Autistic Spectrum Disorder: EEG Analysis and Classification

Z. H. Chan, R. Sudirman and C. Omar
Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia.
rubita@utm.my

***Abstract*—Autistic spectrum disorder (ASD) which also known as autism is a syndrome shows neurological disorder found in brain development. Autistic patients suffer from communication disorder and lack of social interaction. This study is aimed to integrate the Electroencephalogram (EEG) signal processing and classification into a graphical user interface (GUI). In this study, severity of the autistic children is classified into three stages, namely, mild, moderate and severe which determined from their sensory response. An electrical signal is obtained by attaching the electrode onto the scalp by following the rules of the system. Then, sensory response test is carried out. The targeted channels on the scalp of the subject are C_3, C_z and C_4. The signal obtained from these three channels processed for artefact and noise removal suing band pass filter. Features extracted from the preprocessed signal is analysed using Short Time Fourier Transform (STFT.) These extracted features will undergo multilayer perceptron neural network and genetic algorithm for the classification process. The task is performed by implementing the algorithms of signal analysis and classification in the simplest form into GUI. The pattern of the signal and the result of the autism severity are shown in the window from GUI. The GUI also allows the user to insert the profile of the patient as a record to prevent mixing of data and for reference purpose. The GUI designed has to successfully classify the sensory data to identify the level of severity of the autistic child.**

***Index Terms*—Autism; Electroencephalogram; Multilayer Perceptron; Spectrum disorder.**

I. INTRODUCTION

Autism Spectrum Disorder (ASD) is a behavioral syndrome. An autistic patient suffers from the non-verbal communication disorder, lack of attention and having difficulties in relatedness [1]. The children who suffer from autism have difficulty to involve themselves in the normal human interaction. For parents and children both with autism, they are unable to interpret the thinking and feeling of others. Besides that, they are also having difficulties in giving an opinion from another person's perspective.

With the aid of evidence provided in Boutros's study, for 25 autistic children, 30% of them have seizures and 80% of them have abnormal EEG [4]. This situation indicates the serious situation of the autism.

Electroencephalography (EEG) is a useful tool for the analysis of neurophysiologic disorders as it can provide a clearer understanding about the mechanism causing disorder [2]. Analysis of EEG signal involves data acquisition, signal filtering and feature extraction [3]. Raw signal obtained by using EEG machine is then filtered to remove unnecessary signal which known as noise. Interested feature of EEG signal extracted from the filtered signal through the process of STFT. STFT give the output signal in time-frequency representation. Classification of analyzed signal is done in this study, according to the severity of autism disorder. This precaution way prevents inappropriate treatment is given to the autistic patient.

There are many methods of signal classification such as a linear classifier which is useful for linear signal, Kalman filter which is an algorithm that needs transcendent knowledge, and artificial neural network (ANN) which is essential for nonlinear signal [3]. However, there are some limitations for the EEG signal analysis and classification by using neurological method, such as neural network allow exploration in new realms of human capabilities only with personal discipline and extensive training.

Therefore, the purpose of this study is providing another solution in analysis and classification of EEG signal by following the severity of autism to tackle the rising number of autistic patients.

II. LITERATURE REVIEW

A. Sensory Response in Autism

Sensory response is declared as feature of diagnostic conditions. Five types of sensory of a child included visual, taste, vestibular, touch and sound. Sensory responses are important for the human brain to analyse and produce knowledge, perception and awareness [5]. Research on the sensory response indicator results in audio gives the highest sensory response and followed by a taste of salt and taste of sweet [2]. Visual sensory gives the lowest response among the children due to inability to focus.

Taste is the sense that arises from sensation originating in our mouth which involved the interaction of water soluble chemicals with taste buds [6].

Sensory response is declared as feature of diagnostic conditions [7]. Sensory responses are important for the human brain to analyze and produce knowledge, perception and awareness [2]. The types of sensory required in this study are three tastes sensory (salty, sour and sweet), vestibular, touch, audio and visual.

B. Electroencephalogram (EEG) Measurements on the Human Brain

The electroencephalogram (EEG) is a record of time series of potentials caused by systematic neural activities in the brain. By placing electrodes with conductive gel filled on the gab of scalp, the human EEG signal is measured [7]. In this study, 10-20 EEG system is used to read the pattern of brain activity in autistic children through sensory stimulation. Nasion – inion distance is measured and the labeling of the electrode placement is based on the adjacent brain areas [2]. EEG signal can be classified into different bands, namely, gamma, beta, alpha, theta and delta [6], refer to Table 1 for detailed distribution.

Table 1
Wavelet Coefficient of EEG Signal

Wavelet Coefficient	Rhythm	Frequency (Hz)
D1	Noise	250-500
D2	Noise	125-250
D3	Noise	60-125
D4	Gamma	30-60
	High Beta	18-30
D5	Mid range Beta	15-18
	Low Beta	12-15
D6	Alpha	8-12
D7	Theta	3-8
D8	Delta	0.1-3

The level of consciousness of a person will decide the EEG signal. When the activity decreases, the EEG will be shifted to lower frequency but with higher amplitude. For example, when the person is falling asleep, the dominant EEG frequency will decrease. On the other hand, when the person's brain is actively solving problem, the dominant EEG frequency will increase [6].

Employment of EEG analysis can be used to investigate the anomaly of neuro development between brain hemispheres of an autistic child [1]. Studies show that the dipole of midline spikes is present in the deep midline frontal lobe of the brain. The results obtained from the study show that the frontal dysfunction takes the important role in the mechanism of symptoms in autism [7]. One of the research shows that the low alpha band gives less coherence for autistic patient and frontal lobe has low connectivity with the rest of the cortex.

