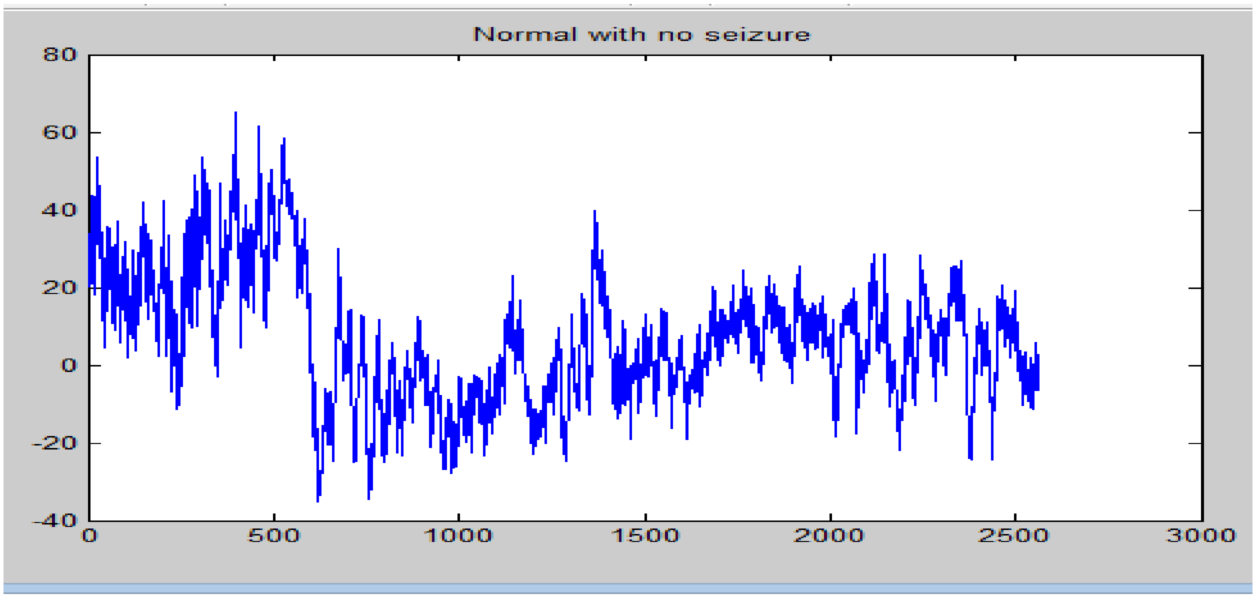

Figure 4.7: EEG of FT10-T8 channel with No Seizure

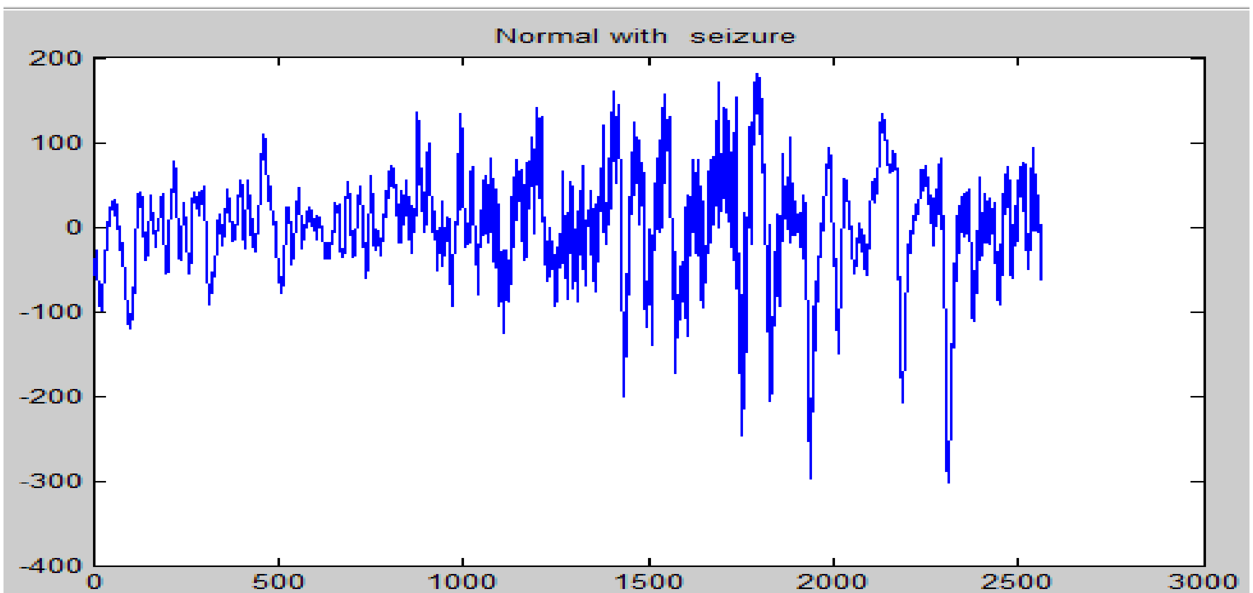

Figure 4.8: EEG of FT10-T8 channel with Seizure

Second Part: In second part we make use of multiple channels for the sonification. As shown above we have a total of 23 channels in our data. We performed different pre processing's on the data before the sonification like:

