Flat electroencephalography's cluster centers movement tracking during epileptic seizure

Cite as: AIP Conference Proceedings **2016**, 020103 (2018); https://doi.org/10.1063/1.5055505
Published Online: 27 September 2018

Syu'aiba Mukhni, Tan Lit Ken, Nor Azwadi Che Sidik, et al.

Flat Electroencephalography's Cluster Centers Movement Tracking During Epileptic Seizure

Syu'aiba Mukhni[1, a)], Tan Lit Ken[1, b)], Nor Azwadi Che Sidik[1], Goh Chien Yong[2], Lee Kee Quen[1], Chuan Zun Liang[3], and Yutaka Asako[1]

[1]*Malaysia-Japan International Insititute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur*
[2]*Xiamen University Malaysia, Jalan Sunsuria, Bandar Sunsuria, 43900 Sepang, Selangor.*
[3]*Universiti Malaysia Pahang, Lebuhraya Tun Razak, 26300 Gambang, Pahang.*

[a)] syuaibamukhni@hotmail.com
[b)] tlken@utm.my

Abstract. Epilepsy is a term used for a chronic disorder caused by excessive and abnormal nerve cell activity within the brain. This dynamic process is often associated with electroencephalography (EEG), which is an electrophysical method to record the electrical activity of the brain. For epilepsy patients, their EEG signals are characterized by abnormal signal flow and large spikes. This shows the excessive electrical activity within the brain can be extracted thus locating problematic cells of epilepsy is possible. However, it is very challenging due to the complexity of the signals to be analyzed. Through *fEEG*, the signals can be viewed in a Cartesian plane which consists of EEG's channels and cluster center of electrical potential during epilepsy. To date, no research has been done on across time-frame of *fEEG*. In order to gain better insight into the dynamic process of epilepsy, a dynamic study on the cluster center movement across time-frame is necessary. Therefore, this study to shows the tracking of cluster centers movements across time-frame of *fEEG*. This movement tracking is essentials to understand the behavior of epilepsy such as the patterns of electrical potential. Further studies on the model could potentially assist in locating the problematic cells caused by epilepsy**.**

INTRODUCTION

Epilepsy is a neurological disorder described by epileptic seizures [1, 2]. Fisher et al. [3], defined it as a short-term episode of signs and symptoms due to abnormal excessive or synchronous neuronal movement in the brain. However, it is not contagious and also not a form of mental illness. Even though it can be treated easily by medicine (Megiddo et al.) [4], approximately around 30% of epilepsy patients cannot bear with the side effects of the drugs thus opt to undergo the surgery to remove the problematic cells that caused by epilepsy.

The cells can be traced with aid from the EEG. According to Niedermeyer & da Silva [5], EEG is an electrophysical monitoring method to record the voltage fluctuation of ionic activity produced by neurons. It is a non-invasive instrument used to measures and records the electrical activity as a visual trace (waveform) for a period of time. Thus, it allows researchers to analyze the signals then located the problematic cells of the brain. Hence, assists in planning for the surgery to lessen the risk of injury to the patient's brain. However, currently, a very challenging of visual inspection of highly skilled electroencephalographers are still used to detect the problematic cells (Sanei & Chambers) [6].

Proceedings of the 3rd International Conference on Applied Science and Technology (ICAST'18)
AIP Conf. Proc. 2016, 020103-1–020103-6; https://doi.org/10.1063/1.5055505
Published by AIP Publishing. 978-0-7354-1734-2/$30.00

LITERATURE REVIEW

Flat Electroencephalography *(fEEG)*

In 2008, *fEEG* was developed by Fauziah [7] which is a novel method to flatten EEG signals from a high dimensional signal into a low dimensional signal. This method allows EEG signals to be viewed on the Cartesian plane such in Figure 2. The magnitude and orientation of the signals are preserved in the transformation. Therefore, these signals (Figure 1) can be compressed and analyzed. This flattening method has been coded as a software and received copyright © *2006 Universiti Teknologi Malaysia – All Rights Reserved.*

