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Aarti Sharma

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Computerised detection of autism spectrum disorder using EEG signals

Aarti Sharma

Department of ECE,
Inderprastha Engineering College,
Site-IV, Ghaziabad, India
Email: aartibhavya@gmail.com

Abstract: Autism spectrum disorder (ASD) is one of the most common neurological disorders. Detection of ASD is based on behavioural analysis made by clinician by conducting interviews with the parents of the child. This paper presents computer aided diagnostic tool to detect autism disorder. This paper presents the detection of ASD based on biological markers. An early diagnosis is essential to confirm that the child have ASD. In this paper, power spectral density and phase locked values have been extracted from gamma band of EEG signals for autistic and normal subjects. Gamma band from EEG signals is extracted using band pass filter. Significant decrement in these features is observed for the autistic subjects in comparison to normal subjects. Above findings are statistically validated though ANOVA. Anomalies in EEG signals can be used as potential biomarker for detection of ASD.

Keywords: autism; electroencephalogram; EEG; gamma wave; computer aided diagnosis.

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Biographical notes: Aarti Sharma received her BTech in Electronics Engineering from the Punjab Technical University, Jalandhar, India, in 2002, MTech in Instrumentation from Sant Longowal Institute of Engineering and Technology, Longowal, India, 2004 and Doctoral degree from Amity University, Sec-125, Noida, India, in 2019. Presently, she is working as an Assistant Professor in the Department of Electronics and Communication Engineering, Inderprastha Engineering College, Ghaziabad, Uttar Pradesh, India. She has published papers in conferences and journals. Her current research includes biomedical signal processing.

1 Introduction

Autism spectrum disorder (ASD) is the neurodevelopment mental disorder that is characterised by abnormal functioning in communication, behaviour and social interaction of the children. ASD is manifested before the age of three. Approximately 13 million children suffer from autism in India (Sinha et al., 2019). Earlier, the medical techniques were not available for diagnosis of autism. Autism is detected by conducting regular interviews with the parents of autistic subjects (Bosl et al., 2018). This kind of

assessment is highly subjective and requires psychological experts for detection of disease and also the diagnoses based on these behavioural symptoms are less efficient. Different neuroimaging modalities like magnetic resonance imaging (MRI) and diffusion tensor imaging (DTI) are used for detection of autism. Larger growth rate in brain of autistic subjects is observed in comparison to the normal subjects. Overgrowth is observed in frontal and temporal regions of the brain (Coben et al., 2014). Electroencephalogram (EEG) signals that are captured from human brain have great potential for analysis of brain conditions (Ibrahim et al., 2018). In past research, EEG signals have been used for diagnosis of ASD (Machado et al., 2015).

EEG signals are highly nonlinear and non-stationary signals and have complex patterns. Despite the fact that spatial resolution of EEG signals is poor but it have several other advantages of having high temporal resolution and easy availability. There are different sub bands (delta, theta, alpha, beta and gamma). Gamma band presents the memory and activity related task so, reduced activity in gamma band is observed for autistic subjects in comparison to the normal subjects (Hisan et al., 2016).

Numerous methods for analysing nonlinear EEG time series are available in literature. Correlation dimension, sample entropy and multiscale entropy (Bosl et al., 2011) are used as potential features for detection of ASD.

Various linear and nonlinear methods in time and frequency domain are used to access functional connectivity. Correlation and coherence are used to find synchronisation between signals in time and frequency domain, respectively (Sheela and Puthankattil, 2018). Both of the above mentioned measures find the combination of amplitude and phase information which makes them incompetent to find the relationship between phases of signals.

It is difficult to detect and treat ASD completely as it is lifelong disorder. The objective this research is to assist psychological experts with computerised detection of ASD that would help early intervention and increase the child response rate to the treatment.

