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The effect of power spectral density on the electroencephalography of autistic children based on the welch periodogram method

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Abstract — Autism spectrum disorder is a serious mental disorder affecting social behavior. Some children also face intellectual delay. In people with autism spectrum disorder, the signals detected have abnormalities compared to normal people. This can be a reference in diagnosing the disorder with electroencephalography. This study will analyze the effect of power spectral density on the electroencephalography of autistic children and also compare it with the power spectral density value on the electroencephalography of normal children using the Welch periodogram method approach. In the preprocessing stage, the independent component analysis method will be applied to remove artifacts, and a finite impulse response filter to reduce noise in the electroencephalography signal. The study results indicate differences in the power spectral density values obtained in the autistic and normal electroencephalography signals. The power spectral density value obtained in the autistic electroencephalography signal is higher than the normal electroencephalography signal in all frequency sub-bands. From the study results, the highest power spectral density value obtained by the autistic electroencephalography signal is in the delta sub-band, which is 54.06 dB/Hz, while the normal electroencephalography signal is only 33.14 dB/Hz at the same frequency sub-band. And in the Alpha and Beta sub-bands, the normal electroencephalography signal increases the power spectral density value, while in the autistic electroencephalography signal, the power spectral density value decreases in the Alpha and Beta sub-bands. In addition, finite impulse response and independent component analysis methods can also reduce noise and artifacts contained in autistic and normal electroencephalography signals.

Keywords – autism spectrum disorder, electroencephalography, power spectral density, periodogram welch

I. Introduction

Autism spectrum disorder (ASD) is a serious disorder that affects cognitive and social behavior. Some children also face intellectual delay. The exact cause of ASD has not been found, and there are no biological tests to diagnose ASD. Moreover, current diagnostic practice is based solely on behavioral patterns [1]. But as we know that ASD is a disorder in a person's brain, so there have been many studies to scan a person's brain signals to detect the abnormality [2].

Many studies were conducted on ASD using electroencephalogram (EEG) and aimed to reveal differences between the brain states of autistic participants and controls [3]. In people with ASD, the signals detected have abnormalities compared to normal people. In another study, EEG was used to study ASD subjects at rest. It was found that there was a big difference between ASD participants and controls, where ASD participants showed excessive power in the low and high-frequency bands [4]. This can be a reference in diagnosing ASD abnormalities with EEG. The study of EEG signals involves the use of a brain-computer interface (BCI). BCI is a system that provides direct communication between the brain and a computer or other external device [5].

In this study, the autism EEG and normal EEG signals will be analyzed, which have the parameter power spectral density (PSD). And the results of the PSD parameters of the two signals will be analyzed for differences. The PSD parameter of the EEG signal needs to be analyzed because, in previous studies, it was explained that subjects with brain disorders had higher PSD values than normal subjects [6]. So that there is a difference between the PSD value of a normal EEG signal and an EEG signal that has abnormalities in brain activity, one of which is in people with autism.

However, before getting the PSD parameters on the EEG signal, it is necessary to do a preprocessing stage first. At the preprocessing stage, artifacts will be removed, and artifacts are signals that do not come from the brain but from eye blinks, heartbeats, and other muscle movements so that it can reduce the quality of the EEG signal. For this reason, the independent component analysis (ICA) method is used. ICA involves a linear decomposition of the aggregate channel activity into an independent component series spatially filtered from the EEG time series. So that it can eliminate artifacts and components that represent the original brain activity [7].

The method used to obtain the PSD parameter in this study is the Welch Periodogram method. This method has been widely used to obtain PSD parameters from EEG signals in previous studies and obtained satisfactory results [8]–[13]. This method also performs satisfactorily in obtaining PSD parameters than other methods, such as Burg, Multitaper, and periodogram [14]–[16]. Not only in epilepsy and autism, but the Welch method is also used in people with Parkinson's, sleep disorder, and stress to analyze differences in PSD values [8], [9], [17]. Due to this reason, this method is used in this study to obtain the PSD value.

This study analyzes PSD parameters in normal EEG and autism EEG signals. PSD values will be obtained for each frequency sub band, namely Delta, Theta, Alpha, and Beta, as has been done in previous research in calcifying emotions [18]. This is done because each frequency sub band represents a person's activities, as high frequencies represent concentration and intense mental activity (known as Alpha and Beta waves). In contrast, low-frequency packets represent low mental activity, namely, sleep situations (represented by Delta and Theta) [19]. And as it is known that people with autism have difficulty controlling and expressing their emotions in social interactions, the PSD value obtained in each frequency sub band has a different value between normal EEG signals and autistic EEG signals. It is hoped that the PSD value in each frequency sub-band can be a reference in detecting autism.

