2021 IEEE International Conference on Biomedical Engineering, Computer and Information Technology for Health (BECITHCON)

ASD Detection using Higuchi's Fractal Dimension from EEG

Zahrul Jannat Peya
Dept. of Computer Science and Engineering
Khulna University of Engineering & Technology
Khulna, Bangladesh
Email: jannat.kuet@gmail.com

Md. Ferdous
Dept. of Computer Science and Engineering
Khulna University of Engineering & Technology
Khulna, Bangladesh
Email: md.ferdous.kuet@gmail.com

M. A. H. Akhand
Dept. of Computer Science and Engineering
Khulna University of Engineering & Technology
Khulna, Bangladesh
Email: akhand@cse.kuet.ac.bd

Mohammed Golam Zilani
James Cook University
Queensland, Australia
Email: mgzilani15@gmail.com

Nazmul Siddique
School of Computing, Engineering and Intelligent Systems
Ulster University
United Kingdom
Email: nh.siddique@ulster.ac.uk

2021 IEEE International Conference on Biomedical Engineering, Computer and Information Technology for Health (BECITHCON) | 978-1-6654-6621-9/21/$31.00 ©2021 IEEE | DOI: 10.1109/BECITHCON54710.2021.9893548

Abstract— **Autism or Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder marked by repetitive and characteristic patterns of behavior as well as social communication and interaction impairments. Nowadays ASD is a great concern worldwide and its detection is an important issue for the better treatment. As ASD is neurodevelopmental disorder, brain signals play, especially electroencephalography (EEG), is shown potential sources for ASD detection. There are different approaches for ASD detection with processing and/or transforming EEG signals. This study investigated ASD detection employing fractal dimension measure on EEG data. Higuchi's Fractal Dimension (HFD) is measured in resting-state eyes-closed EEG recording of 25 subjects. It is identified that HFD is sensitive to the brain activity and ASD detection is possible from HFD values.**

Keywords— Autism Spectrum Disorder, Electroencephalogram, Higuchi's Fractal Dimension.

I. Introduction

Autism or Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder marked by repetitive and characteristic patterns of behavior as well as social communication and interaction impairments. All people with ASD face difficulties including mental health issues, intellectual limitations, anxiety, and others [1] [2]. Many of these patients do not have access to the treatment they require. While there is no cure for autism, early intervention treatments can significantly save long-term healthcare costs associated with autism. For autistic people, timely detection decreases negative behavior, develops critical life skills, and improves overall performance.

Nowadays ASD is a great concern worldwide. The prevalence of ASD is approximately 1 in 54 children in the United States in the year 2021[2]. Boys are diagnosed with autism than girls (1 in 34 boys versus 1 in 144 girls). Approximately 20% of children with ASD suffer from severe symptoms of inattention, impulsiveness, and hyperactivity [3]. In South Asian countries ASD is predicted to affect one out of every 160 children [4]. Bangladesh's Bangabandhu Sheikh Mujib Medical University (BSMMU) recently revealed that about 2 out of 1000 children in Bangladesh had ASD. The prevalence of the disease is higher in urban regions than in rural areas. There is increasing evidence that these early interventions help to improve the situation of the child with ASD.

There are several ways for ASD detection, among them brain signal-based method is the most popular. Screening is the pioneer method for ASD diagnosis [5]. The method provides a questionnaire-based screening of patients and children that can only give a suggestion. Some methods use multidisciplinary teams, visual gaze, eye gaze, etc. But as ASD is a neurodevelopmental disorder, ASD detection through brain signals is most promising. Among several brain signals, EEG is being investigated as a possible clinical technique for monitoring brain functions as it has high temporal resolution and is more accessible than other brain signals [6]. EEG signals are complex and can vary widely between individuals at different times and while performing different tasks [7]. It is an objective measurement of brain activity that provides a global description of brain dynamics [8]. The EEG signal is being studied more and more as a possible clinical tool for diagnosing ASD.