The main contribution of this paper is to determine functional connectivity between different regions of brain using EEG signals. The statistical coupling between different regions of brain has been explored using phase locked value (PLV) from pairwise combination of electrodes. This study analyses the PLV between different electrode pairs from gamma band and power spectral density (PSD) for normal and autistic subjects. Computerised detection of neurological disorder using EEG signals will act as a low cost tool for initial screening and aid neurologist in decision making. EEG database for normal and autistic subjects is presented in Section 2. Complete procedure and extracted features are explained in Section 3. Results followed by conclusions are presented in Section 4 and 5, respectively.

2 Material and methods

Detection of ASD will be great help to neuroclinician in decision making. The complete methodology is described in the following paragraphs.

2.1 EEG database

EEG database for normal and autistic subjects is made available by Alhaddad et al. (2012). EEG signals are sampled at 256 Hz. Notch filter between the frequency range [0.1–60 Hz] is used to remove power grid interference. Data is recorded according to uni-polar montage of electrodes. EEG is recorded from 16 basic locations in accordance with the 10–20 placement of electrode system (Jurack et al., 2007). EEG signals are recorded from FP1, F3, F7, T3, T5, O1, C4, FP2, Fz, F4, F8, C3, Cz, Pz, Oz and O2 electrodes. Data recording time is not less than ten minutes for normal and autistic subjects. Epoch of two minutes is considered for the analysis of normal and autistic subjects. Since the sampling rate is 256, so total 30,720 samples have been analysed. In the present study, dataset of 11 autistic subjects and five normal subjects have been considered.

2.2 Method

Diagnosis of ASD from EEG signals has potential benefits. Methodology describing the pre-processing of EEG signals, sub-band extraction, feature extraction, statistical analysis using analysis of variance (ANOVA) and independent component analysis (ICA) followed by topographical plot is presented in the following steps:

Step 1 Read the EEG data of normal and autistic subjects (EEG data is read in MATLAB using BIOSIG toolbox).

Step 2 Preprocessing of EEG signals which includes average referencing and wavelet-based de noising.

In average referencing, average of signals from 16 EEG electrodes has been subtracted from each individual electrode signal. Since the sampling rate of EEG data is 256 Hz and the information content is present between [0–128 Hz] so, the required frequency band is extracted using wavelet-based de-noising which includes decomposition, thresholding and reconstruction.

Step 3 Extraction of gamma band (> 30 Hz) of EEG signals using band pass filter.

Different frequency bands (delta, theta, alpha, beta and gamma) are presents in EEG signals. Gamma band (> 30 Hz) is related to memory and cognition related task. It has been proved in Hisan et al. (2016) that changes in gamma band are observed for the autistic subjects. So, gamma band is extracted using band pass filter.

Step 4 Computation of phase of each signal using Hilbert transform.

Phase angle of EEG signals from 16 electrodes have been calculated using Hilbert transform.

Step 5 PLV is calculated from the electrode pairs.

In order to find functional connectivity between different regions of brain PLV is determined.

Step 6 Calculation of PSD from the dataset of normal and autistic subjects.

Step 7 Statistical test ANOVA is performed on the results obtained from the extracted features of normal and autistic subjects.

This test is performed to check whether considerable variations exist among normal or autistic subjects or not. This test will return p-value. Smaller the value of p, more significant is the test.

Step 8 Source potential are separated using ICA.

ICA is used to decompose multivariate signals into independent signals (Hamaneh et al., 2014). After application of ICA topographic plots of the brain are also plotted which reveals that which area of brain is affected during autism.

Step 9 Topographic plot of brain are plotted for normal and autistic subjects.

3 Extracted features

Features of a signal reveal the important information present in it. In present work, time domain and frequency domain features have been extracted from EEG signals.

3.1 Time domain feature

3.1.1 Phase locked value

The synchronisation of neural activity of brain from EEG signals can be investigated using PLV (Lachuax et al., 1999). It is measured between phases of two EEG signals. Phase of a signal can be measured by using Hilbert transform. Hilbert transform is used to measure instantaneous amplitude and phase of a signal. In the present work phase difference between pair of electrodes ($\Delta\phi$) is considered for further analysis. PLV is calculated using equation (1)

$$PLV = \left| E\left[e^{\Delta\phi} \right] \right| \tag{1}$$

where $E|.|$ denotes the expected value. $\Delta\phi$ is calculated using equation (2).

$$\Delta\phi = \phi_1 - \phi_2 \tag{2}$$

where ϕ_1 and ϕ_2 denotes the phase of the two different electrode signals. Since the data for the normal and autistic subjects is recorded using 16 electrodes so there will be 120 electrode pairs. There will be a total of 120 PLV from one subject. If EEG signals rise or fall concurrently more than base line value, then the connectivity between different regions of brain will increase and the rise or fall less than the baseline value reveals decreased connectivity.