II. Research Method

This study will analyze the PSD value of autistic and normal EEG signals using Welch's Periodogram method before filtering using FIR to remove noise above 30 Hz and below 0.5 Hz. The ICA method will also eliminate artifacts in the EEG signal channel for better analysis results. The following is the flowchart of the study flow.

A. Material

This study used datasets from King Abdul Aziz University (KUA) recorded using BCI2000. BCI is a system that provides direct communication between the brain and a computer or external device [20]: using 16 electrodes at locations Fp1, F3, F7, T3, T5, O1, C4, Fp2, Fz, F4, F8, C3, Cz, Pz, Oz, and O2. The reference electrode is placed on the right ear and the ground electrode at the AFz location. In addition, this dataset has a sampling rate of 256 Hz, and the data was obtained using a notch filter at 60 Hz and a passband filter between 0.1 Hz and 60 Hz. The electrode placement configuration on the scalp is as follows [21].

B. Finite Impuls Response (FIR)

Finite impulse response (FIR) has a finite response and has no poles compared to IIR filters. Also, FIR is more stable than other digital filters and is preferred by researchers. In general, the FIR filter output $y[k]$ can be expressed mathematically as (1) [22].

$$y\left[k\right]\sum_{M-1}^{n=0}=h\left[n\right]x\left[k-n\right] \tag{1}$$

Finite impulse response may produce excessive ripples in the pass-band and create low stop-band attenuation. Windowing techniques can overcome this problem during the filtering process. If given a window function ($w[n]$) and the impulse response of an ideal filter ($h_d[n]$), then the impulse response of the actual filter can be expressed in (2) [22].

$$h\left[n\right]=h_d\left[n\right]w\left[n\right] \tag{2}$$

Fig. 3 shows the application of the study flow in applying FIR filtering to normal and Autistic EEG signals.

C. Independent Component Analysis (ICA)

ICA is a technique that enables the separation of signal mixtures into distinct sources. ICA extracts the sources by exploring the underlying independence of the measured data. It involves higher-order statistics to recover statistically independent signals from unknown linearly mixed observations. This technique becomes superior to other techniques, such as principal component analysis (PCA) [23]. The generative model of ICA

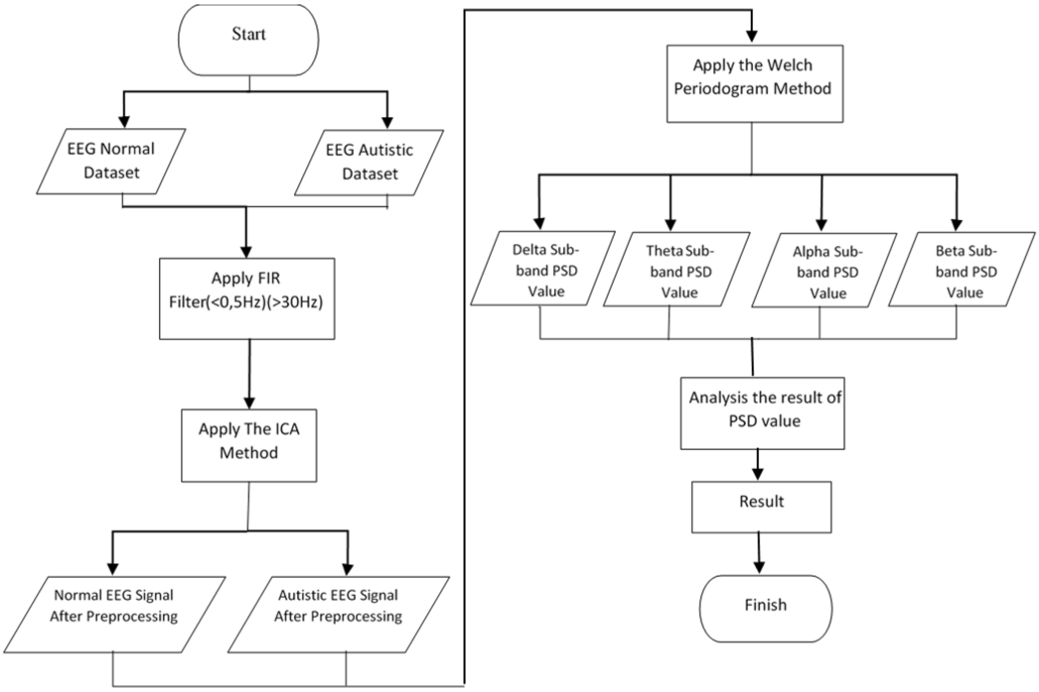

Fig. 1. Method proposed.