a) **Arithmetic Mean**: In this part we take the arithmetic mean of the data of all channels and got a single array of data. As we have 23 channels, we took the mean of first

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column and record the value. Similarly for the next column and so on. The final data contains the arithmetic mean of all the channels in a single array.

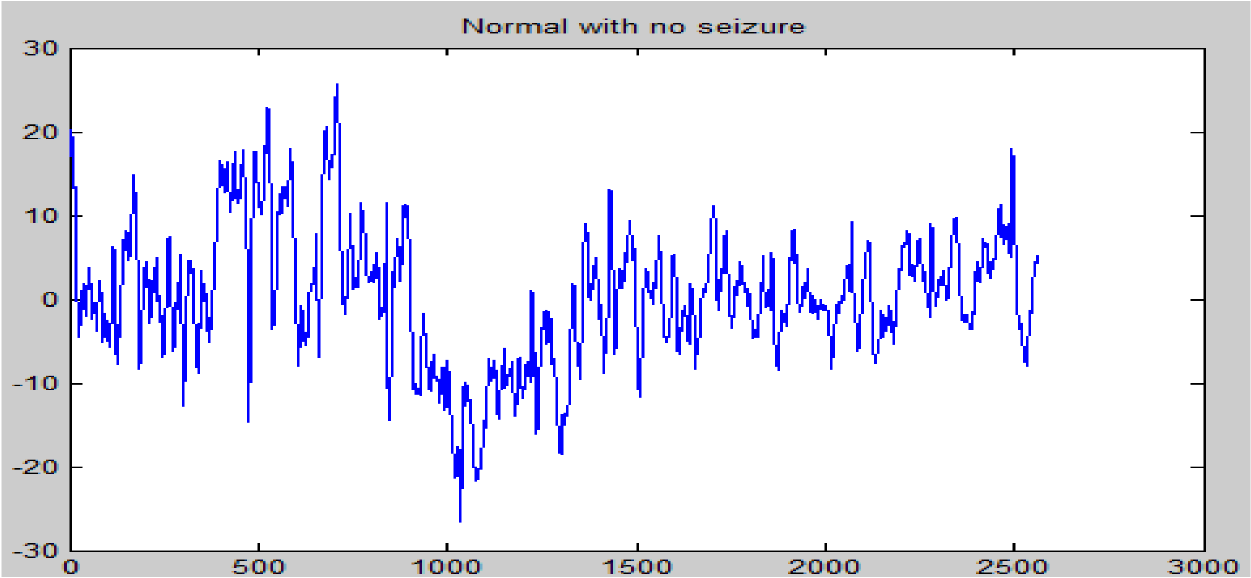

Figure 4.9: EEG with No Seizure of multiple channels by taking their arithmetic mean