There are several studies for ASD detection using EEG signals [9][10]. In [11] individual EEG channel data are transformed into two-dimensional image form using Pearson's Correlation Coefficient (PCC). Then the images were classified into two groups i.e., ASD and control subjects through the Convolutional Neural Network (CNN) of Deep Learning**.** EEG signal was used as an useful biomarker for ASD detection in [12] through nonlinear feature extraction. They used various learning models and feature vectors to use the minimum number of EEG channels. Using a Random Forest classifier, single and multi-channel EEG signals were analyzed for diagnosing epilepsy and ASD [13]. They extracted EEG signal features through Discrete Wavelet Transform (DWT) and classification was performed using Random Forest (RF).

Recently, EEG data transformation through the fractal dimension is applied to ASD detection. Fractals [14] are geometrically complicated mathematical sets that can be used to simulate a variety of natural occurrences. Among numerous natural processes, EEG signals are an effective class of fractals described by time-series measurements [8]. Higuchi's Fractal Dimension (HFD) is the well-studied method for the computation of FD of EEG signals [6, 15-16]. This method may be used with EEG data sets, and it may be a better option for fractal dimension estimation in real-time EEG data processing where the small number of points is the primary constraint. Portnova et al. [17] explored ASD children's reactions to emotionally laden nonverbal sounds. They showed that children with ASD exhibited considerably higher HFD than the control group for all circumstances except for

978-1-6654-6621-9/21/$31.00 ©2021 IEEE

sounds of crying and laughter. Ahmadlou et al. [6] investigated FD for analysis of the complexity and dynamical changes in the ASD brain. They calculated FD through HFD and Katz's Fractal Dimension (KFD) and used wavelet-chaos-neural network methodology for EEG-based ASD diagnosis. Radhakrishnan et al. [18] analyzed the effect of brain dynamics with HFD of ASD subjects. They devised an approach for determining the best time parameter value in calculating HFD for each channel.

This study aims to investigate the potential use of HFD for the EEG signal as a biomarker for ASD. Resting-state 19 channel EEG data of 25 patients were collected as input. HFD value was calculated for all channels of EEG signals. Then average, minimum, and maximum HFD values were calculated for both male (ASD and control) and female (ASD and control) subjects respectively. The result indicates that the minimum HFD values of control participants are greater than the ASD subject.

The rest of the paper is organized as follows. Section II describes the methodology in detail. Section III presents experimental results and discussion. The conclusion of the paper is discussed in Section IV.

II. ASD Diagnosis using Fractal Dimension from EEG

ASD diagnosis through fractal dimension measure from EEG data is the focus of this study. The well-known HFD is considered in this study.

A. *FD of EEG signal*

The FD [14] is an important property of fractals that can be used to describe and classify them. It assesses the degree of boundary fragmentation or irregularity at various scales. The capacity dimension, the correlation dimension, and the information dimension can all be used to calculate the FD. It is feasible to measure how the signal's complexity evolves under stress and other abnormalities using fractal analysis. The fractal dimension is a statistical measure of the complexity of an object, signal, or quantity that is self-similar over a certain region of space or time period. Because brain signals are self-similar, those can be considered as fractal bits and use fractal geometry to acquire them [19]. Therefore, it may be able to identify a decline in the FD of EEG signal under cognitive stress in an area where persons on the autistic spectrum do not operate as well. At a glance, fractal analysis from EEG data is a way to analyze ASD issues. There are many methods for fractal analysis, HFD is the most common and considered in this study.

B. *Higuchis Fractal Dimension (HFD)*

Higuchi [19] proposed an algorithm for the estimation of FD directly in the time domain. The HFD value of a time series is a number between 1 and 2, with higher HFD values indicating greater signal complexity. If the scaling parameters of a signal fit a scale-free behavior, i.e., the same features appear at smaller and larger time scales, the signal is fractal. Since, the dynamics of the EEG time series show statistical similarities, the EEG signal of brain activity has fractal features. HFD follows several steps to calculate fractal dimensions from raw data.