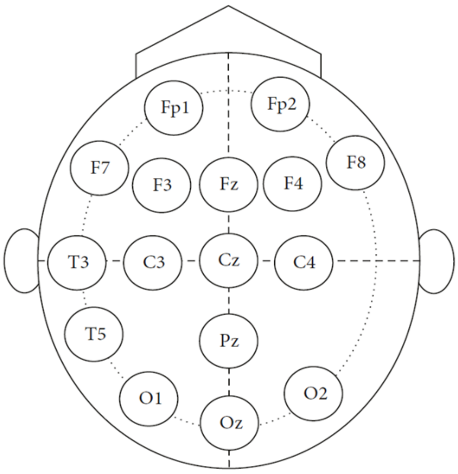

Fig. 2. Placement of 16 electrodes on the datasets (KAU).

(*i.e.*, the model that explains how the mixture signal is generated) can be seen in (3) as follows:

$$X = AS \tag{3}$$

This model assumes that the mixed signal is the product of instantaneous linear combinations of independent sources. Or in other words, the mixed signal consists of the mixing matrix (A) and the signal's independent components (S). The goal of ICA is only to recover the original signal from the observations. Therefore, it is necessary to obtain the un-mixing matrix W, which is the inverse matrix of the mixing matrix, as in (4) [24].

$$S = WX \tag{4}$$

Fig. 4 shows the application of the ICA method to reduce artifacts in the autistic and normal EEG signals used in this study.

D. Periodogram Welch

PSD describes the way the power of a signal or time series is distributed with frequency. PSD is the Fourier transform of the autocorrelation function of the signal. The power of a signal in a particular frequency band can be calculated by integrating the positive and negative frequencies [25]. PSD is a good tool for stationary signal processing and is suitable for narrowband signals. The PSD method is a common signal-processing technique that distributes signal power through frequency and shows energy power as a function of frequency [26].

PSD displays the power distribution between frequency components. Using the pwelch function of MATLAB, this estimator is applied to fragmented time samples. In short, this method divides the time series data into several parts and then, for each part, calculates a new period, and the average PSD is estimated [27]. Based on Welch's method, PSD estimation involves dividing the signal into segments, taking the modified periodogram of these segments, and averaging the modified periodogram [28], [29]. Mathematically, the Welch Periodogram is formulated as (5):

$$A_l\left(k\right) = \sum_{n=0}^{N-1} x_l\left(n\right) w e^{-j\frac{2\pi}{N}nk} \tag{5}$$

where $A_l(k)$ is FFT from segment windowed. In order to gain $A_l(k)$, it is needed the input signal of ($x_l(n)$) and the window function ($w(n)$).

$$\phi_l\left(k\right) = \frac{1}{NP}\left|A_l\left(k\right)\right|^2, l = 1, \cdots, L \tag{6}$$

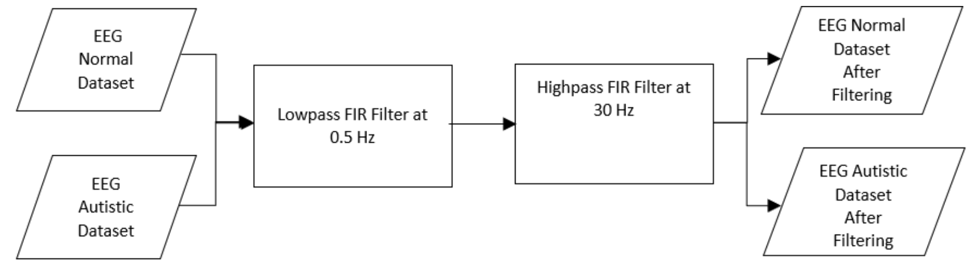

Fig. 3. Implementation of FIR filter.

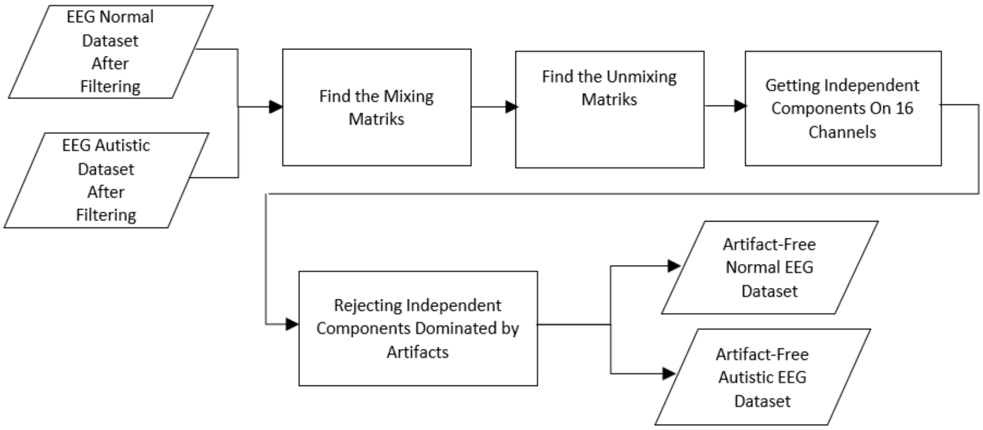

Fig. 4. Implementation of ICA method.

