Classification and Severity Measurement of Epileptic Seizure using Intracranial Electroencephalogram (iEEG)

Sanjay Shamrao Pawar, Sangeeta Rajendra Chougule

Abstract**: *The Epileptic seizure is one of major neurological brain disorders and about 50 million of world's population is affected by it. Electroencephalography is medical test which records brain signal by mounting electrodes on scalp or brain cortex to diagnosis seizure. Scalp Electroencephalography has low spatial resolution and presence of external artifact as compared to Intracranial Electroencephalography. In Intracranial Electroencephalography strip, grid and depth type of electrodes are implanted on cortex of brain by surgery to measure brain signal. Analysis of brain signal was carried out in past in diagnosis of Epileptic seizure. Seizure classification and Severity measurement of Epileptic Seizure are still challenging areas of research. Seizures are classified as focal seizure, generalized and secondary generalized seizure depending upon the area of brain which it generates and how it spreads. Classification of seizure helps in treatment of seizure and during brain surgery to operate on brain part which is responsible for continuous seizures generation. Developed seizure classification algorithm classifies seizures as focal Seizure, generalized Seizure and secondary generalized seizure depending on the percentage of iEEG electrodes detecting seizure activity. Seizure severity measurement scale is developed by modification in National Hospital Seizure Severity Scale. Seizures are graded as Mild seizure, Moderate seizure and severe seizure depending on its severity. Seizure Classification and Seizure Severity Measurement improves life quality of Epileptic patients by proper drug management.***

Keywords: Epileptic Seizure, Intracranial Electroencephalography, Quality of life, Seizure Classification, Seizure Severity Scale

I. INTRODUCTION

The function of brain represents the status of whole human body. The neurons present in Central nervous system (CNS) transmit information in responses to simulation. The action potential is generated in response to simulation, which is in the voltage range between negative 60 millivolt to positive 10 millivolt. The action potential generated remains for time period of 5 Mill second to 10 Mill seconds [1]. Electroencephalography is a medical test used for recording the brain signal by placing electrodes on scalp or implanting electrodes on cortex of brain. The brain signals are used to diagnosis various neurological disorders and to detect abnormalities in human body. Scalp Electroencephalography and Intracranial Electroencephalography (iEEG) are used for diagnosis of Epileptic seizure and testing of anti-epileptic drug effect on Epilepsy patients [2]. Scalp Electroencephalography has low spatial resolution as compared to Intracranial Electroencephalography (iEEG). The brain signals acquired by scalp EEG may be contaminated with presence of artifacts and may affect accuracy during seizure classification and seizure severity. Intracranial Electroencephalography (iEEG) is a clinical technique where strip, grid or depth electrodes are implanted over the cortex of brain by surgery to monitor brain activities. Classification of seizure provides exact region of brain from where the seizures are generated and how it is spread. Classification is helpful in drug management and epileptic surgery. Seizure severity measurement and grading the seizure as Mild seizure, Moderate seizure and severe seizure is helpful in surgical treatment and drug management. Classification of seizure and severity measurement can improve life quality of Epileptic patients by proper drug management. Diagnosis of Epileptic seizures using scalp Electroencephalography (EEG) dataset and Intracranial Electroencephalography (iEEG) dataset has attracted many researchers to develop various algorithms. Seizure classification and seizure severity measurement still remains neglected area of research. Automatic seizure detection was carried out by implementation of wavelet decomposition in five scales of multi-channel intracranial EEG. Features such as Energy, relative amplitude, coefficient of variation and fluctuation index were extracted and classified using support vector machine for seizure detection [3]. One–class support vector machine novelty detection method was implemented for detecting of seizure using Intracranial Electroencephalography. Short-time, energy-based statistics were computed. Validation of detector was done using leave-one-out cross-validation [4]. Seizure detection was carried out using Lacunarity and Bayesian Linear Discriminant Analysis (BLDA) using long-term Freiburg intracranial EEG dataset. Wavelet decomposition was done up to five scale and features such as Lacunarity and Fluctuation index were extracted [5]. Novel patient specific algorithm for seizure predication was presented for single or bipolar channel, features such as spectral power are extracted and ratios were computed [6].