1. Consider a finite set of time series observations taken at a regular interval:
$$\{x(1), x(2), x(3), \cdots, x(N)\}$$
Where N is the length of data sequence x.
2. From a given time series, first, construct a new time series, x_m^k defined as:
$$x_m^k = \left\{ x(m), x(m+k), \cdots, x\left(m + \left\lfloor \frac{N-m}{k} \right\rfloor \cdot k\right) \right\},$$
$$\text{for } m = 1,2,\cdots,k \qquad (1)$$
where $\lfloor . \rfloor$ denotes floor value (Gauss' notation) and both k and m are integers. m and k indicate the initial time and the interval time, respectively.
3. The average length $L_m(k)$ of the curves x_m^k is constructed according to
$$L_m(k) = \frac{1}{k}\left[\left(\sum_{i=1}^{\left\lfloor \frac{N-m}{k} \right\rfloor} \left| x(m+ik) - x(m+(i-1)k) \right| \right) \frac{N-1}{\left\lfloor \frac{N-m}{k} \right\rfloor k}\right] \qquad (2)$$
where $\frac{N-1}{\left\lfloor \frac{N-m}{k} \right\rfloor k}$ represents the normalization factor for each subset time series of k. An average length is computed for all time series with the same delay (or scale) k, as the mean of the k lengths $L_m(k)$ for $m = 1,2,\cdots,k$. This procedure is repeated for each k ranging from 1 to $k_{\max}$. Here, k_{max} is a parameter that represents the maximum number of scales to explore in the process of calculation [20].
4. Length of the curve for a certain time interval k is denoted by $\langle L(k) \rangle$, where $\langle L(k) \rangle$ is the average value over k sets of $L_m(k)$.
$$L(k) = \sum_{m=1}^{k} L_m(k) \qquad (3)$$
5. The total average length for scale k, $L(k)$, is proportional to k^{-D}, where D is the FD by Higuchi's method. The FD is estimated by the slope of the least-squares linear best fit of the curve of $\ln(L(k))$ versus $\ln(1/k)$ of Eqn. (5).
$$D = \frac{\ln(L(k))}{\ln(k)} \qquad (4)$$

C. *ASD Diagnosis through HFD*

To diagnose ASD, HFD value of every channel is computed first. This gives HFD values for all channels for a subject. Applying the same process, HFD values of all subjects are calculated. Then minimum, maximum, and average of HFD values are obtained for the individual channels for each subject. In this study, the value of k_{max}

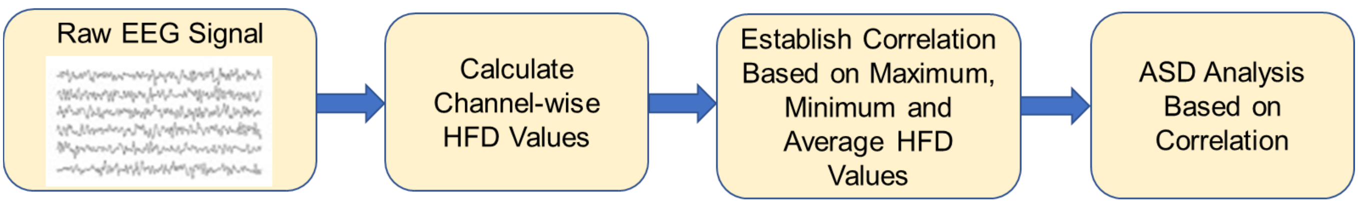

Fig. 1. Proposed ASD Diagnosis system through HFD.

started from 2 and varied up to 128. The process of finding HFD values from EEG data is described by the following steps in Fig. 1.