As mentioned, after obtaining the FFT from windowed segment ($A_l(k)$), then, periodogram ($\phi_l(k)$) are gained and P show the window power of ($w(n)$) [28]:

$$P = \frac{1}{N}\sum_{n=0}^{N-1} |w\left(n\right)|^2 \tag{7}$$

The PSD calculation with Welch is the average of the periodogram, which is [28]:

$$S\left(k\right) = \frac{1}{L}\sum_{l=1}^{L} \phi_l\left(k\right) \tag{8}$$

It can be seen that Welch's method calculates the periodogram of overlapping segments with 50% overlap. Calculating L for the N-point FFT is necessary, assuming that the input signal is divided into L segments of length N. With a 50% overlap, half of the samples over two consecutive segments will be the same [28]. For the selection of the window used, there are two requirements for the window function: the width of the main lobe should be as narrow as possible to obtain a better resolution, and the side lobes should be as small as possible to increase the energy in the main lobe and increase the stopband attenuation [30].

III. RESULT

A. Finite Impulse Response (FIR) Filter Application Results

This study will analyze the application of the FIR filter on normal and autistic EEG signals. In this EEG signal dataset, a passband filter has been applied between 0.1 Hz to 60 Hz, but because the EEG signals analyzed are only in the delta (1-4 Hz), theta (4-8 Hz), alpha (8-15 Hz), and beta (15-30 Hz) frequency sub-bands, FIR filter is applied at the upper limit of 30 Hz and for the lower limit of 0.5 Hz.

The FIR filter is applied using EEGLAB, where the basic FIR filter feature is used in EEGLAB, where the Basic FIR filter feature on this EEG lab uses a hamming window. This Basic FIR filter feature can determine the length of the window automatically, which is determined by the passband edges [31]. The application of the FIR filter at the lower limit of 0.5 Hz is made because the ICA method is sensitive to frequencies below 0.5 Hz. In addition to eliminating unwanted frequencies, the FIR filter at the upper limit of 30 Hz also reduces artifacts. The following are the results of applying the FIR filter to the EEG signal.

Fig. 5 shows the results of normal EEG signals in the frequency domain or PSD parameters, where the PSD value of the normal EEG signal has been applied to the FIR filter in the range of 0.5 Hz to 30 Hz. It can be seen in Fig. 5 that the PSD value of the normal EEG signal in the frequency domain is zero at frequencies above 30 Hz. This is done because the EEG signal to be analyzed is only up to the Beta frequency sub-band (15-30 Hz), for that frequency above 30 Hz is not needed, so that the FIR filter is applied at the upper limit of 30 Hz. besides the application of the FIR filter at the upper limit of 30 Hz also aims to reduce artifacts caused by muscles. The FIR filter is applied to all autistic and normal EEG signals.

B. Implementation Result of ICA

In this study, the autistic and normal EEG datasets used still contain artifacts and noise that result in poor

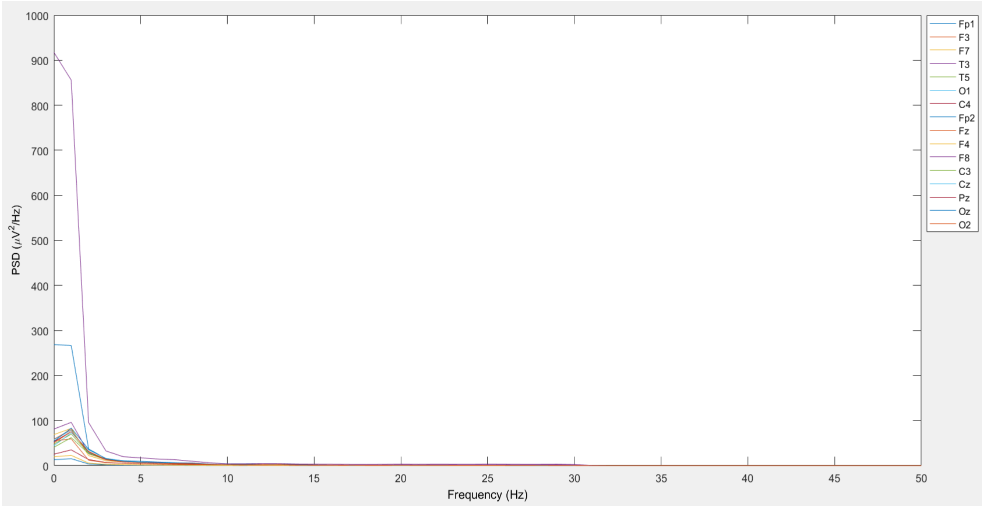

Fig. 5. Results of applying FIR filter to the EEG signal of the 1st normal subject.

