International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2019): 7.583

Complexity Analysis of Brain under Mobile Phone Radiation using Lyapunov Exponent

C. K. Smitha[1], N. K. Narayanan[2]

[1]Department of Electronics and Instrumentation Engineering, College of Engineering, Vadakara, Kerala, India
smithack[at]cev.ac.in

[2]Indian Institute of Information Technology, Kottayam, Kerala, India
nknarayanan[at]gmail.com

Abstract: ***In this paper, Lyapunov Exponent - a nonliearity measure of EEG is used to analyze the change in complexity of brain while using mobile phone. Avg Lyapunov Exponent (Avg.LE) of the data set prepared with EEG record of 54 subjects with and without phone is analyzed using non parametric Kruskal Wallis test. The test is not significant for any of the electrodes. The symmetry of brain using asymmetry index is analysed for further verification and found within allowable range. It is concluded that there is no significant change in complexity of brain while using mobile phone***

Keywords: EEG, Mobile phone Radiation, Average Lyapunov Exponent, Asymetry index Kruskal Wallis test

1. Introduction

As the usage of mobile phone increases, the concern about the effect of radiation on human brain increases. A number of studies [1-7] shows some adverse effects and some others [8-13] ascertain that there is no clear evidence to link the relationship between the changes in test body and mobile phone usage.

According to basics of biology, for any changes in cellular level, mutation of cell is to be taken place and mutation can be initiated by ionizing radiation. According to basics of radiation physics, the frequency of ionizing radiation is greater than the frequency of visible light (>8x10^{14} Hz). The frequency range of electromagnetic field (RF-EMF) generated by mobile phones are very much less than that of visible light, they are not able to produce any effect on human tissue. The changes in brain will be reflected in EEG, hence we choose EEG signal for the analysis. The bio-physical process in the brain which generates EEG have high degree of complexity and nonlinear measures will be more suitable for analysis. Being chaotic in nature,the attractor dimension is suitable forthe evaluation of changes in EEG. We tried to investigate the changes in brain due to mobile phone radiation by using Lyapunov Exponent a nonlinear measure.

From the review of literature, it is learned that Lyapunov Exponent is not used for the analysis of the effects of mobile phone radiation. In the previous work by the same authors, signal complexity of EEG with radiation from mobile phone was analyzed using various nonlinear measures namely fractal methods [14-19], entropy [20-22] and largest Lyapunov exponent LLE [34]. The results showed that, there were some changes in single electrodes but the effect is not prominent while analyzing the signals in 21 electrodes. So, in this paper we attempted to study the effect of mobile phone radiation on brain by analyzing Average Lyapunov Exponent (Avg.LE) of 21 electrodes of the EEG data set.

The paper is outlined as follows: The methods of feature extraction and analysis included in section 2. Results obtained and the discussions of the result are detailed in section 3 and conclusion in section 4.

2. Methods

The electroencephalogram (EEG) makes scalp recording of electrical activity. EEGs were recorded with 21 scalp electrodes placed as per conventional 10–20 system of electrodes.

2.1 Data Acquisition

54 healthy individuals of different age groups (39.8$\pm$11.8) were participated in the study. EEGs were recorded from EEG Lab under Neurology Department of Malabar Institute of Medical Sciences Hospital, Calicut using Galelio N.T machine. EEG of the volunteers is recorded at rest and by keeping mobile phones near to right ear for five minutes each with two types of mobile phone one GSM with SAR 1.3W/Kg and the second one a CDMA phone with SAR 0.987W/Kg..During the procedure the volunteers were instructed to lie down and relax, EEGs were taken initially at rest and the phone is switched on (in talking mode) and kept near the right ear and were unaware of the instant of switching of mobile phone.

2.2 Preprocessing

Unwanted signals or artifacts are removed by visual inspection and filtering. A notch filter is used to remove 50 Hz line frequency Wavelet algorithm using threshold filtering [23] is used to de-noise the signal.The SNR obtained using this method is 12 to 17 dB.