III. Experimental Results and Discussion

A. Experimental Data

This study uses an EEG dataset collected from Villa Santa Maria Institute, Italy [10]. The 19-channel dataset is collected from 15 (3 female, 12 male) ASD subjects and 10 (6 female, 4 male) controlled subjects. The age range of ASD subjects was 7 to 14 years and 7 to 12 years for the control subject respectively. The EEG signals were filtered applying a bandpass filter of 0.3–70 Hz. The EEG electrodes were placed according to the international 10-20 system (i.e. Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2 and Common Ground) as shown in Fig. 2. Data recording was approximately 3 minutes of duration at a sample rate of 256 Hz. The subjects had their eyes closed which avoided artefacts of eye blinking. -- >> Highlight the channels on Fig 2.

B. Result and Analysis

The EEG data has been partitioned into four categories i.e., (i) ASD male, (ii) ASD female, (iii) Control male, and (iv) Control female. Three different types of measurements were adopted such as the average, minimum and maximum of HFD values to find the relationships among four types of classes.

Table I summarizes different measures of HFD values for different k_{max} values of 2, 60, 100, and 128 for better realization. From the table, it is observed that distinguishing ASD from control subjects is difficult based on average HFD values. HFD values for ASD and control subjects are very close in all the cases for both male and female cases. Besides average HFD values, promising features for detecting ASD are revealed from minimum and maximum HFD values. In the case of minimum HFD values, there is a clear observation for higher k_{max} values and HFD values for ASD subjects which are lower than control subjects (i.e., non-ASD patients). As an example, for k_{max} =128, minimum HFD values are 1.178 and 1.189 for male and female cases respectively. On the other hand, for the same k_{max} minimum

TABLE I. Average, minimum and maximum Higuchi's Fractal Dimension (HFD) values for different k_{max} values.

k_{max}	Participants	Average of HFD	Minimum of HFD	Maximum of HFD
2	ASD male	1.375	1.036	**2.872**
	ASD female	1.431	1.095	**2.147**
	Control male	1.276	1.043	**1.583**
	Control female	1.247	1.083	**1.928**
60	ASD male	1.629	1.227	1.951
	ASD female	1.627	1.227	1.858
	Control male	1.697	1.548	1.855
	Control female	1.654	1.443	1.779
100	ASD male	1.645	1.197	1.929
	ASD female	1.635	1.198	1.886
	Control male	1.728	1.563	1.839
	Control female	1.685	1.438	1.803
128	ASD male	1.649	**1.178**	1.925
	ASD female	1.637	**1.189**	1.901
	Control male	1.744	**1.571**	1.857
	Control female	1.697	**1.432**	1.823

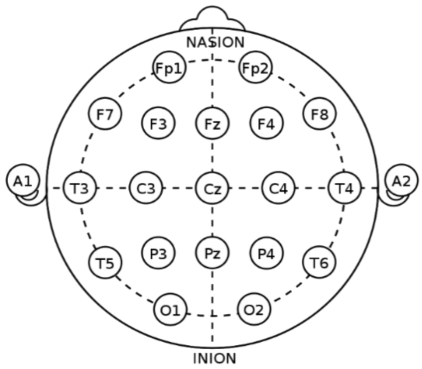

Fig. 2. Placement of the Electrodes for EEG recording of the International 10-20 method.

HFD values in the case of control subjects are 1.571 and 1.432 for male and female cases, respectively. Thus, a minimum HFD lower than 1.2 may consider for ASD detection. In the case of maximum HFD values, HFD values for ASD patients are always higher than control subjects (i.e., non-ASD patients) but clear visible observation is seen for lower k_{max} values. As an example, for k_{max}= 2 maximum HFD values are 2.872 and 2.147 for male and female cases. On the other hand, for the same k_{max} maximum HFD values in the case of control subjects are 1.583 and 1.928 for male and female cases, respectively. Thus, a maximum HFD higher than 2.0 may consider as ASD.

Based on the observations presented in Table I, a heat map, shown in Fig 3, is computed to illustrate the correlation between k_{max}, average HFD, minimum HFD and maximum HFD. The heat map shows strong correlation between k_{max} and the average HFD. The correlation between k_{max} and minimum HFD and maximum HFD values is not significant.