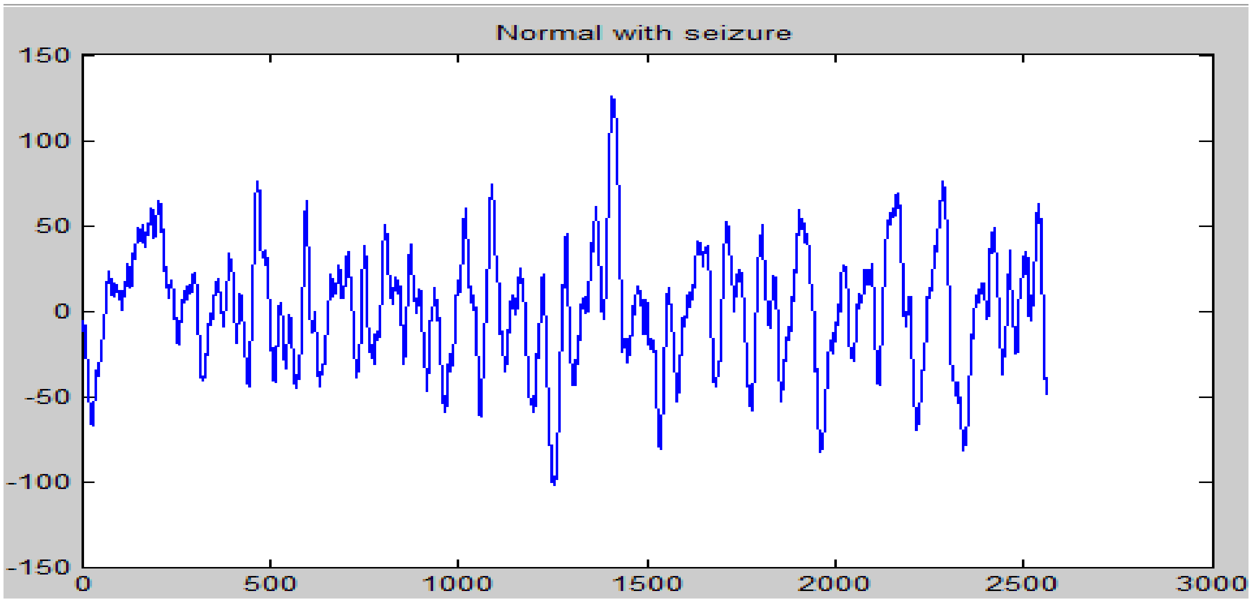

Figure 4.10: EEG with Seizure of multiple channels by taking their arithmetic mean

b) **Minimum Value**: In this part we took the minimum value from the data. Similar to above we read the minimum value from the channel and record it and similarly for the next and so on. The final file contains the minimum values of all the channels in a single array.