2.3 Feature Extraction

Lyapunov exponent is one of the best attractor dimensions in case of a chaotic signal. The Lyapunov exponent [32-37] measures the rates at which nearby trajectories in phase space converge or diverge. Quantitatively, the separation of two trajectories in phase space with initial distance ΔZ_0 can be represented as

$$|\Delta Z(t)| \approx e^{\lambda t}|Z_0| \qquad (1)$$

where λ is the Lyapunov exponent.

2.3.1 Estimation of Lyapunov Exponents from the Time Series

Wolf [33] proposed the method for calculation of Lyapunov exponent from a time series. A finite embedding sequence is constructed from the finite time series of $2N + 1$ components as

$$x(0), x(\tau), x(2\tau), x(3\tau), \dots \dots \qquad (2)$$

This is called the reference trajectory upon which the model builds. If the starting point is not given, a point $x(k_0\tau)$ may be chosen from this sequence that approximates the desired initial point $z_0(0)$ such that

$$|x(k_0\tau) - x(0)| < \delta \qquad (3)$$

where δ is an *a priori* chosen tolerance. This point may be renamed as

$$z_0(0) = x(k_0\tau) \qquad (4)$$

Then the successors of this point are known as

$$z_0(r\tau) = x((k_0 + r)\tau), r = 1, 2, 3, \dots \dots .. \qquad (5)$$

Now there are two trajectories to compare. The logarithmic error amplification factor for the first time interval becomes

$$l_0 = \frac{1}{\tau}\log\frac{|z_0(\tau) - z_0(0)|}{|x(\tau) - x(0)|} \qquad (6)$$

This procedure is repeated for the next point $\mathbf{x(\tau)}$of the reference trajectory. For that point another point $\mathbf{z_1(\tau)}$ is to be formed from the trajectory. If the previous trajectory is morecloser to the reference trajectory, continue with it by setting $\mathbf{z_1(\tau)} = \mathbf{z_0(\tau)}$. This yields an error amplification factor '$\mathbf{l_1}$'. Other factors, $\mathbf{l_2}, \dots \dots .. \mathbf{l_{m-1}}$ can be found by repeating the same procedure for the complete segment of the time series. Fig.1 [33] shows the pictorial representation of the process.

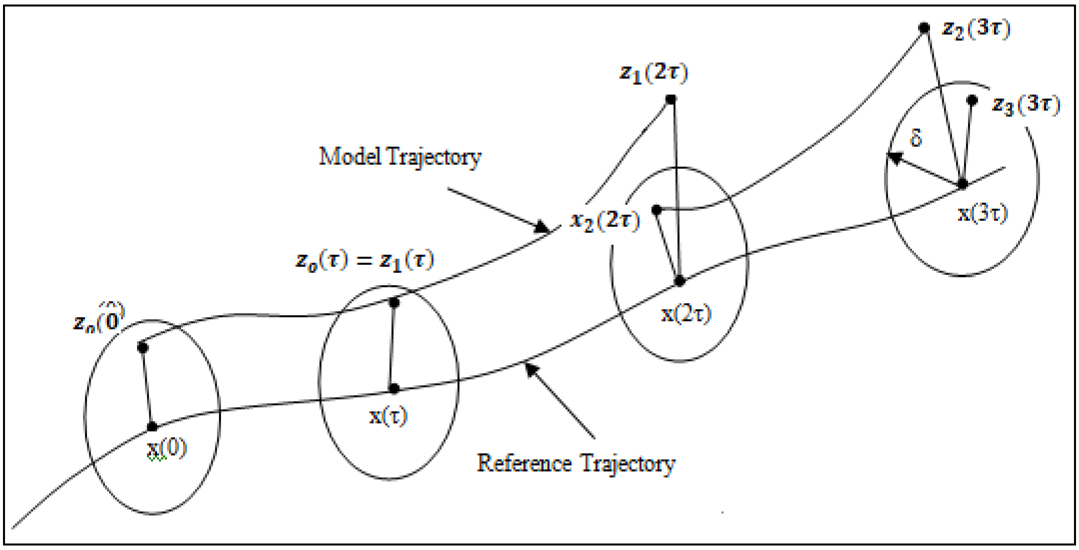

Figure 1: The reference and the model trajectories, evolution of the error, and start and end of the model trajectory segments

Average or maximum of the logarithmic error amplification factors over the whole reference trajectory will give the approximation to the largest Lyapunov exponent, λ can be represented as

$$\boldsymbol{\lambda} = \frac{\mathbf{1}}{\mathbf{m}}\sum_{\mathbf{j=0}}^{\mathbf{m-1}} \mathbf{l_j} \qquad (7)$$

In this study, the average value of the error amplification factor is taken as feature. Positive Lyapunov exponent means that the trajectories are diverging and the system is chaotic.