3.1.2 Power spectral density

PSD represents the signal power content at various frequencies (Wang et al., 2015). PSD is used to find anomalies in autistic brain. Moving window of one second (256 samples) is used. $x_w(n)$ is the windowed segment of signal and can be written using equation (3).

$$x_w(n) = x(n) * l(n) \tag{3}$$

where $l(n)$ is the window function and contains 256 samples. So, PSD is defined as squared magnitude of fast Fourier transform (FFT) of $x_w(n)$ divided by $l(n)$. PSD can be calculated using equation (4).

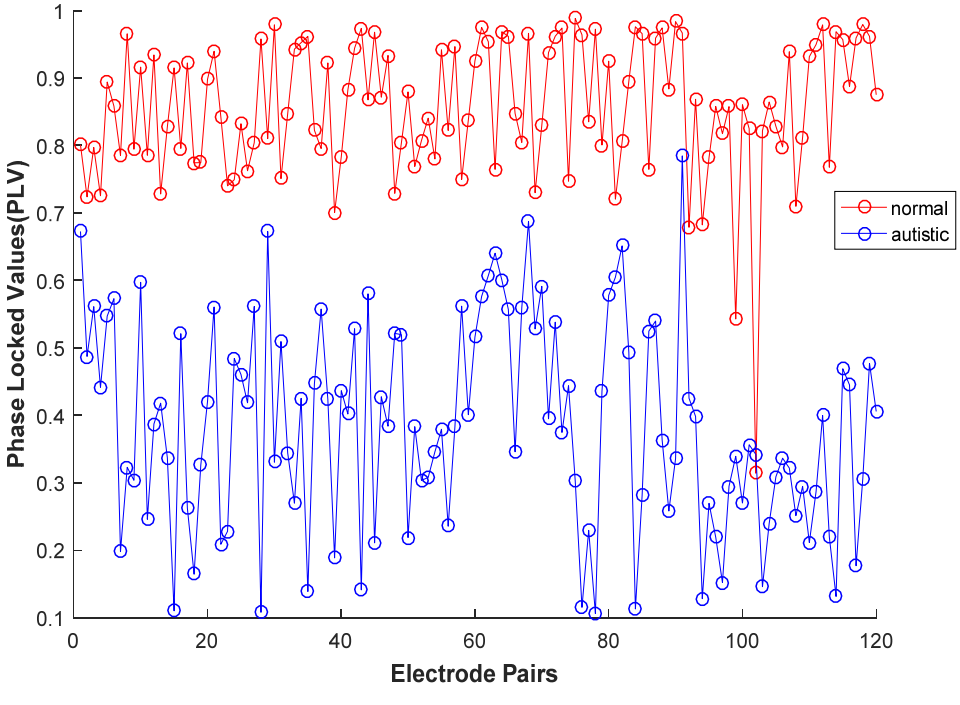
$$P_x(w) = \frac{1}{M}\left|FFT\left(x_w(n)\right)\right|^2 \tag{4}$$

where M represents the total number of samples.

4 Results

In the present study, aforementioned methodology has been validated on the dataset of eleven autistic and five normal subjects using MATLAB. Analysis has been done on two-minute duration EEG signals. Since there are 16 electrodes and PLV has been calculated pairwise so, a total of 120 PLV have been obtained from single subject as shown in Figure 1.