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Classification of seizure based on its location, generation and its spreading and measurement of seizure severity are challenging areas for researchers. The objective of the research is to classify seizure as focal seizure and generalized seizure. The other objective is to measure seizure severity and graded it as mild seizure, moderate seizure and severe seizure. Development of algorithm and system will improve the medical treatment and life quality of Epileptic patient.

II. SEIZURE CLASSIFICATION SYSTEM

Seizure occurrence is due to activation of large number of brain cell abnormally which is similar to electrical storm in brain. Seizure classifications over the years are broadly classified as Focal Seizures and Generalized Seizures. Classification of seizure will help clinical expert and surgeon for treatment and surgery. Focal Seizures are those which start at one side or one area of brain but do not extend or spread over entire brain. Focal seizures are generated or cover only small area of brain. Generalized seizures are those which start on one side or one area of brain and extend to other side or which starts on both side of brain simultaneously.

Fig.1 represents Seizure Classification System in which the brain signals acquired through Intracranial Electroencephalography (iEEG) for seizure classification. The signals are online available on SWEC-ETHZ iEEG database. The iEEG signals brain signals are recorded using strip, grid and the depth electrodes, these electrodes are implanted over the cortex of brain. The iEEG signals ictal segment is preprocessed to remove power noise. The ictal segment of iEEG signals are analyzed in wavelet domain by implementation of Daubechies Discrete Wavelet Transform with eight level of decomposition. The alpha and beta sub-band of frequency are extracted and the features such as Kurtosis, Skewness, Kolmogorov Entropy, Lacunarity, Energy & Entropy and Fluctuation index are found out [7]. The features extracted from testing Ictal segment and features extracted training Ictal segment are compared to mark whether the electrode analyzed has seizure signal or not.

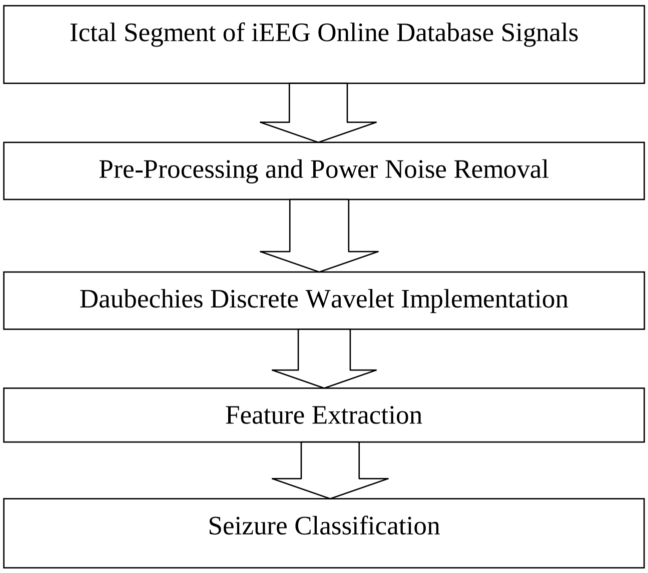

Fig.1. Seizure Classification System

A. Ictal Segment of Intracranial Electroencephalography online Database Signals

The iEEG database is downloaded from SWEC-ETHZ iEEG database which is free of charge to researchers. The signals are recorded at Sleep Wake Epilepsy Center at university department of Neurology at the Inselspital Bern and the Integrated Systems Laboratory of the ETH Zurich. In seizure classification system we have analyzed short term recording of 100 seizure signals obtained from 16 patients, which are recorded before epilepsy surgery. The signals are recorded by implantation of strip, grid and the depth electrodes. A 16 bit analog the digital convertor converts recorded analog signals to its digital form. The signals are further passed through Butterworth band pass filter of fourth order with lower cut-off frequency as 0.5 Hz and upper cut-off frequency as 150 Hz. The signals are recorded on disc with the speed of 512 Hz. The recorded signal consists of three minutes recording before the seizure occurs which is called as pre-ictal segment, followed by seizure period which is generally in range from 10 sec to 1002 sec and called as ictal segment, and finally ictal segment is followed by three minutes of recording called as post ictal [8],[9]. The segment important for seizure classification is Ictal segment, so it is extracted form total iEEG signal record. The seizure (Ictal) segment starts after three Minutes of Pre-ictal segment and ends at start of post Ictal segment. The seizure (Ictal) segment is separated out from the total iEEG record stored.