2.4 Methods for analysis of Feature

The features for all the electrodes with size of 54x21x5 (5670) were calculated using MATLAB software and statistical analysis is done using Kruskal Wallis in SPSS software. To get shift invariant feature, segment length, embedded dimension and delay are estimated. The analysis of feature is done as follows:

2.4.1 The percentage increases of features at different conditions with respect to the feature without mobile phone radiation are tabulated and analyzed.

2.4.2 The statistical analysis of the feature set is done using Kruskal Wallis test. Kruskal Wallis Test is a nonlinear hypothesis test. A hypothesis test [30, 31] is a method of making decisions using data from a scientific study. Kruskal Wall is a non parametric test compares samples from two groups based on the median. The test statistic (p value) is calculated and if the p-value is less than the required significance, then the null hypothesis is rejected at the given level of significance.

2.4.3 Asymmetry index of pair of electrodes is assessed using coefficient of variance (CV). Left- right symmetry of brain is analysed using Asymetry index**.**

Left right symmetry is one of the basic parameters used to check the normality of the EEG signals. EEG technicians analysed the status of brain by visual inspection. The EEG waves are classified as abnormal, if the difference of signal in pairs of electrodes is greater than 50%. Coefficient of variance (C V), the ratio of mean to standard deviation [32] of the feature parameter is taken as the asymmetry index. Left and right channels were separated and compared in pairs in terms of asymmetry index.

3. Results and Discussions

3.1 Verification of SAR

We verified the SAR of the mobile phone specified by manufacturers by using FDTD (Finite Difference Time Domain) method of simulationThe value of SAR obtained is less than the prescribed value by the manufacturers of the phone. The prescribed value for GSM phone (Phone-1) is 1.3W/Kg and for CDMA phone is 0.987W/Kg. The maximum value of SAR obtained by method of FDTD simulation is 1.12W/Kg for GSM phone and 0.84W/Kg for CDMA phone.

3.2 Average Lyapunov Exponent

The average Lyapunov exponent of 30 samples having segment length of 1152 points is extracted for the analysis from each electrodes in the the EEG data set. Fig 2 shows the feature values extracted for 30 samples of EEG signal in an electrode for all conditions.

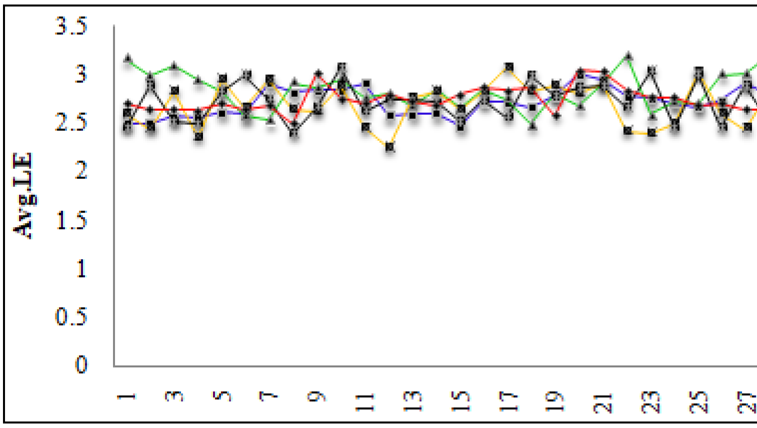

Figure 2: Plot of Avg. Lyapunov exponent for a sample data set, data-1, data-2, data-3, data-4 and data-5 denote EEG without mobile phone radiation, EEG with Phone-1 at ears, EEG with phone -1 at Cz, EEG with Phone-2 at ears and EEG with phone -2 at Cz

The featureset of Avg. Lyapunov exponent(Avg.LE) is prepared with the extracted features of the EEG data set. The Fig 3 shows the plot of average values of features in all electrodes for all conditions.