Figure 1 PLV from normal and autistic subjects (see online version for colours)



It can be clearly observed from Figure 1 that PLV is much lower for the autistic subjects in comparison to the normal subjects which demonstrates that functional connectivity decreases in the brain of autistic subjects. Furthermore, maximum change is observed from electrode pairs 15, 25, 75, 80 and 85 which are electrode pairs from frontal and occipital regions of brain. PSD for the normal and autistic subjects is shown in Figure 2 and Figure 3, respectively.

Figure 2 PSD for normal subject (see online version for colours)

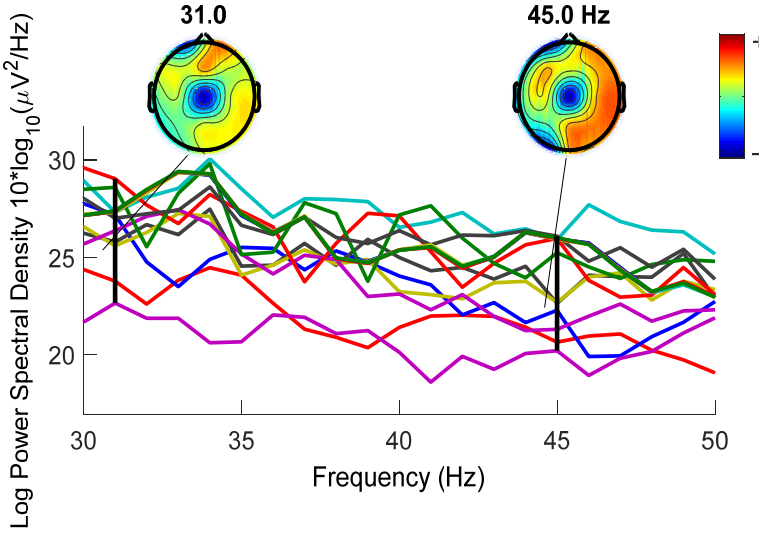


Figure 3 PSD for autistic subject (see online version for colours)

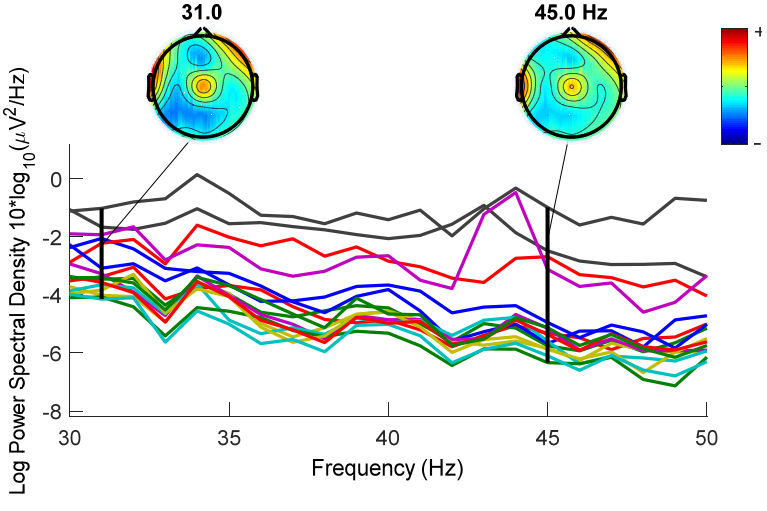
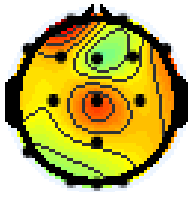
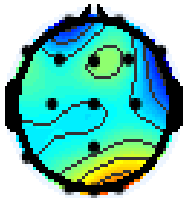
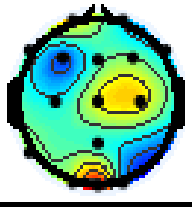


Figure 2 and Figure 3 illustrate the average PSD estimate for 16 EEG channels of normal and autistic subjects, respectively. Analysis has been done for the gamma frequency band [30–50 Hz]. It is evident from Figure 2 and Figure 3 that PSD appear different for the autistic and normal subjects. The lowest value for PSD of normal subject in gamma band is 17 μV^2/Hz while for autistic brain the highest values is around it is 0 μV^2/Hz. A huge difference is observed between these values which can be used to demarcate the autistic subjects from normal subjects. It can be observed from the PSD estimate that most prominent difference in EEG for normal and autistic subjects stem from gamma EEG rhythm [30–50 Hz]. This frequency range is associated with the attention and consciousness. Hence, PSD can be used as a potential biomarker for detection of ASD

using EEG signals. Topographic plots are plotted at frequency of 31 Hz and 45 Hz also. Less activation is observed for the autistic brain as compared to normal brain.