B. Pre-Processing and Artifact Removal

The iEEG signals during recording may be mixed with artifacts and affect the performance of Seizure Classification System [16]. The signals are pre-processed by implementation of Butterworth band pass filter of fourth order with lower cut-off frequency as 0.5 Hz and upper cut-off frequency as 150 Hz. The iEEG are less affected by artifacts as compared to scalp EEG signals. The power noise which may get introduce during recording is removed by implementation of notch filter and required band is extracted by band pass filter.

C. Daubechies Discrete Wavelet Transform Implementation

Intracranial Electroencephalography signals are non-stationary in nature and needs to analyze in both in time and frequency domain. Wavelet transform found to be more powerful mathematical tool to analyze transient signals, which has average value as zero. In wavelet domain signal is analyzed by breaking of signal in scaling and shifting [20]. Daubechies Discrete Wavelet Transform is implemented up to eight levels decomposition to extract alpha, beta, gamma, theta and delta frequency waves. The alpha frequency band and beta frequency band changes its characteristics features during ictal and non-ictal stage. The feature vector extracted from these bands indicates ictal and non-ictal state. The alpha frequency band and beta frequency band are extracted from detail coefficient CD7 and CD6 respectively from Discrete Wavelet Transform decomposition levels. The CD6 and CD7 are only used for further feature extraction.

D. Feature Extraction

Selection of effective features is very important in Seizure Classification System. The features selected should be able to differentiate between ictal state and non-ictal state. Precise information provides by feature vectors helps in seizure classification. The variations in the distribution are measured in terms of parameters of a Gaussian process and the deviation of the distribution from Gaussian. As alpha frequency band and beta frequency band are used in feature extraction and the deviation in Gaussian can be measured by finding the feature vector values of Kurtosis, Skewness, Kolmogorov Entropy, Energy & Entropy, Fluctuation index and Lacunarity of detail coefficients CD7 and CD6.

- **Kurtosis:** It is the measurement whether the given data are flat or peaked in nature at the mean point relative to a normal distribution. The distinct peak near the mean which declines very rapidly with heavy tails has high value of kurtosis flat top near the mean point of the iEEG signal indicates low value of kurtosis.
- **Skewness:** It is a measurement of symmetry or lack of symmetry of given data set distribution. If a data distribution looks exactly similar to the left and right side from the Centre point then it is called as symmetric. If the data distribution is more towards right side from the mean point than the skewness is called to be negative skewness and vice versa. The skewness is zero for symmetric distribution of data.
- **Kolmogorov Entropy:** It is one of statistical properties which is used to measure irregularity of iEEG signal, Kolmogorov Entropy is the entropy of source distribution generating the sequence.
- **Energy and Entropy:** Energy of a signal is represented as strength of signal and is measured as the sum of squared modulus of the sample values [10]. Higher value of Energy indicates presence of Ictal segment in given iEEG signal. Entropy is measured as the uncertainty or randomness in given iEEG signal, it also reflects the event in the measured iEEG signal [11], [14], [15].
- **Fluctuation Index:** It is the measurement of intensity of the fluctuation in iEEG signal. Ictal segment has higher fluctuation Index as compared to non-ictal segment in iEEG signals.
- **Lacunarity:** It is a measurement scale to measure heterogeneity, which quantifies the gaps present in the given surface [13]. Low Lacunarity indicates homogeneous and transitionally invariant and high Lacunarity indicates heterogeneous and not transitionally invariant in iEEG signal.

E. Seizure Classification

The feature vectors extracted from Ictal segment are compared with features vectors of stored training set signals to find out whether the iEEG electrode processed is having seizure or not. The percentage electrodes containing seizure signal is calculated to the total number of iEEG electrodes implanted to cover the entire brain area and the seizure classification is carried out. If 80 percentages of implant electrodes indicates presence of seizure at same instant of time than the seizure is classified as generalized seizure. If 40 percentages of electrodes indicates present of seizure at same instant of time than the seizure is categorized as Focal seizure. If most of electrodes indicates present of seizure with difference in time period than the seizure is categorized as Secondary Generalized seizure. Classifiers such as Support Vector Machines, K-Nearest Neighbor algorithm and Probabilistic Neural Network which are most accurate and widely used are implemented for classification [12], [13], [21].