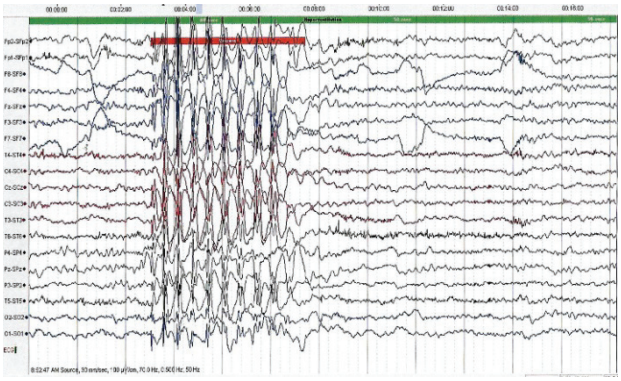


FIGURE 1. EEG signal.

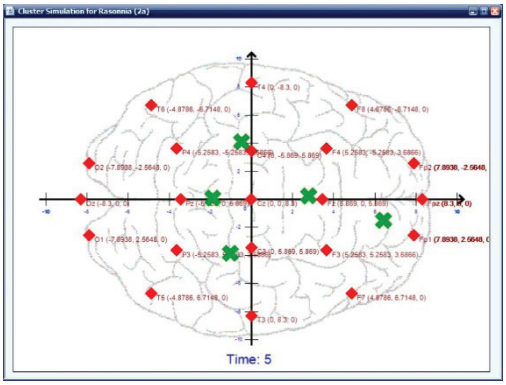


FIGURE 2. Example of *fEEG*.

Fuzzy C-Means (FCM)

Fuzzy C-Means (FCM) is a method to group data points that populate some multidimensional spaces into a specific number of cluster. At first, it was named by Dunn's algorithm then it has been enhanced by Bezdek [8]. This process of fuzzy clustering was applied to cluster the electrical potential into several clusters due to its effectiveness as claimed by Wan Eny Zarina [9].

Generally, FCM algorithm can be divided into four main steps where the first step is to generate an initial random membership matrix and use it as the weight of each sample that belongs to each cluster. Then, the centroids (centers) of each cluster are computed. Thus, the new cluster centers are used to update the membership matrix then the updated membership matrix is compared to the previous one. Finally, if the difference is greater than some threshold, then another iteration is computed. Otherwise, the algorithm is stopped.

Other Definitions

Some other definition used in this study will be described in this subsection to clearly brief reader into the methodology used later.

First, cluster center is attained from the application of FCM to the EEG data. Then, cluster centers will be plotted to *fEEG* to mark as the centroid of the cluster of electrical potential. Hence, the definition of cluster center on *fEEG* are as follows;

Definition 1: Cluster center [10]**:** Let $\mathbb{C}_t$ and $\mathbb{C}_{t+1}$ be the set of cluster centers at time t, i.e.: $\mathbb{C}_t = \{m_1, m_2, m_3, \ldots, m_p\}$ and set of cluster centers at time $t+1$, i.e.: $\mathbb{C}_{t+1} = \{n_1, n_2, n_3, \ldots, n_p\}$, respectively: where p is the number of cluster center. For every cluster center carries the position and electrical potential of *fEEG* as follows;

$$m_{j(t)} = \left((x_{j(t)}, y_{j(t)}), e_{j(t)}\right) \text{ and,}$$

$$n_{j(t+1)} = \left((x_{j(t+1)}, y_{j(t+1)}), e_{j(t+1)}\right)$$

where e_j and e_k is the electrical potential of the cluster center j^{th} at time t and k^{th} at time $t+1$ respectively.

In mathematics, Euclidean distance or known as Euclidean metric is the straight-line distance between two objects in a Euclidean space.