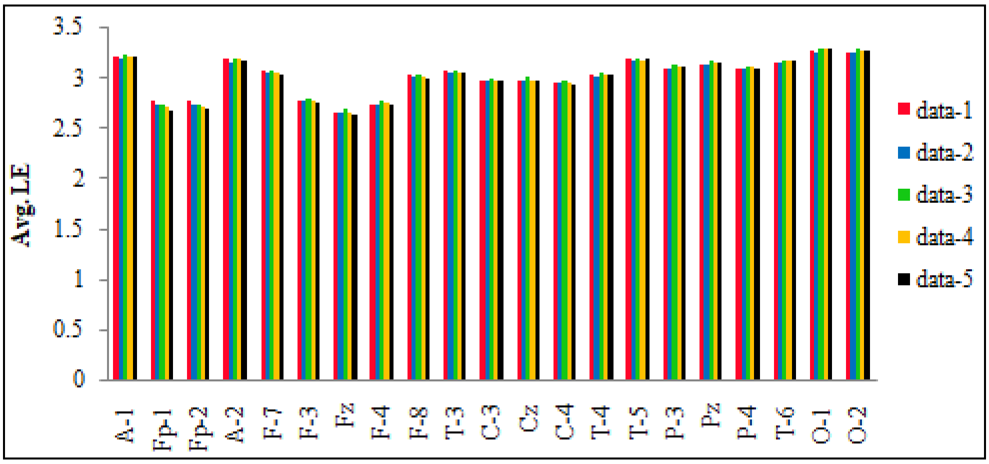

Figure 3: Plot of average value of Avg. Lyapunov exponent in all electrodes for all conditions

The variations of feature (Avg. LE) in electrodes for different conditions are very less, and do not have a peculiar repetitive behavior. The magnitude of Avg. Lyapunov exponent is almost same for all regions. The magnitude is less in frontal, fronto polar areas except at F-7. The magnitude is high for A-1 and A-2 which are closer to the ears and in O-1 and O-2.

Result analysis using Percentage change of feature.

3.2.1 Result analysis using percentage change

The percentage change in Avg LE of EEG withradiation with respect to Avg.LE of EEG at without radiation is tabulated in Table-1. The percentage increase in the features for all 21 channels for different conditions with respect to feature without mobile phone radiation is analyzed and found varying from -0.014 to +0.001 for phone-1 at ears, -0.013 to +0.017 phone-1 at Cz, -0.026 to +0.011 phone-2 at ears and -0.034 to +0.009 for conditions Ph-2 at Cz . The range of percentage increase is very less and can be neglected.

Table 1: The percentage change in Avg. LE of EEG with radiation with respect to Avg.LE of EEG without radiation for all conditions

Electrodes	data-2 – data-1	data-3 – data-1	data-4 – data-1	data-5 – data-1	Electrodes	data-2 – data-1	data-3 – data-1	data-4 – data-1	data-5 – data-1
A-1	0.001	-0.004	0.002	0.003	Cz	0.003	0.001	0.001	0.001
Fp-1	0.002	0.002	0.003	0.004	C-4	0.003	0	0.002	0.002
Fp-2	0.001	0.002	0.002	0.003	T-4	0.003	-0.001	0	0.002
A-2	0.001	-0.003	-0.001	0	T-5	-0.001	-0.005	-0.003	-0.003
F-7	0.004	0.003	0.004	0.006	P-3	0	-0.004	-0.001	-0.001
F-3	0.002	0.003	0.002	0.004	Pz	-0.001	-0.003	0	-0.002
Fz	0.005	0.004	0.005	0.003	P-4	0.001	-0.004	-0.002	-0.002
F-4	0.002	0.002	0.001	0.003	T-6	-0.003	-0.009	-0.007	-0.006
F-8	0.004	0.002	0.003	0.005	O-1	-0.002	-0.009	-0.006	-0.005
T-3	0.003	0	0.002	0.004	O-2	-0.003	-0.007	-0.006	-0.006
C-3	0.003	0.004	0.002	0.003					

3.2.2 Result analysis using Statistical Analysis

Non parametric Kruskal Wallis test is used for the statistical analysis. The decision is taken on the basis of p-value obtained in the Kruskal Wallis test. The test is not significant for any of the electrodes. For further verification of this result, the changes in symmetry of brain in pair of electrodes were analyzed using an asymmetry index.