III. SEIZURE SEVERITY MEASUREMENT SCALE

Measurement of seizure severity was largely neglected and not much research was done on it. Seizure severity measurement is an important parameter which helps in surgical and medical treatment of Epilepsy patient. Seizure severity scale measures components of seizure and categories it as mild seizure, moderate seizure and severe seizure. Traditionally measurements such as seizures per month are inadequate for treatment. Seizure severity measurement plays important role to improve life quality of Epileptic patient. Developed Seizure Severity Measurement Scale should be easily understood by patient and doctor and should vary after treatment. Seizure severity measurement is an outcome which measures the effect of Antiepileptic Drug (AEDs) given to Epilepsy patients [17]. In 1990 Chalfont seizure severity scale was developed which is patient and observer-based scale and has list of 11 factors of enquiry. The patient through interview is enquired about 11 factors and based on response weights and scales were assigned. Observer views are also recorded in combination with patient's response in Chalfont seizure severity scale [18]. National Hospital Seizure Severity Scale (NHS3) is refinement of Chalfont seizure severity scale, which is easy and simple to apply. In National Hospital Seizure Severity Scale (NHS3) four redundant items of Chalfont seizure Severity Scale were eliminated and content of one item is changed. Seizure severity score from 1 to 27 is generated [19]. Seizure Severity Measurement Scale is developed by three modifications in National Hospital Seizure Severity Scale (NHS3) to develop new Seizure Severity Measurement scale. The developed Seizure Severity Measurement Scale is shown in Table 1. Seizure classification, addition of Ictal duration and grading or category of seizures are the three modification implemented. The details of three modifications in NHS3 are as follows

- **Modification 1:** In point 1 seizure classification has been allocated points according to the region of occupancy. Secondary seizure is allocated 3 points as this type of seizure covers most region of brain. Focal seizure is allocated with 1 point as is generated only in specific part of brain. Secondary generalized seizure is allocated 2 points as it starts at one part of brain and extends to other part.
- **Modification 2:** In point 9 Ictal time period is added in seizure severity chart as it is important indicator in measurement of severity. According to duration of Ictal period the points are allocated. Ictal duration greater than 10 Minutes is allocated as 3 points, Ictal duration in between 1Minute to 10 Minutes is allocated as 2 points and the Ictal duration in between 10 Seconds to 60 Seconds is allocated as 1 point. Ictal duration with less than 10 seconds 0 point is allocated.

- **Modification 3:** The total maximum points in modified National Hospital Seizure Severity Scale are now 33 points. Based on total points the seizures are graded as mild seizure, moderate seizure and severe seizure. The seizure is graded as mild seizure if the points are from 1 to 11, seizure is graded moderate seizure if the points are from 12 to 22 and seizure is graded as severe seizure if the points are from 23 to 33.

Table-1: Modified Severity Measurement Chart

Pt. No	PARTICULARS	Score
1	**Mention the Type Seizure that occur** Generalized Seizure=3, Secondary Generalized Seizure=2, Focal Seizure=1	
2	**During the above seizure type does the patient have a generalized convulsion** Yes=4 No=0	
3	**During the seizure occurrence how often has the patient falls on the ground** Nearly always or always=4, often=3, Occasionally=2 Never=0	
4	**During the seizure mention the injuries that occurred** Burns, scalds, deep cuts, fractures= 4, Bitten tongue or severe headaches=3 Milder injuries or mild headaches=2, No injuries=0	
5	**During seizure how often has the patient incontinent of urine** Nearly always or always=4, Often=3, Occasionally=2 Never=0	
6	**Is there a long enough warning for the patient to protect him/herself? If seizure causes loss of consciousness.** Never=2, Sometimes=1, Nearly always or always=0	
7	**How long it takes for patient to come back to normal after occurrence of seizure** Less than 1 Minutes=0, Between 1 and 10 minutes=1 Between 10 Minutes and 1 hour=2 Between 1 and 3 hours=3 More than 3 hours =4	
8	**During seizure weather the following events occur** **Seriously disruptive automatisms** Shouting, wandering, undressing= 4 Mild automatisms or focal jerking=2 None=0	
9	**What's the normal duration of Seizure (Ictal Period)** Less than 10 Sec=0; Between 10 and 60 Sec=1; Between 60 and 600 Sec=2; More than 600 Sec=3	
	Add 1 point to each column	
	Total Score	

IV. RESULT ANALYSIS

Result analysis of Seizure Classification System is done to classify seizures as Focal, Generalized and Secondary Seizure. Analysis of Seizure Severity Measurement Scale is carried to grade the seizure as Mild seizure, Moderate seizure and Severe seizure using 100 iEEG signals from 16 patients, which are acquired through online database.