Definition 2: Euclidean distance [11]**:** The length or distance of the line segment connecting from one object to another object. In Euclidean plane, if $m = (x_p, y_p)$ and $n = (x_q, y_q)$, then the distance is measured by;

$$d(m,n) = \sqrt{(x_p - x_q)^2 + (y_p - y_q)^2} \quad (1)$$

where it is equivalent to the Pythagorean theorem.

Next is location attribute. It can be defined as placeholders assigned directly to a location and contain numerical information of it. In other words, it is the property or characteristic of a location. In this study, location attribute is the numerical value of electrical potential of the cluster centers.

Related Works

Goh [10] conducted a research on the spatial analysis of EEG signals during epileptic seizure. The research mainly focused on the interaction between cluster centers on a single frame of *fEEG*. The results of the research show that the interaction between cluster centers are not directly proportionally related to its electrical potential, size of the cluster, or the cluster centers' location.

Abdy & Ahmad [12] have segmented the electrical potential of EEG signals where they implemented it by focusing on the size of the cluster on a single frame of *fEEG*. By using FCM, they clustered electrical potential into regions where classify it by certain color. they concluded the same color on the segmentation at a certain time show the locations of the source of electrical potential which has nearly equal electrical potential strength.

In conclusion, a lot of researches have been studied based on *fEEG* as in [13-16], however their research focus on a single frame of *fEEG*. Hence, a tracking equation of cluster centers across time-frame of *fEEG* is developed in this study. A comprehensive analysis of this study can provide new insights into the epileptic seizure and may have considerable utilization in the diagnosis and treatment of the seizure. Next section will describe the methodology used in this study.

METHODOLOGY

The tracking equation to determine the cluster centers' origin and its destination will consist of the distance and the electrical potential of cluster centers at time *t* and cluster centers at time *t+1* of *fEEG,* hence it followed basic assumption concerning interaction model as claimed by Hua & Porell [17].

First, FCM will be applied to EEG data which consists of EEG's channels with its averaged electrical potential to attain cluster centers of *fEEG* per seconds [7]. Then, two consecutive times of *fEEG* marks as at time *t* and *t+1* will be used. This *fEEG*s will consist of cluster centers and EEG's channels which are in the Cartesian plane.

Then, a tracking equation will be applied to the data. Thus, cluster centers can be identified its origin on *fEEG* at time *t* and its destination on *fEEG* at time *t+1.* The construction of tracking equation defined as in next subsection.

Tracking Equation Construction

Definition 3: Distance: A distance of cluster center across time-frame of *fEEG*, i.e. a cluster center at time *t* of *fEEG* and a cluster center at time *t+1* of *fEEG*. Thus, the distance between every pair of cluster center across time-frame of *fEEG* is defined as follows;

$$D = \left\{ d(m_j, n_k) \ni m_j \in \mathbb{C}_t, n_k \ni \mathbb{C}_{t+1} \right\}.$$

Next, the difference of electrical potential across time-frame of *fEEG* will be regarded as positive [10] due to the positive and negative value is meant to supply a sense of direction to the flow of current in the brain. It can be defined as follows;

Definition 4: Difference in electrical potential: A measure of the difference of electrical potential between cluster center at time *t* and *t+1* of *fEEG* as follows;

$$e(m_j, n_k) = \left| e_j - e_k \right| \quad (2)$$

where m_j is a cluster center at time *t* of *fEEG* and n_k is a cluster center at time *t+1* of *fEEG*. Thus, the difference for a set of cluster centers across time-frame of *fEEG* can be defined as follows;

$$E = \{e(m_j, n_k) \ni m_j \in c_t, n_k \in c_{t+1}\}.$$

Since the distance between cluster center at time t and $t+1$, and the difference of electrical potential of cluster center at time t and $t+1$ has been defined, thus the equation of tracking cluster center across time-frame of *fEEG* is defined as follows;