EEG signal quality. Artifacts in EEG signals can be in the form of eye blinks, muscle movements, and heart rate. The most common type of artifact found in EEG signals is eye blink. Since artifacts are signals that do not originate from the brain, they must be removed from EEG signals to improve accuracy in analysis.

The ICA method will be applied to the EEG signal. The EEG signal will be made into independent components by obtaining the unmixing matrix of the normal EEG signal by using the EEGLAB feature, namely "decomposed data by ICA". This EEGLAB feature uses the following command:

[weights,sphere] = runica(data);

The command will output two variables, weights, and sphere, where weights are the ICA weight matrix and sphere is the data sphering matrix. The unmixing matrix is obtained by multiplying the two variables. The '**runica**' command uses trial and training methods on the data so that the weight and sphere variables are obtained [32]. Since the data of a signal consists of a mixing matrix and independent components, multiplying with the unmixing matrix, the independent components of the signal will be obtained. The following are the results of applying ICA to autistic and normal EEG signals.

Fig. 6 determines the comparison between the EEG signal of the 1st normal subject before and after applying the ICA method. It can be seen that before the 31st second, there is a significant voltage drop in the EEG signal of the 1st normal subject before the ICA method is applied. This is caused by the movement of closing the eyes when recording the EEG signal of the 1st normal subject.

After applying ICA, the artifacts in the form of eye blinks can be reduced by removing the independent components in the signal originating from eye blinks. It can be seen in Fig. 4 b that the voltage drop of the EEG signal of the 1st normal subject is reduced in all EEG signal channels, especially in the Fz channel to C3 channel, where the voltage drop due to the artifact of closing the eyes in these channels can be eliminated. This is because the independent components that contain eye artifacts in these channels can be removed from the EEG signal using the ICA method. after removing some independent components that contain artifacts.

As in normal EEG signals, the ICA method is also applied to autistic EEG signals. It can be seen in Fig. 7 a that in the T3, FP2, and Cz channels, there is a significant increase and decrease in voltage which indicates that in these channels, there are artifacts that can cause a decrease in the quality of the EEG signal to be analyzed.

However, after applying ICA and the independent components containing artifacts are removed, it can be seen in Fig. 7 b the artifacts contained in the T3, FP2, and Cz channels have disappeared due to the rejection of the independent components containing these artifacts so that the original EEG signal can be maintained. That way, the analysis results obtained will be more accurate.

C. Analysis of the Calculation Results of the PSD Value using the Welch Periodogram Method

After obtaining the results of autistic and normal EEG signals that have been applied, FIR filters and ICA methods removed independent components containing artifacts. Next is calculating the power spectral density value on normal and autistic EEG signals. The calculation of the PSD value will be carried out in the MATLAB application. EEG signal data applied to FIR and ICA filters in the previous stage is inputted into MATLAB to calculate the PSD value using the Welch Periodogram method. The following are the results of PSD values on normal and autistic EEG signals. Fig. 8 to Fig. 11 is the PSD value obtained using the Welch periodogram method in the frequency range of 0 Hz to 30 Hz. Where the PSD value will be analyzed at several frequency sub-bands, namely Delta (0 Hz-4 Hz), Theta (4 Hz-8 Hz), Alpha (8 Hz-15 Hz), and Beta

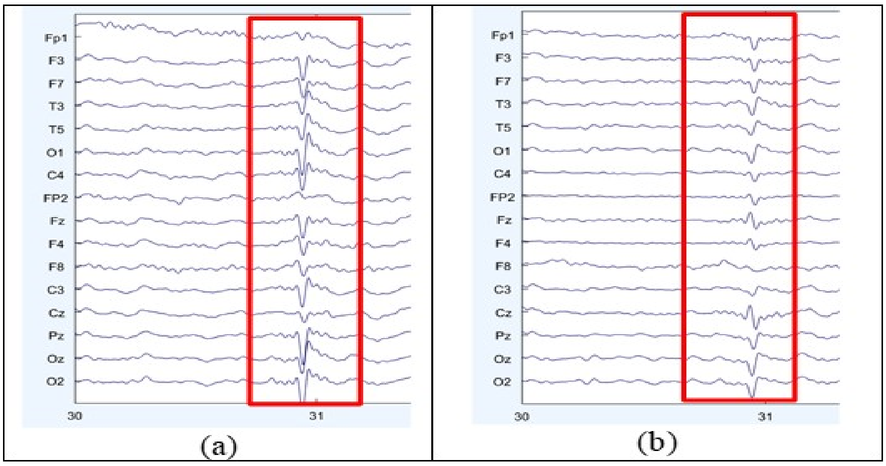

Fig. 6. EEG signal of the 1st normal subject: a) before applying ICA b) after applying ICA.