A further analysis is carried using the pair plot on the data to illustrate the relationship between k_{max}, participants, and HFD values (i.e. average, minimum and maximum). The pair plot is shown in Fig 4, which presents some interesting features to identify the suitable range of values of the parameter space. Fig. 4 shows k_{max} has strong correlation (0.85) with the average HFD and negative correlation with maximum HFD. Higher values of k_{max} (between 60 and 120) have stronger relation. It also reveals that the average HFD values between 1.45 and 1.7 are significant and may contribute to classification.

So HFD value can be used as a biomarker for detecting ASD. We tried to do a boundary line between ASD and control

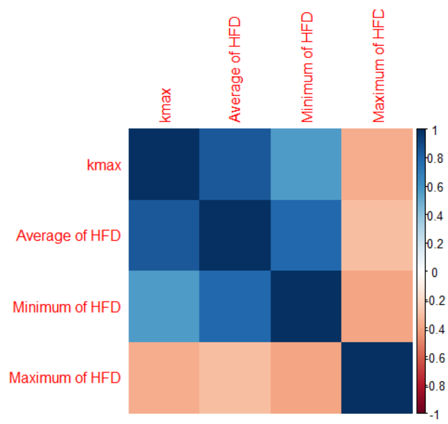

Fig. 3. Heat map of k_{max} and HFD (avg, min, max) values.

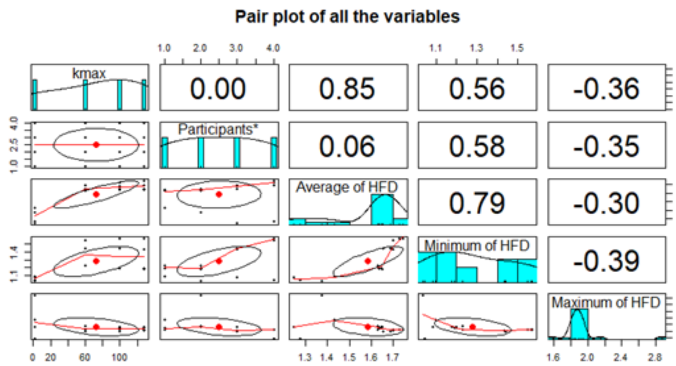

Fig. 4. Pair plot of k_{max}, participants, HFD values, and their

participants' HFD values for deciding that one participant is ASD or control only using its EEG data but it is not possible because some value overlaps between two supergroups. Another finding is that this HFD value of participants can also be used for classification problems. Finally, experimental results clearly revealed the effectiveness of HFD based ASD detection from EEG signals.

IV. Conclusions

As a common neurodevelopmental condition with a high risk of failure to adapt across social, scholastic, and psychological outcomes, ASD is a serious public health problem. To overcome the problem, ASD intervention should start as soon as signs are manifested. As it is a neurodevelopmental disorder, brain signal-based intervention methods are most promising. This study uses EEG signal for ASD diagnosis as it is simple to use and inexpensive. By applying fractal analysis, it is possible to measure how the complexity of the signal changes under different disorders like ASD. HFD has been proven as a good indicator for assessing the complexity of EEG-derived brain activity in ASD patients. Experiments on 19-channel resting-state EEG data showed that the HFD values of ASD patients have different characteristics than control subjects (i.e., non-ASD cases) participants. At a glance, HFD values from EEG have features to diagnosis ASD.

References

[1] C. P. Johnson and S. M. Myers, "Identification and Evaluation of Children With Autism Spectrum Disorders," *Pediatrics*, vol. 120, no. 5, pp. 1183–1215, Nov. 2007.

[2] "Autism Statistics & Rates in 2021." https://www.elemy.com/studio/autism/statistics-and-rates (accessed Aug. 01, 2021).

[3] B. J. Tonge and A. Brereton, "Autism spectrum disorders," *Aust. Fam. Physician*, vol. 40, no. 9, pp. 7–11, 2011, [Online]. Available: https://www.racgp.org.au/download/documents/AFP/2011/September/201109tonge.pdf.