Definition 5: Tracking function: A measure to track each of cluster centers in a set of cluster center across time-frame of *fEEG*. This can illustrate by taking both equation (1) and (2) as follows;

$$f(d,e) = \min\left\{\sum_{i=1}^{|D|} d(m_n, n_k) + \sum_{i=1}^{|E|} e(m_j, n_k)\right\} \quad (3)$$

where the minimized value from combinations of pairs of cluster centers is selected. The minimized value is used to find the lowest local range of the distance and electrical potential to track a cluster center on across time-frame *fEEG*. Thus, this minimized value represents for the close related from cluster center of *fEEG* at time t and cluster centers at time $t+1$.

Definition 6: Combination of pairs: A number of combination depends on the number of cluster centers set up in FCM algorithm. This can be defined as follows;
$CP=n!$ where CP is the number of combination of the pairs and n is the number of cluster centers of *fEEG*. For example, for two cluster centers are as follows;

$$\mathbb{C}_t = \{m_1, m_2\} \text{ and } \mathbb{C}_{t+1} = \{n_1, n_2\}.$$

Thus, the combinations of the pairs are;

$$\mathbb{C}_t \text{ X } \mathbb{C}_{t+1} = \{(m_1n_1, m_2n_2), (m_1n_2, m_2n_1)\} = CP=2!.$$

DISCUSSION

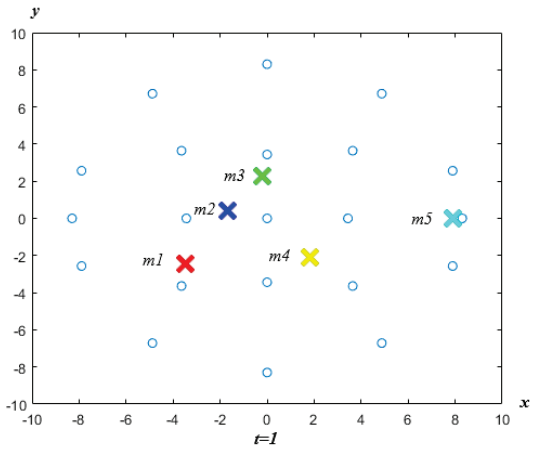
Implementation

Firstly, FCM algorithm will be applied to the data of EEG signals to attain the cluster centers. Since [7] has claimed that by using compactness and separation of cluster validity, the optimal number of cluster centers of *fEEG* is five. Thus, two sample of consecutive time-frame of *fEEG* (t = 1 and t = 2) will be used in this section such as the data in Table 1. Note that the circle represents EEG's channels placed on top of the patient's head while the X mark is the cluster center of electrical activity. Each of cluster center on *fEEG* at t = 1 will be labeled randomly then fixed as *m1, m2, m3, m4,* and *m5* while each of cluster center at t = 2 labeled randomly and fixed as *n1, n2, n3, n4*, and *n5*.

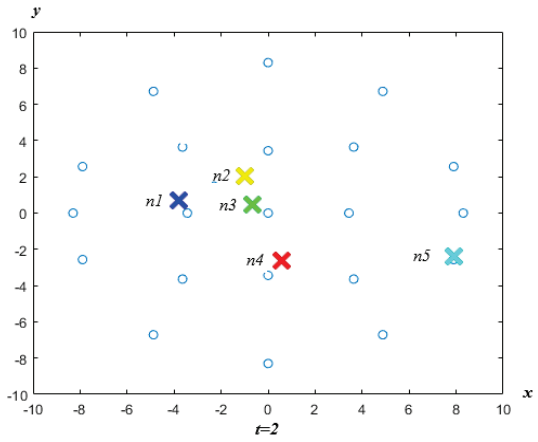
Table 1. Cluster centers with its electrical potential for t = 1 and t = 2.