3.2.3 Result analysis using Asymmetry Index

To study the impact of this difference, the variation of feature in pair of electrodes is assessed using asymmetry index to check the variation in symmetry of two hemispheres. We grouped the channels in left (odd numbered) and right (Even numbered) hemisphere separately and analysed. Fp1 - Fp2, F3 - F4, F7 - F8, C3 - C4, T3 - T4, T5 - T6, P3 - P4 and O1 - O2 are the pairs in channels. Asymmetry index of pair of these significant electrodes (Fp1- Fp2, F7- F8, F3-F4, C3-C4, P3-P4 T5-T6 and O1-O2) are analysed.The percentage change in asymmetry index in the significant electrodes (Fp1- Fp2, F7-F8, F3-F4, C3-C4, P3-P4, T5-T6 and O1-O2) is tabulated in Table-2

Table 2: The percentage change in asymmetry index with respect to left side

Conditions	A-1/ A-2	Fp-1/ Fp-2	F-7/ F-8	F-3/ F-4	T-3/ T-4	C-3/ C-4	T-5/ T-6	P-3/ P-4	O-1/ O-2
At rest	-0.119	-0.058	-0.074	0.053	-0.016	0.049	0.026	-0.027	0.006
Ph-1 at ears	0.043	-0.032	-0.066	0.048	-0.015	0.102	0.009	0	0.011
Ph-2 at ears	-0.027	-0.003	-0.111	-0.011	0.007	0.058	0.032	0.036	0.015
Ph-1at ears	0.001	-0.078	-0.036	0.104	-0.02	0.102	0.045	0.046	0.023
Ph-2 at ears	-0.005	-0.086	-0.035	0.113	0.045	0.1	0.062	0.003	0.037

Table 2 shows the percentage change in the asymmetry index in pair of electrodes. The magnitude obtained from different pairs varies from-0.005 to 0.043, -0.086 to -0.003, -0.111 to -0.035, - 0.011 to +0.113, -0.02 to +0.007, 0.049 to +0.102, 0.009 to +0.062, -0.027 to -0.046 and 0.006 to +0.037 for the pair of electrodes A-1/A-2, Fp-1/Fp-2, F-7/F-8, F-3/F-4, T-3/T-4, C-3/C-4, T-5/T-6, P-3/P-4, O-1/O-2. These values also come under the specified limit (<1.5). This can be interpreted as radiation from mobile phone cannot alter the functioning of the brain.

4. Conclusions

Whenever the magnitude of Liapunov exponent is larger, behaviour of the nonlinear system become more complicated. On the interpreting the increase in AvgLE based in the context of complexity of EEG, it indicates the increase in the neural excitability and the increased disturbance in inhibitory system. According to paper [34], the test static is significant for 8 electrodes on using data for 35 subjects, As the number of subjects are increased the hypothesis test become non-significant for any of the electrodes, this study is done using data from 54 subjects.

Here the test statistic for hypothesis test) is not significant for any of the electrodes and the value of asymmetry index is within the specified limit (<1.5). So it is clear that phone radiations are not able to change the complexity and symmetry of the brain. The measured value of potential in an electrode is the sum of the potential of a group of neurons comes under that particular electrode. The change in feature parameter shows the variations in EEG signal whereas using the mobile phone, which demonstrates transformation in the activities of the brain due to radiation. The change in EEG signals is due to activation or in activation of group of neurons comes under each electrode. Since this value is within the limit, it can be concluded as there is no activation of neurons took place due to radiation from mobile phones.So it is concluded that the radiation from the two phones which is used for the study is not able to produce significant changes in nonlinear features of the brain

5. Acknowledgements

The data set was prepared from MIMS hospital, Calicut solely for this research purpose, without any financial assistance. We thank Director, Management of the Hospital for the consent to use Lab facility and also thank Dr. Ashraf and staff members of Neurology department of Hospital, for helping with their EEG expertise.