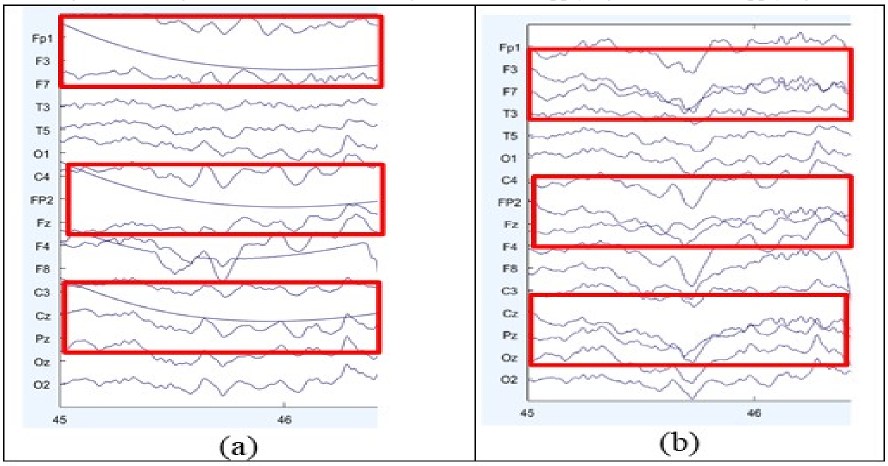

Fig. 7. EEG signal of 1st autistic subject: a) before applying ICA b) after applying ICA.

(15 Hz-30 Hz). This is done because each frequency sub-band represents different brain activity, so there will be differences in PSD values in each sub-band between normal and autistic EEG signals.

1) PSD analysis of the delta sub-band

Fig. 8 to Fig. 11 are the results of PSD values obtained on autistic and normal EEG signals using the welch periodogram method. It can be seen in Fig. 8, and Fig. 9 that the PSD value obtained in the delta sub-band (0 Hz-4 Hz) of the normal EEG signal is lower than the PSD value obtained in the autistic EEG signal as seen in Fig. 10 and Fig. 11. The highest PSD value obtained in the normal EEG signal is only 33.14 dB/Hz in the normal EEG signal of the 2nd subject, while in the autistic EEG signal the highest PSD value obtained is 52.17 dB/Hz in the autistic EEG signal of the 2nd subject. From the results obtained, it can be seen that the PSD value obtained is getting lower as the frequency increases in both normal EEG signals and autistic EEG signals.

2) PSD analysis of the theta sub-band

The next frequency sub-band to be analyzed is the Theta frequency sub-band in the frequency range of 4 Hz to 8 Hz. It can be seen in Fig. 8 to Fig. 11 that the PSD value obtained in autistic and normal EEG signals is lower than the previous Delta sub-band. This is because the PSD value will be lower as the frequency increases, just like in the previous Delta sub-band. The PSD value on the autistic EEG signal is higher than the PSD value on the normal EEG signal. In the normal EEG signal, the highest PSD value obtained is only 15.26 dB/Hz in the 2nd normal subject, while in the autistic EEG signal, the highest PSD value obtained is 43.4 dB/Hz in the 2nd autistic subject.

3) PSD analysis of the alpha sub-band

It can be seen, Fig. 11 shows the Alpha sub-band (8 Hz-15 Hz) of autistic and normal EEG signals. In both normal EEG signals, there is an increase in PSD value along with the increase in frequency, whereas this does not occur in autistic EEG signals. In the autistic EEG signal, the PSD value continues to decrease as in the previous frequency sub-band. However, the PSD value obtained in the autistic EEG signal remains higher than the normal EEG signal, just like in the previous frequency sub-band. In the autistic EEG signal, the highest PSD value obtained is 37.76 dB/Hz in the 2nd autistic subject, while in the normal EEG signal, the highest PSD value obtained is only 10.31 dB/Hz in the