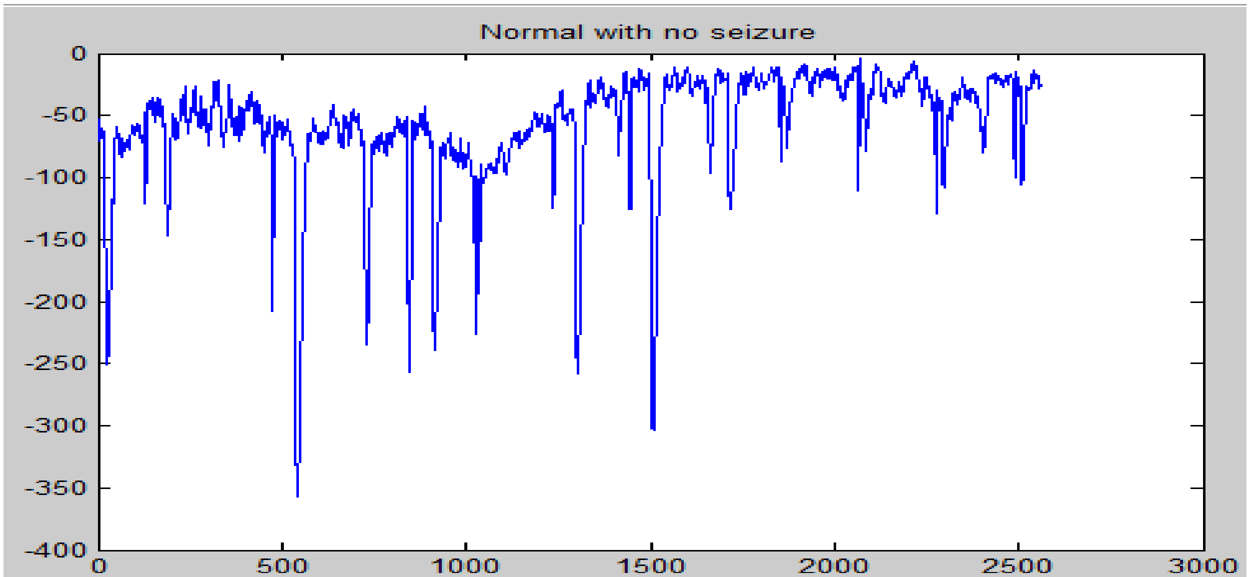

Figure 4.11: EEG with No Seizure of multiple channels by taking their minimum value

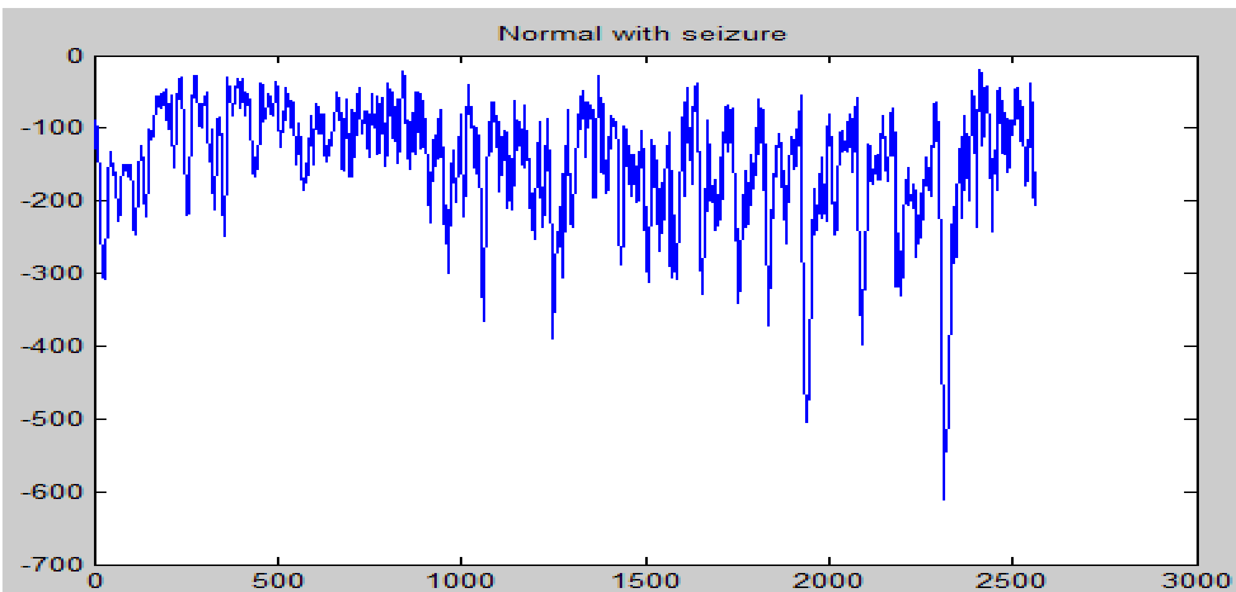

Figure 4.12: EEG with Seizure of multiple channels by taking their minimum value

c) **Maximum Value**: In this part we took the maximum value from the data. Similar to above we read the maximum value from the channel and record it and similarly for the next and so on. The resulting file contains the maximum values of all the channels in a single array.