A. Result Analysis of Seizure Classification System

In Seizure Classification System 100 iEEG signals from 16 patients were acquired through online database using strip, grid and depth electrodes. Each iEEG signal recording consists of three minutes of recording of pre-ictal segment followed by ictal segment which varies from 10 seconds to 1002 seconds and finally a recording of three minutes post ictal segment as shown in Fig. 2. Seizure Classification system extracts and analyze ictal segment for classification.

Pre-Ictal Segment	Ictal Segment	Post-Ictal Segment
3 Min= 92160 Samples	10 Seconds to 1002 Seconds	3 Min=92160 Samples

Fig. 2. Recorded iEEG Segment

Table 2 shows the classification of seizure of 16 patients with respect to percentage of electrodes detecting seizure. The seizures are classified as Focal seizure, Generalized seizure and Secondary Generalized seizure depending on percentage electrodes indicating seizure and the area it covers or spreads.

Table-2: Classification of Seizure

Patient ID	% of Electrode with Seizure	Seizure(Ictal) Duration in Seconds	Classification
ID1	47	125	Focal
ID2	42	96	Focal
ID3	98	125	Generalized
ID4	62	160	Secondary
ID5	54	154	Focal
ID6	64	89	Secondary
ID7	36	14	Focal
ID8	59	52	Focal
ID9	56	104	Focal
ID10	97	22	Generalized
ID11	57	135	Focal
ID12	49	23	Focal
ID13	87	83	Generalized
ID14	68	1002	Secondary
ID15	61	126	Secondary
ID16	52	117	Focal

B. Result Analysis of Seizure Severity Measurement Scale

Using the Table 1 of Modified Severity Measurement Chart the total seizure score is calculated by receiving input from patient manually, duration of seizure and time taken by to the patient to return to normal is calculated out by analysis of iEEG signal. Providing the inputs to seizure severity measurement scale the seizures are graded as Mild seizure, Moderate seizure and Severe seizure based on total score.

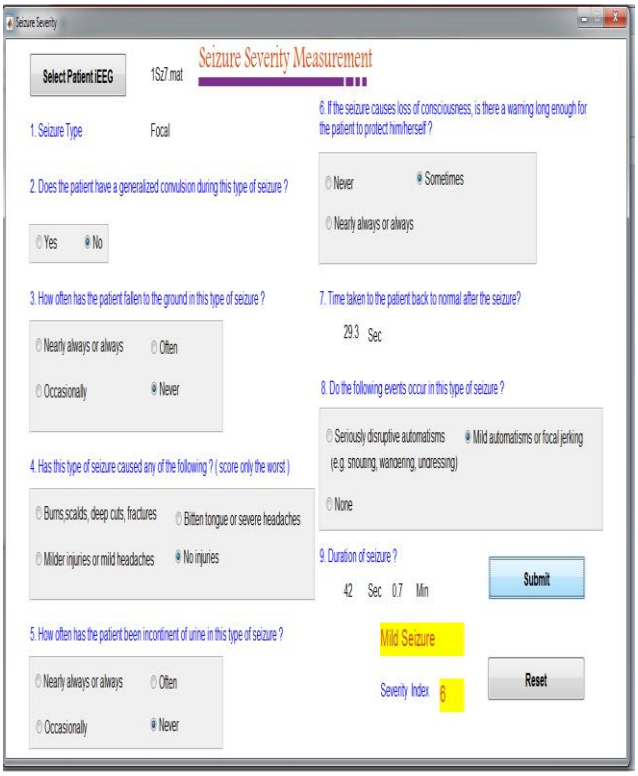

Fig. 3. Seizure Severity Measurement with Mild Seizure

Fig. 3 shows the result of patient ID1, seizure time is calculated as 42 seconds and time taken by patient to come to normal state is 29.3 seconds. The other detail needs to be filled by acquiring information from patient or relative of patient in our case we have marked randomly. The result obtained is Mild seizure with severity index as 6.