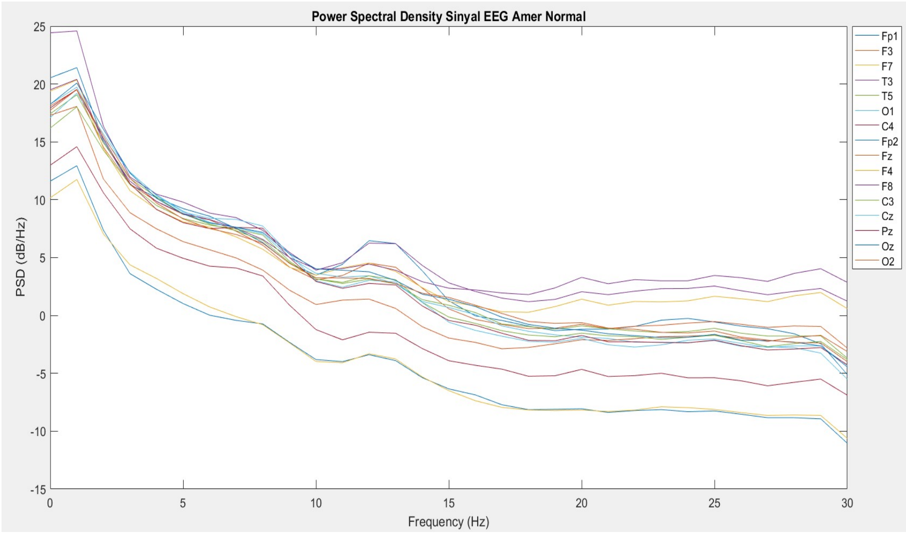

Fig. 8. PSD value of EEG signal of 1st normal subject.

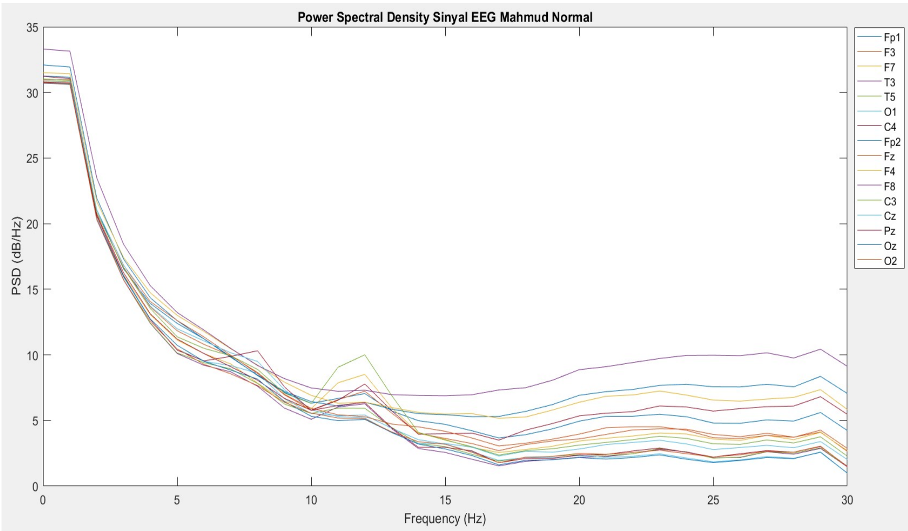

Fig. 9. PSD value of EEG signal of 2nd normal subject.

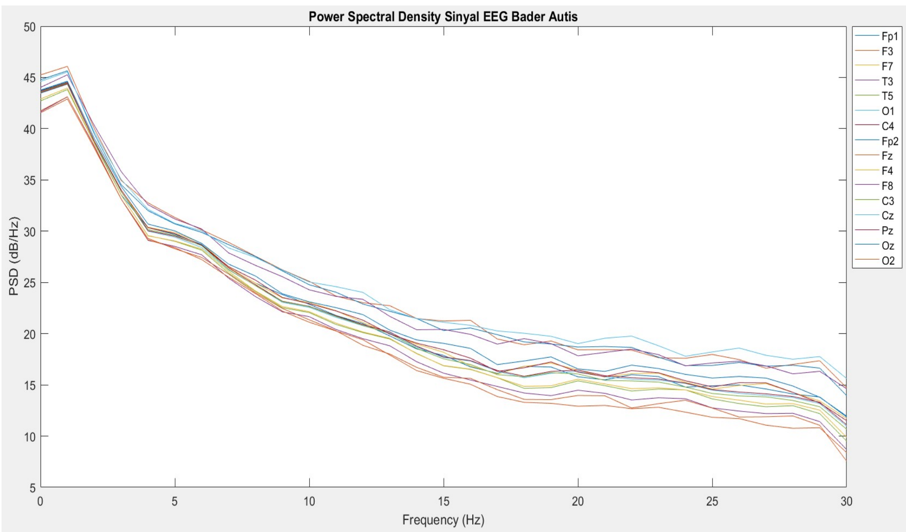

Fig. 10. PSD value of EEG signal of 1st autistic subject.