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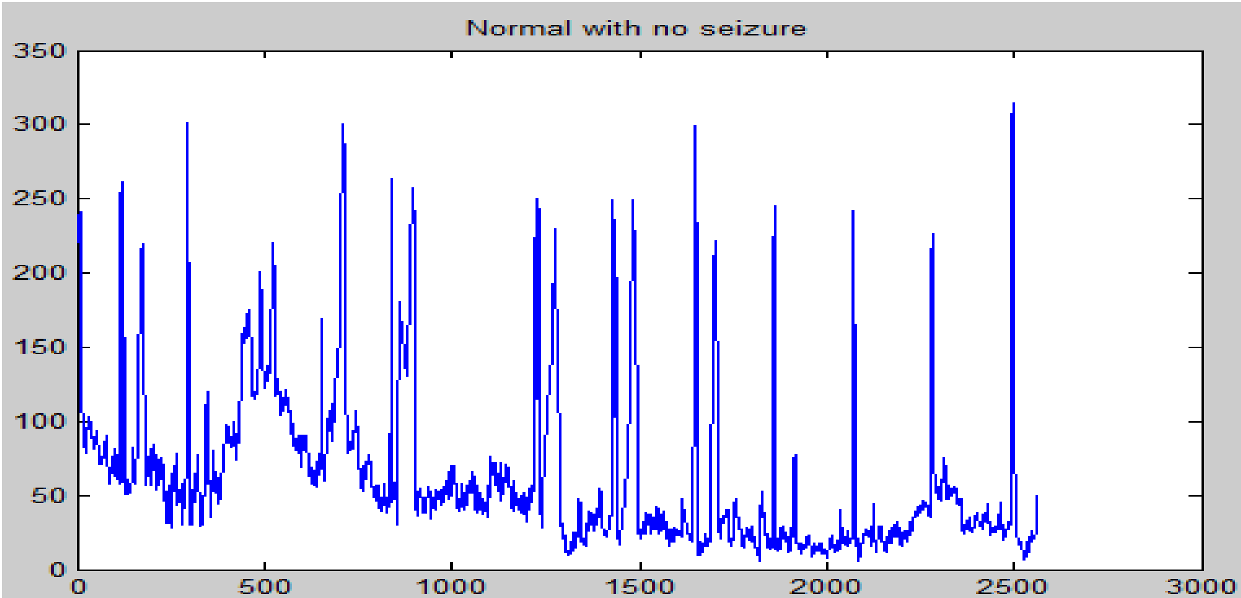

Figure 4.13: EEG with No Seizure of multiple channels by taking their maximum value