References

[1] Hardell L, Hallquist A, Mild H, et al, Cellular and cordless telephones and the risk for brain tumors, 2002, Fur J Cancer Prev 11:377–386

[2] Min Kyung Chu ,HoonGeun Song, Chulho Kim and Byung Chul Lee,, " Clinical features of headache associated with mobile phone use: a cross-sectional study in university students", BMC Neurology 2011

[3] Ashok Agarwal, FnuDeepinder, Rakesh K.Sharma, Geetha Ranga, and Jianbo Li, "Effect of cell phone usage on semen analysis in men attending infertility clinic: an observational study", American Society for Reproductive Medicine, Published by Elsevier Inc. 124-128,2008

[4] James C Lin, "Cellular Telephone Radiation and EEG of Human Brain',IEEE Antennas and Propagation Magazine. Vol 45, No -5 October 2003.

[5] H. D'Costa, G.Trueman, L.Tang, U.Abdel-rahman, U.Abdel-rahman, K Ong and I Cosic" Human brain wave activity during exposure to radiofrequency field emissions from mobile phones", Australasian Physical & Engineering Sciences in Medicine Volume 26 Number 4, 2003

[6] Eleni Nanou, Vassilis Tsiafakis, E. Kapareliotis, "Influence of the Interaction of a 900 MHz Signal with Gender On EEG Energy: Experimental Study on the Influence of 90MHz Radiation on EEG", The Environmentalist, 25, 173–179, 2005.

[7] Hie Hinkirikus, Maie Bachmann, Ruth Tomson and JaanusLass,"Non-Thermal Effect of Microwave Radiation on Human Brain", The Environmentalist, 25, 187–194, 2005

[8] IARC//WHO (2011) Classifies radiofrequency electromagnetic fields as possibly carcinogenic to humans. Press release.

[9] Ghosn, Rania, ThuroczyGyörgy, Loos Nathalie , Brenet-Dufour Valérie , Liabeuf Sophie, de Seze Rene," Effects of GSM 900 MHz on Middle Cerebral Artery Blood Flow Assessed by Transcranial Doppler Sonography", Radiation Research, vol.178, no.6, p.543-50,2013

[10] N. Perentos, R J Croft, RJ Mc Kenzie, I Cosic, "Comparison of the effect of continuous and pulsed mobile phone like RF exposure on human EEG", Australian Physical and Engineering Science in Medicine , vol 30 No 4, pp 274-280,2008

[11] Michael H.Repacholi, Alexander Lerchl, Martin Rosli, Zenon Sienkiewicz, "Systematic Review of Wireless Phone Use and Brain Cancer and Other Head Tumors", Bioelectromagnetics ,187-207, 2011, DOI 10.1002/bem.20716

[12] Myoung-Soo Kwon, Jaaskelaine Satu K, Toivo, Tim Hamlainen, Heikki, "No effects of mobile phone electromagnetic field on auditory brainstem response", Bioelectromagnetics, vol.31, no.1, p.48-55 2010

[13] Hirose Hidek Sasaki, Atsush Ishii Nana, SekijimaMasaru, Iyam Takahiro, Nojima Toshio, Ugawa, Yoshikazu,"1950 MHz IMT-2000 field does not activate microglial cells in vitro", Bioelectromagnetics, vol.31, no.2, p.104-12, 2010.

[14] C. K. Smithaand N. K. Narayanan" Effect of mobile phone radiation on brain using EEG analysis by Higuichi's fractal dimension method ",Proc. SPIE 8760, International Conference on Communication and Electronics System Design, 87601C (January 28, 2013); doi 10.1117/12.2012177

[15] C. K. Smitha and N.K.Narayanan, "Study of Brain Dynamics under Mobile Phone Radiation Using Various Fractal Dimension Methods", Proce. of International Conference on Signal processing, image processing and pattern recognition (February 7 2013). doi10.1109/ICSIPR.2013.6497942, p 288-292

[16] C. K. Smitha and N.K.Narayanan," Effect of Mobile Phone Radiation on EEG Using Various Fractal Dimension Methods" in International Journal of Advancements in Research & Technology, Volume 2, Issue5, May-2013 IJOART (ISSN 2278-7763)