For testing the difference statistically one-way ANOVA is performed on average PLV for eleven autistic and five normal subjects. There are total 240 data points (120 PLV values from each subject) so the degree of freedom is 239. F test is significant at $p < 0.0002$, so the null hypothesis that no difference exits between PLV values for normal and autistic subjects can be rejected.

Table 1 Results of topographic plots of brain from different electrodes (see online version for colours)

S. no.	*Topographic plot*	*Name of electrode*	*S. no.*	*Topographic plot*	*Name of electrode*
1		Prefrontal electrode (FP1)	5		Prefrontal electrode (FP2)
2		Temporal electrode (T3)	6		Central electrode (CZ)
3		Central electrode (C3)	7		Occipital electrode (O1)
4		Frontal electrode (Fz)	8		Occipital electrode (O2)

ICA can separate data from different electrodes that are placed on scalp (Sharma et al., 2020). Topographic plot of brain gives the idea of brain activation. The functionality and connectivity between different regions of brain can be observed by plotting topographic maps. Since for the acquisition of data 16 electrodes are used as mentioned in the database so, 16 topographic maps are obtained. Results of topographic maps for the eight electrodes are shown in Table 1. Different colours topographic map indicates the functionality and connectivity between different regions of brain. On RGB scale activity is highest for red colour, moderate for green and least for blue colour. As it is clear from Table 1 that least activity is observed from occipital electrodes (O1 and O2). So, it is

clear that the results are in accordance with the findings that minimal activity is observed from the electrodes 15 and 16 which are the occipital electrodes.

Table 2 shows the comparison of various methods for detection of ASD using EEG signals. None of the work demonstrates the localisation of the most effected part of the brain in autism disorder.

Table 2 Comparison of autism detection methods

Ref no./year published	*Techniques*	*No. of participants*	*Result*	*Region identification and topographic plots using ICA*
Sinha et al. (2019)	Mean Variance Skewness Entropy	Normal = 20 Autistic = 10	KNN Accuracy = 92.8%	No
Haputhanthri et al. (2019)	Discrete wavelet transform Correlation-based feature selection	Normal = 5 Autistic = 10	Random forest classifier Accuracy = 93%	No
Hadoush et al. (2019)	Averaged multiscale entropy	Normal = 18 Autistic = 18	Entropy is higher for autistic subjects	No
Present work	Phase locked value Power spectral density Independent component analysis Analysis of variance (ANOVA)	Normal = 5 Autistic = 11	Phase locked value as well as power spectral density decreases for autistic subjects	Yes

5 Conclusions

Functional connectivity between different regions of brain is used as efficient biomarker in this study because efficient communication leads to healthy brain and disturbance in these functions leads to decline of cognitive abilities. Analysis of EEG signals of eleven autistic and five normal subjects have been done in this work. PLV from gamma band of 120 electrode pairs and PSD from 16 electrodes are used as potential features for detection of autism. Decrement in PLV is observed for the autistic subjects in comparison to the normal subjects and the maximum changes are observed from frontal and occipital regions of brain. These findings are further validated by plotting topographic plot of the brain for autistic subjects from which it is clear that minimal activity is observed from the occipital regions of brain. Decrement in PSD is observed for the autistic subjects. The obtained results are statistically validated using ANOVA and $p < 0.0002$ is obtained. The results suggest that EEG signals can be used for detection of ASD which may lead to development of computerised tools that can access neurologist and psychiatrist in decision making. This will incite suitable therapies that are required to cure autism.

Future work will be carried out to use machine learning algorithms for automatic decision making and validation on a bigger dataset.

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