Cluster Center at t=1	Coordinate of x	Coordinate of y	Electrical potential
m1	-3.4828	-2.4526	81.8207
m2	-1.6696	0.3803	159.3855
m3	-0.2184	2.2487	37.1059
m4	1.8083	-2.0837	4.3312
m5	7.8929	-0.0229	409.3101
Cluster Center at t=2	Coordinate of x	Coordinate of y	Electrical potential
n1	-3.8203	0.7069	148.1264
n2	-0.9888	2.0458	8.3006
n3	-0.6906	0.4507	44.4980
n4	0.5784	-2.6165	86.5397
n5	7.8923	-2.3993	311.8178

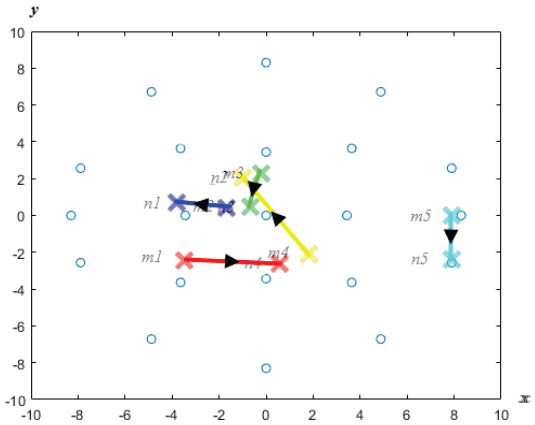
From there, the tracking function was applied to data as in Table 1 to identify the origin and destination of cluster center across two time-frame of *fEEG*. Note that the combination of pairs of cluster centers 120 different pairs, computed by using equation $CP=n!$. The results are as colored Figure 3 ((a) and (b)) as follows where the same color represent for its origin on *fEEG* at t = 1 and its destination on *fEEG* at t = 2.



(a) *fEEG* at $t = 1$.



(b) *fEEG* at $t = 2$.



(c) Combined *fEEG at t = 1 and t = 2.*

FIGURE 3.

From Figure 3 (c), the arrow represents the movement from its origin to its destination. The value of tracking function for this sample is 140.295 which is the minimized of lowest value from every combination of pairs calculated. As in Figure 3 (c), it shows that the pairs of cluster centers origin and its destination are {(m_1n_4), (m_2n_1), (m_3n_3), (m_4n_2), (m_5n_5)}. The highest distance movement from cluster center's origin to its destination is the pair of (m_4n_2) with 4.98764 and the lowest distance is the pair of (m_3n_3) with 1.85898. However, the highest electrical potential difference is the pair of (m_5n_5) while the lowest electrical potential difference is the pair of (m_4n_2) with 97.4925 and 3.96948 respectively. This result follows the claim that made by [10] where it does not directly proportional to the cluster centers' attributes, location or size. Full results are as shown as in Table 2.

Table 2. Cluster Centers Tracking Results

Pairs of Cluster Centers	Distance	Electrical Potential
m_1n_4	4.065453	4.71895
m_2n_1	2.17544	11.2593
m_3n_3	1.85898	7.39216
m_4n_2	4.98764	3.96948
m_5n_5	2.37633	97.4924

CONCLUSION

In this paper, a function to track cluster centers across time-frame of *fEEG* has been developed where to track its movement across time-frame of *fEEG* thus further analysis on the pattern of the movement can be studied. A sample

of *fEEG* at *t=1* and *t=2* were used. The application of graph theory can be developed later on to visualize the movement of a cluster center from time to time during epilepsy. Thus, this could probably assist in understanding the behavior of epilepsy, and could potentially assist in predicting the seizure onset.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to the faculty of Malaysia-Japan International Institute of Technology (MJIIT) for the student incentive and Universiti Teknologi Malaysia for supporting this research through GUP Tier 1 Research Grant Vot No. 15H42. The researchers would also like to acknowledge Dr. Wong Wai Kit from Hospital Selayang for the consultations given.