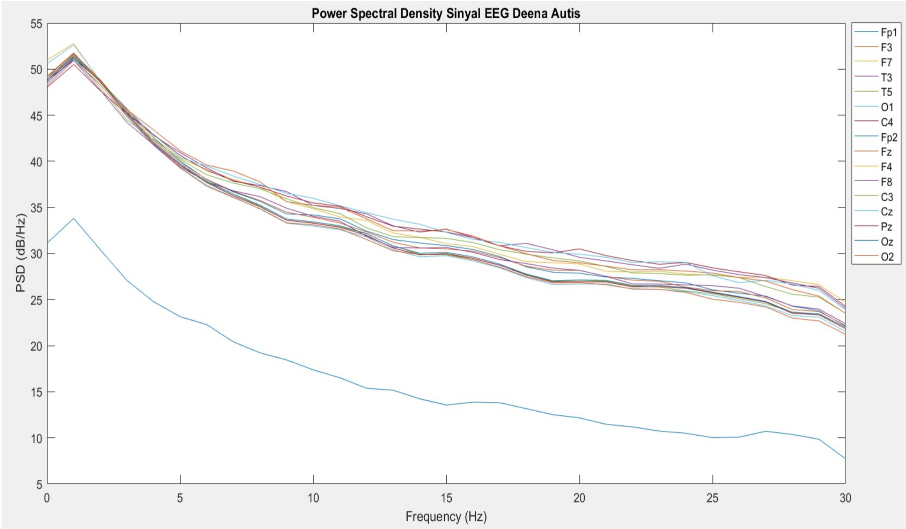

Fig. 11. PSD value of EEG signal of 2nd autistic subject.

2nd normal subject.

4) PSD analysis of the beta sub-band

In the Beta sub-band (15 Hz-30 Hz), the same thing happens as in the Alpha sub-band, where in the Beta sub-band, there is an increase in the PSD value in normal EEG signals along with the increase in frequency as seen in Fig. 8 and Fig. 9. While in the autistic EEG signal, the PSD value decreases as in the previous frequency sub-band. The Beta sub-band has the lowest PSD value compared to the previous sub-band, and this is because the Beta sub-band has the highest frequency compared to other sub-bands. The PSD value in the autistic EEG signal is also higher in this Beta sub-band, where the highest PSD value obtained is 32.64 dB/Hz in the 2nd autistic subject. In comparison, in the normal EEG signal, the highest PSD value is only 10.43 dB/Hz in the 2nd normal subject.

IV. Discussion

After obtaining the PSD value in the Delta, Theta, Alpha, and Beta frequency sub-bands on all normal EEG signals and autistic EEG signals, it can be said that the PSD value obtained on the autistic EEG signal is higher than the normal EEG signal as a whole in the frequency range 0 Hz to 30 Hz, this is following what was obtained in previous studies [6], that the PSD value in subjects affected by brain disorders has a higher PSD value compared to normal subjects. What distinguishes this study from the previous study [6] is that in the previous study, the PSD value obtained was the PSD value in people with brain disorders in general. Whereas this study only focuses on autistic people. This study analyzes the PSD value in each frequency sub-band (Delta, Theta, Alpha, and Beta). Unlike the previous study [6], the PSD value is analyzed only in general. It can be seen from the study results that the Delta frequency sub-band has the highest PSD value of the other frequency sub-bands both in normal EEG signals and in autistic EEG signals. And the PSD value obtained in the autistic EEG signal is higher than the normal EEG signal, wherein the autistic EEG signal, the highest PSD value obtained is 52.17 dB/Hz in the Delta sub-band of the autistic EEG signal. And in the normal EEG signal the highest PSD value is only 33.14 dB/Hz in the Delta sub-band of the normal EEG signal. In addition, in normal EEG signals, there is an increase in PSD values in the Alpha and Beta frequency sub-bands, while in autistic EEG signals, the PSD values in the Alpha and Beta frequency sub-bands have decreased.

V. Conclusion

There are differences in PSD values obtained in autistic and normal EEG signals, where the autistic EEG signal has a higher PSD value than the normal EEG signal in all frequency sub-bands. It can be seen from the study results that the highest PSD value obtained by the autistic EEG signal is in the Delta sub-band, which is 52.17 dB/Hz, while the normal EEG signal is only 33.14 dB/Hz. And in the Alpha and Beta frequency sub-bands, there are differences in the pattern of PSD values obtained in normal EEG signals, were in both normal EEG signals, the PSD value increases in the Alpha and Beta sub-bands. In contrast, in autistic EEG signals, the PSD value decreases in both sub-bands. So this can also be a reference in detecting autism. FIR filter and ICA method also perform well in reducing noise and removing artifacts in EEG signals.

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