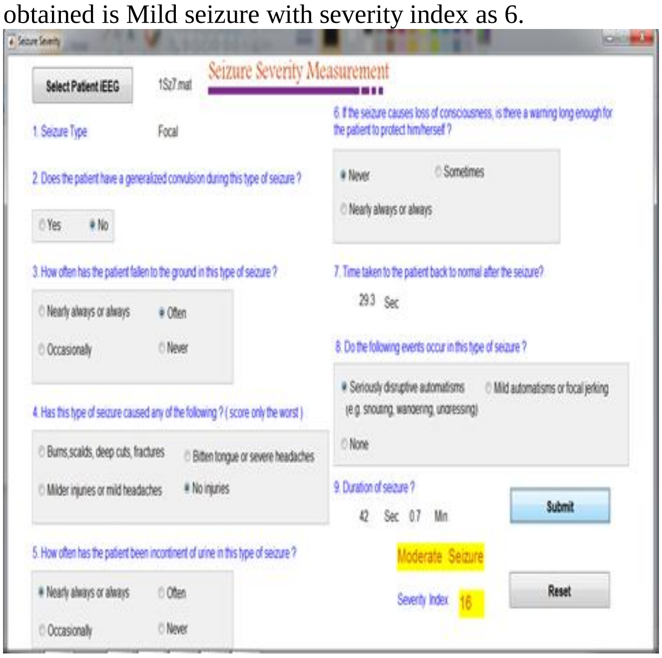

Fig. 4. Seizure Severity Measurement with Moderate Seizure

Fig. 4 shows the result of patient ID1, seizure time is calculated as 42 seconds and time taken by patient to come to normal state is 29.3 seconds. The other detail needs to be filled by acquiring information from patient or relative of patient in our case we have marked randomly and changed from above input. The result obtained is Moderate seizure with severity index as 16.

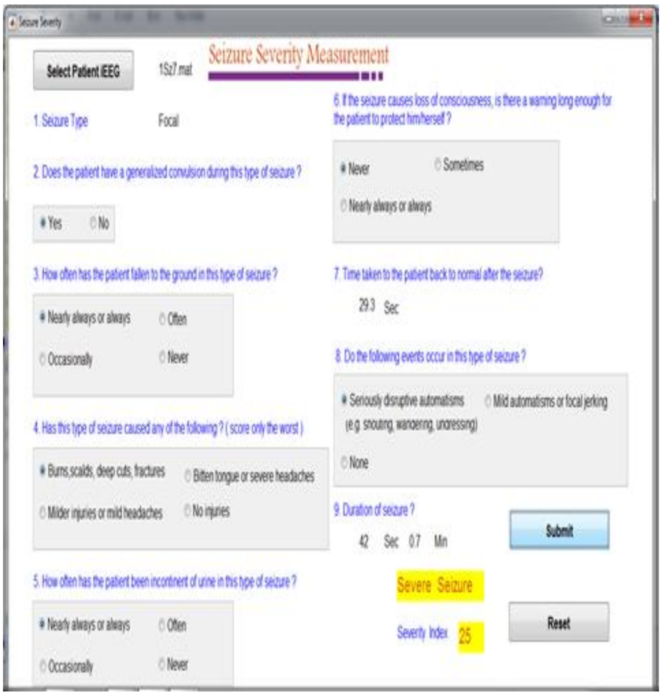

Fig. 5. Seizure Severity Measurement with Severe Seizure

Fig. 5 shows the result of patient ID1, seizure time calculated remains to be 42 seconds and time taken by patient to come to normal state is 29.3 seconds. The other detail needs to be filled by acquiring information from patient or relative of patient in our case we have marked randomly and changed from above input. The result obtained is severe seizure with severity index as 27.

V. CONCLUSION

Intracranial Electroencephalography signals are analysed for seizure classification and severity measurement. The developed Seizure Classification System is significant tool for classifying the seizure as Focal seizure, generalized seizure and secondary generalized seizure. Seizure classification is useful to understanding the region of brain from where seizure originates and spreading of seizure, which can be further used for seizure treatment and brain surgery. Seizure severity Measurement scale is important parameter to measure the effect of anti-epileptic drug and to know improvement in Epileptic patient. Seizure severity measurement scale is developed by modification in National Hospital Seizure Severity Scale and grading the seizure severity as Mild seizure, Moderate seizure and severe seizure. Classification of seizure and Severity Measurement scale helps to improve life quality of Epileptic patients by proper drug management. In future the hardware proto type of seizure classification and severity measurement scale can be developed.

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