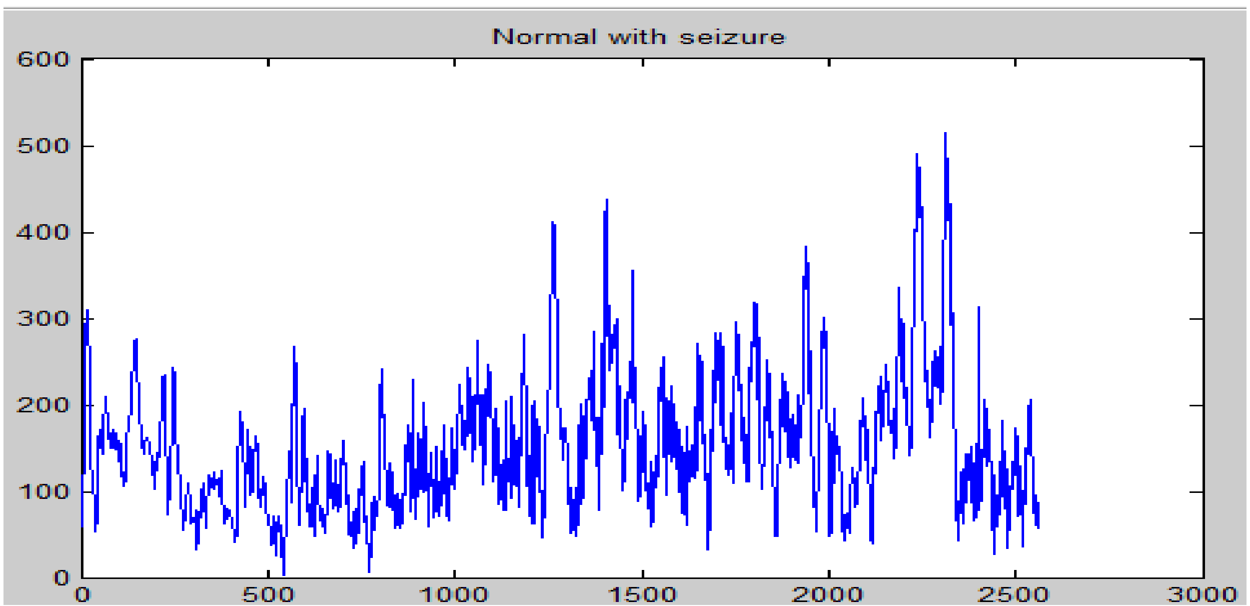

Figure 4.14: EEG with Seizure of multiple channels by taking their maximum value

d) **Weighted Average**: This is the most important and most effective method for the EEG sonification. In this method we took the weighted average of the data. As weighted average is the type of simple average in which each value in the data set is multiplied with fixed value before calculation. In our case two channels are most important i.e. Fz-

Cz and FT10-T8. We first multiply Fz-Cz with all the data and calculated the weighted average and same for the other channel.

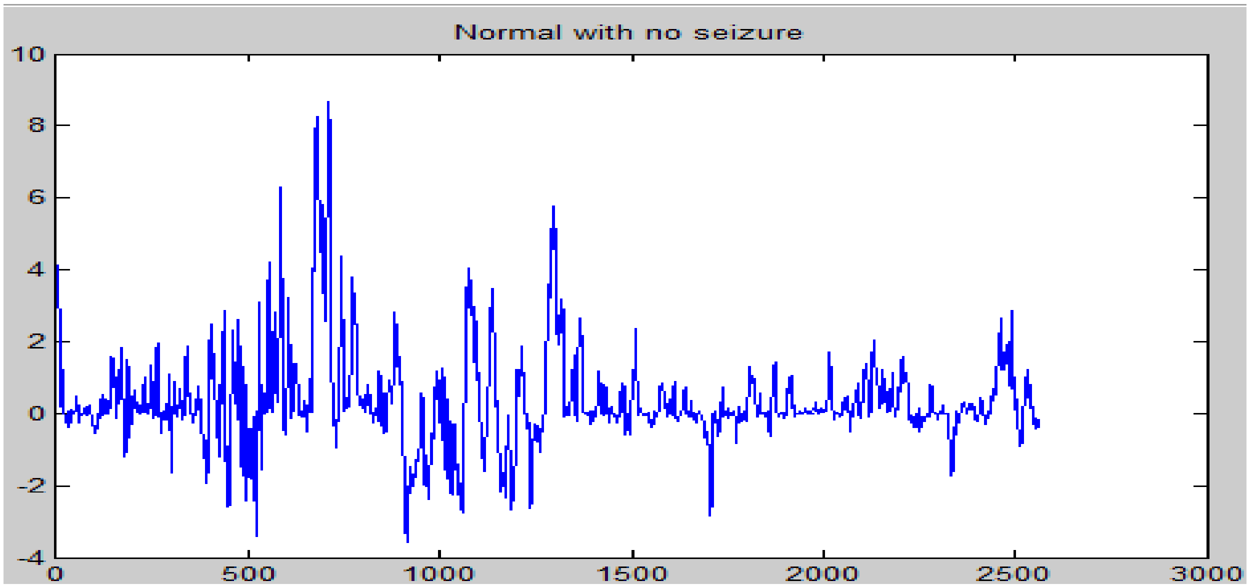

Figure 4.15: EEG with No Seizure of multiple channels by taking their weighted average using Fz-Cz channel