REFERENCES

1. Chang, B. S., & Lowenstein, D. H., Epilepsy, *The New England Journal of Medicine*. Vol: 349(13): 1257-66, 2003.
2. Fisher, R., S., Acevedo, C., Arzimanoglou, A., Bogacz, A., Cross, J. H., Elger, C. E., Engel, J. Jr., Forsgren, L., French, J. A., Glynn, M., Hesdorffer, D. C., Lee, B. I., Mathern, G. W., Mosche, S. L., Perucca, E., Scheffer, I. E., Tomson, T., Watanabe, M., & Wiebe, S., "ILAE Official Report: A practical clinical definition of epilepsy, *Epilepsia*, Vol: 55(4): 475-82, 2014.
3. Fisher, R., van Emde Boas, W., Blume, W., Elger, C., Genton, P., & Engel, J., Epileptic Seizure and Epilepsy: Definitions Proposed by the International League Against Epilepsy (ILAE) and the International Bureau for Epilepsy (IBE), *Epilepsia*, 46(4): 470-2, 2005.
4. Megiddo, I., Colson, A., Chisholm, D., Duaa, T., Nandi, A., & Laxminarayan, R., Health and Economy Benefits of Public Financing of Epilepsy Treatment in India: An Agent-based simulation model, *Epilepsia*, Official Journal of the International League Against Epilepsy, 2016.
5. Niedermeyer, E., & da Silva F. L., Electroencephalography: Basic Principles, Clinical Application, and Related Fields., Lippincott Williams & Wilkins, 2004.
6. Sanei, S., & Chambers, J. A., *EEG Signal Processing*: Johan Wiley & Sons Ltd, England, 2007.
7. Fauziah Zakaria, Dynamic profiling of Electroencephalography Data During Seizure Using Fuzzy Information Space, Universiti Teknologi Malaysia: Ph.D. Thesis, 2008.
8. Bezdek, J. C., *Fuzzy Mathematics in Pattern Classification*. Center for Applied Mathematics, Cornell University, Ph.D. Thesis, 1973.
9. Wan Eny Zarina Wan Abdul Rahman, *Determination of Multiple Sources of Currents using FTTM*, Universiti Teknologi Mara. Ph.D. Thesis, 2006.
10. Goh C. Y., Spatial Analysis of Signal During Epileptic Seizure on Flat Electroencephalography, Universiti Teknologi Malaysia, Ph.D. Thesis, 2017.
11. Deza, E., & Deza, M. M., Encyclopedia of Distances. Springer, p. 94, 2009.
12. Abdy, M., & Ahmad, T., Segmentation of Electroencephalogram Signals During Epileptic Seizure by Using Fuzzy C-Means, *American Journal of Applied Sciences*, Vol: 11(10): 1830-1835, 2014.
13. Abdy, M., & Ahmad, T., Transformation of EEG Signal into Image Form During Epileptic Seizure, *International Journal of Basic & Applied Sciences*, Vol: 11, 2011.
14. Ali Barja, A. O., Ahmad, T., & Binjadhan, F. A. M., Group Complexity for Semigroup of Electroencephalography Signals during Epileptic Seizure, *Research Journal of Applied Sciences, Engineering, and Technology*, Vol: 11(2), pp. 150-157, 2015.
15. Binjadhan, F. A. M., & Ahmad, T., EEG Signals During Epileptic Seizure as a Semigroup of Upper Triangular Matrices, *American Journal of Applied Sciences*, Vol: 7(4), pp. 540-544, 2010.
16. Tan, L. K., Ahmad, T., Mohd, M. S., Su, K. N., Suwa, T., & Ong, S. M., Topological Properties of Flat Electroencephalography's State Space, *Progress in Applied Mathematics in Science and Engineering Proceedings*, 2016.
17. Hua, C., & Porell, F., A Critical Review of the Development of the Gravity Model. *International Regional Science Review*. 4(2), pp., 97-126, 1979.