[17] C. K. Smitha and N.K.Narayanan "Effect of Mobile Phone Radiation on EEG Third International Conference on Advances in Computing and Communications (ACC-2013) (29-31 August 2013) DOI 10.1109/ICACC.2013.28

[18] C.K. Smitha and N. K. Narayanan "Brain Dynamics under Mobile Phone Radiation Using Various Fractal Dimension Methods" in International Journal of Imaging and Robotics, Volume 13, Issue Number 2, p 166-180,2014

[19] C. K. Smitha and N.K. Narayanan," *Analysis of Fractal Dimension of EEG Signals under Mobile Phone Radiation*", IEEE international Conference on Signal Processing, Informatics, Communication and Energy Systems (IEEE SPICES) 2015 , pp 1-5, DOI : 10.1109/SPICES.2015.7091494.IEEE

[20] C. K. Smitha, N. K. Narayanan," Interaction of Mobile Phone radiation with Brain", presented at the proce. of 14th Biennial International Symposium on Antenna and Propagation APSYM 2014,CUSAT, Cochin, Vol -1pp 57-60, ISBN 978-93-80098-60-8

[21] C. K. Smitha and N.K. Narayanan," *Analysis of the Effects of Mobile Phone Radiation on Brain using Approximate entropy*", presented at the proce. of Joint International Conferences on ITC 2015. Published by McGraw-Hill Education , pp 208-215

[22] C. K. Smitha and N.K. Narayanan, "Entropy Analysis to Study the Effects of Mobile Phone Radiation on Brain", Proce. of the International Conference on Information and Communication Technology Research (IEEE ICTRC) 2015, pp

[23] Abdullah Al Jumah "Denoising of an Image Using Discrete Stationary Wavelet Transform and Various Thresholding Techniques" Journal of Signal and Information Processing, 2013, 4, 33-41 doi:10.4236/jsip.2013.41004.

[24] SaeidSanei and J.A. Chambers, "EEG Signal Processing", John Wiley and Sons 2007

[25] AlanWolf, Jack B swif, Harry L. swinney and John A Vastano, " Determining Lyapunov exponent from time series, Physica D 65 (1985) 285-317 North-Holland

[26] Michael T. Rosenstein', James J. Collins and Carlo J. De Luca, "A practical method for calculating largest Lyapunov exponents from small data sets, Physica D 65 (1993) 117-134, North-HollandSDI: 0167-2789(92)00033-6

[27] ElifDeryaÜbeyl, NanGuler, " Statistics over Lyapunov Exponents for Feature Extraction:

Electroencephalographic Changes Detection Case "World Academy of Science, Engineering and Technology 2 2007,pp 624-628

[28] Pengjian Shang a,*, Xuewei Li b, Santi Kamae, "Chaotic analysis of traffic time series",Chaos, Solitons and Fractals 25 (2005) 121–128

[29] Marc W Slutzky, Predrag Cvitanovic and David J Mogul "Deterministic Chaos and Noise in Three In Vitro Hippocampal Models of Epilepsy", Annals of Biomedical Engineering, Vol. 29, pp. 1–12,

[30] Irwin Miller and John E Freund, "Probability and Statistics for Engineers" 4th Edn, Prentice Hall, 1985

[31] A Stuart and MG Kendall, "Statistical Inference and Statistical Relationship The theory of Statistics vol-2', Hafers Press ,1986

[32] Kenneth Hugdahl, "Symmetry and asymmetry in the humanbrain", European Review, Vol.13, Supp.No. 2, 119133, UK, 2005

[33] SaeidSanei and J.A. Chambers, EEG Signal Processing, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England.

[34] C.K. Smitha, N.K. Narayanan, "Analysis of the complexity of Brain under Mobile Phone Radiation using Largest Lyapunov Exponent", Proce of the International Conference on Signal, Networks, Computing, and Systems ICSNCS-2016, JNU Delhi, Lecture notes in Electrical Engineering 396, Springer, pp. 147-154, ISBN : 978-81-322-3592-7, DOI . 10.1007/978-81-322-3589-7_15.