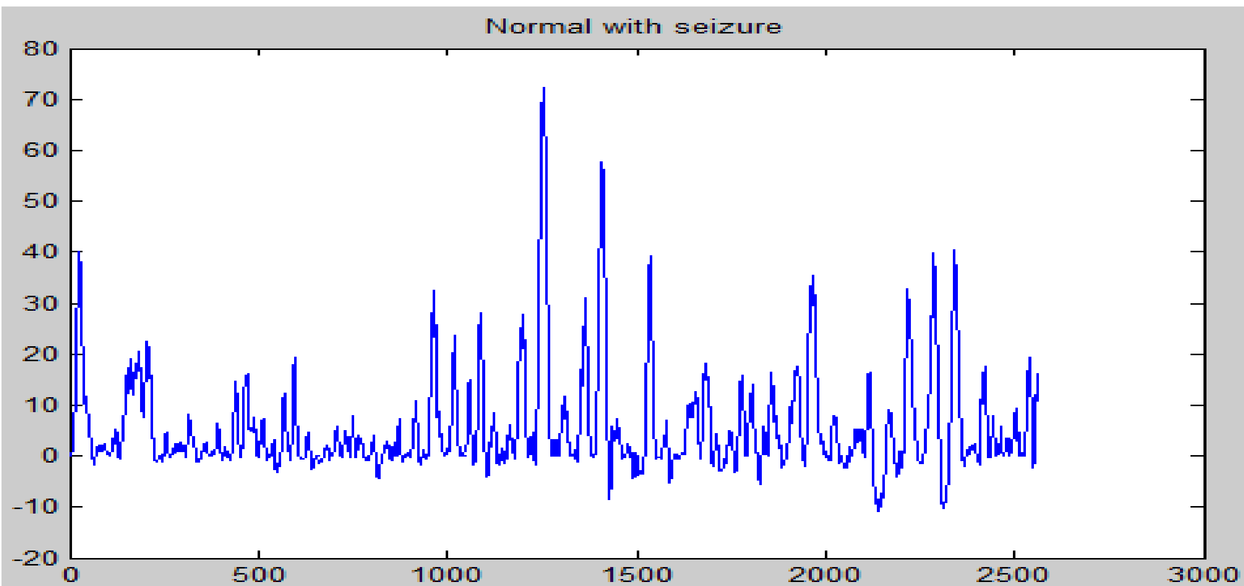

Figure 4.16: EEG with Seizure of multiple channels by taking their weighted average using Fz-Cz channel

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And the same weighted average for the other channel i.e FT10-T8

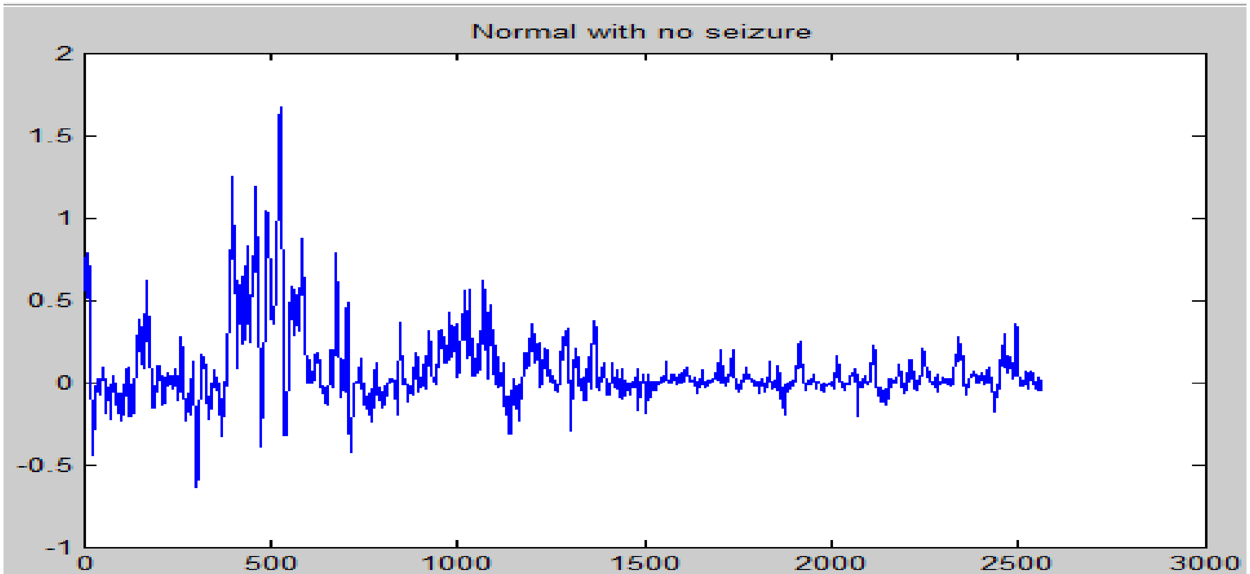

Figure 4.17: EEG with No Seizure of multiple channels by taking their weighted average using FT10-T8 channel