[4] M. S. Hasan, "ASD and its Care in Bangladesh." The Daily Star, 25th August 2021.

[5] "Autism Screening," *Centers for Disease Control and Prevention*, 2018. https://www.cdc.gov/ncbddd/autism/screening.html.

[6] M. Ahmadlou, H. Adeli, and A. Adeli, "Fractality and a wavelet-chaos-neural network methodology for EEG-based diagnosis of autistic spectrum disorder," *J. Clin. Neurophysiol.*, vol. 27, no. 5, pp. 328–333, 2010.

[7] A. Accardo, M. Affinito, M. Carrozzi, and F. Bouquet, "Use of the fractal dimension for the analysis of electroencephalographic time series," *Biol. Cybern.*, vol. 77, no. 5, pp. 339–350, 1997.

[8] C. Hospital and C. Cross, "Measuring the fractal dimension of EEG signals: selection and adaptation of method for real-time analysis', Transactions on Biomedicine and Health vol 1, © 1993 WIT Press, www.witpress.com, ISSN 1743-3525," vol. 1, 1993.

[9] L. Raja and M. M. Priya, "Eeg based diagnosis of Autism Spectrum Disorder using static and dynamic neural networks," *ARPN J. Eng. Appl. Sci.*, vol. 12, no. 21, pp. 6020–6029, 2017.

[10] E. Grossi, C. Olivieri, and M. Buscema, "Diagnosis of autism through EEG processed by advanced computational algorithms: A pilot study," *Comput. Methods Programs Biomed.*, vol. 142, pp. 73–79, 2017.

[11] Z. J. Peya, M. A. H. Akhand, J. Ferdous Srabonee, and N. Siddique, "EEG Based Autism Detection Using CNN through Correlation Based Transformation of Channels' Data," in *2020 IEEE Region 10 Symposium, TENSYMP 2020*, 2020, no. June, pp. 1278–1281.

[12] W. J. Bosl, H. Tager-Flusberg, and C. A. Nelson, "EEG Analytics for Early Detection of Autism Spectrum Disorder: A data-driven approach," *Sci. Rep.*, vol. 8, no. 1, pp. 1–20, 2018.

[13] F. A. Alturki, K. Alsharabi, A. M. Abdurraqeeb, and M. Aljalal, "Eeg signal analysis for diagnosing neurological disorders using discrete wavelet transform and intelligent techniques†," *Sensors (Switzerland)*, vol. 20, no. 9, 2020.

[14] B. B. Mandelbrot, *The fractal geometry of nature*. New York : W.H. Freeman, 1983.

[15] S. Kesić and S. Z. Spasić, "Application of Higuchi's fractal dimension from basic to clinical neurophysiology: A review," *Comput. Methods Programs Biomed.*, vol. 133, pp. 55–70, 2016.

[16] F. M. Smits, C. Porcaro, C. Cottone, A. Cancelli, P. M. Rossini, and F. Tecchio, "Electroencephalographic fractal dimension in healthy ageing and Alzheimer's disease," *PLoS One*, vol. 11, no. 2, pp. 1–16, 2016.

[17] G. V Portnova and A. V. Maslennikova, "Atypical EEG Responses to Nonverbal Emotionally Charged Stimuli in Children with ASD," *Behav. Neurol.*, vol. 2020, 2020.

[18] M. Radhakrishnan, D. Won, T. A. Manoharan, V. Venkatachalam, R. M. Chavan, and H. D. Nalla, "Investigating electroencephalography signals of autism spectrum disorder (ASD) using Higuchi Fractal Dimension," *Biomed. Eng. / Biomed. Tech.*, vol. 66, pp. 59–70, 2020.

[19] T. Higuchi, "Approach to an irregular time series on the basis of the fractal theory," *Physica*, vol. 31, pp. 277–283, 1988.

[20] E. Ruiz-Padial and A. J. Ibáñez-Molina, "Fractal dimension of EEG signals and heart dynamics in discrete emotional states," *Biol. Psychol.*, vol. 137, pp. 42–48, 2018.