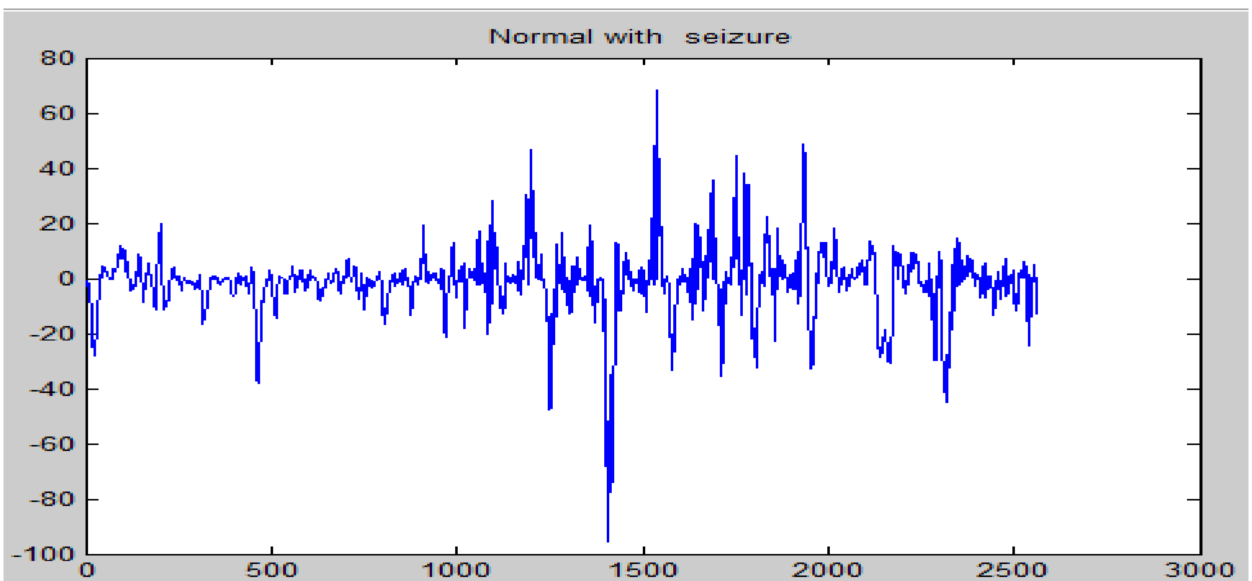

Figure 4.18: EEG with Seizure of multiple channels by taking their weighted average using FT10-T8 channel

To summarize we are predicting that the users by listening the audio created by the sonification of EEG using our algorithm will be able to recognize seizure by using the auditory modality alone.

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Chapter 5
Conclusions and Future Work

5.1 Conclusions:

In our work we explored the technique for the sonification of EEG for the detection if the seizure. Firstly we used single channel then we moved to multiple channels. In multiple channels we had used different approaches like mean, weighted average etc. We concluded that when we use the single channel, the channel FT10-T8 gives the best results for the seizure detection and as far as multiple channels are concerned weighted average using the FT10-T8 is best for seizure detection. We had developed an algorithm of data importing and then done its sonification and created an audible representation of brain activity of persons with seizure and non seizure and also demonstrated that the audience without having musical training can easily differentiate between seizure and non seizure. Our algorithm can be used in the real time that is the real goal of the sonification.

As expected that the sound created using EEG data of non seizure is almost normal means that there is no transaction between low and high frequency where as the seizure sound is of high frequency which will easily be noticed by the listener and on the basis of the generated sound the listener will take proper care of the patient.

5.2 Future Work

The future work will be focused on the refining and optimization of sonification algorithm. We hope that on the basis of our work seizure can easily be identified even in the noisy environment. Our algorithm will be the alternative of visual EEG monitoring.

We had made used of the audiofication technique. In future studies other techniques of sonification will be implemented for the betterment of the algorithm that will make seizure detection more easily and more perfectly.

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