C. Feature Extraction

Short-Time Fourier Transform (STFT) is introduced to apply in EEG spectral analysis process. STFT act as a local frequency parameter to the window over the EEG signal so that the signal is approximately stationary [8]. The calculation for the Fourier Transform of the windowed signal is shown in (1) [9].

$$F(\omega) = F(f(t)) = \int_{-\infty}^{\infty} e^{-i\omega t} f(t)dt \qquad (1)$$

D. Neural Network

Neural network (NN) is a computer modeling system designed for classifying the analysed signal [12]. In this study, multilayer perceptron neural network is used to classify the EEG signal into different class of autism severity [10]. Feed-forward Neural Networks is a better way to handle the task in pattern recognition and regression due to its adaptable non-linear structure [11]. Figure 1 shows the architecture of a multilayer perceptron neural network used in this study.

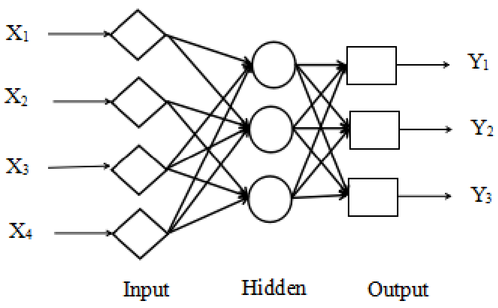

Figure 1: Multilayer perceptron neural network

Figure 1 shows that the multilayer perceptron consists of three stages, namely input layer, hidden layer and output layer which are interconnecting nodes throughout the system [14].

III. METHODOLOGY

The flow of the study includes preprocessing of raw signal, feature extraction, training of neural network, classification of signal and development of GUI which integrates analysis and classification of signal. The whole process is shown in the flowchart in Figure 2.

A. Subject

There are a total of 30 subjects which carrying abnormal condition being used in this study included 26 subjects for building the neural network while another 4 subjects for testing the network. All of the subjects are the autistic patients who aged between 1 to 12 years old. The acquired subjects contain the sensory signal from a sense of salty, sour, sweet, touch, vestibular, audio and vision.

B. Data Acquisition

This study is conducted based on the sensory response of the autistic children. The targeted tastes sensory are salty, sour and sweet which, stimulated by using different solution, namely salt solution, vinegar solution and sugar solution respectively. Before the process of data acquisition is conducted, the subject is made sure to be relaxed and sit comfortably to avoid the signal is interrupted by further physical movement. Neurofax JE-921A multi-function electrode junction box is used to obtain data by setting sampling frequency at 500Hz. The process of data acquisition is conducted in a dark and quiet room to reduce the noise present in the signal. To obtain more accurate results, plain water is given to wash away the residual taste stimuli in between changing the different solution. This precaution step is taken to prevent the stimuli from mixing with the next stimuli. After the process is done, the data obtained is recorded and saved in ASCII file of the recording computer.

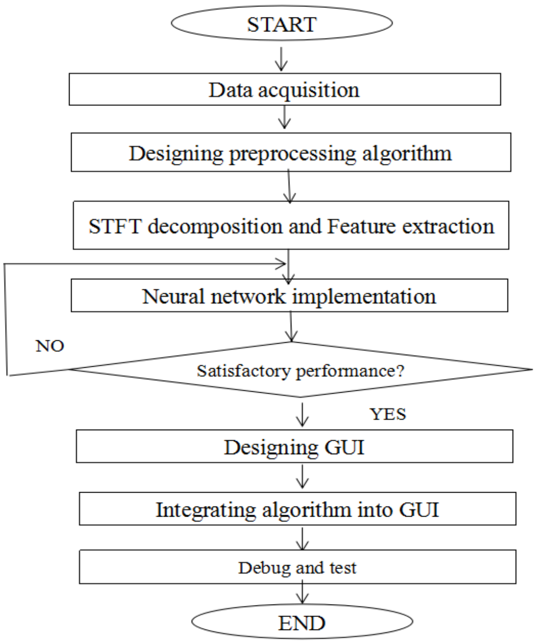

Figure 2: Flow process of the study

C. Filtering of Signal

The band pass filter is designed with the interested frequency band of the signal is set between 0.4 Hz to 60 Hz as the targeted frequency band (alpha band) is lie between the interested frequency bands [10-11]. The algorithm for this part works to remove the noise from the signal. The flat line of the signal from 0Hz to 800Hz is removed as there is no signal detected. The significant fluctuation of the signal from 800 to 2500 ms is also removed as noise detected. The trimmed signal has then undergo filtering process. The parameter of the filter is shown in Table 2.

Table 2
Specification of Band Pass Filter

Type of filter	FIR band pass filter
Order of filter	100
Low cutoff frequency	0.4 Hz
High cutoff frequency	60 Hz
Sampling frequency	500 Hz

D. Signal Decomposition & Feature Extraction

In this study, Short time fourier transform (STFT) is chosen to extract the targeted feature from preprocessed signal. STFT perform the feature extraction by using equation (2).

$$F(w,\tau)=\int_{-\infty}^{\infty} f(t)\psi^*(t-\tau)e^{-jwt}dt \qquad (2)$$

The Alpha band is interested in this study as the autistic characteristic can be analyzed through the band. Different autism severity gives different amplitude in alpha band frequency. Alpha band is extracted for analysis to eliminate the unwanted signal and fasten the process of analysis. Accurate results can be obtained through feature extraction as the algorithm system only work on the targeted signal [11]. The algorithm is illustrated in Figure 3.

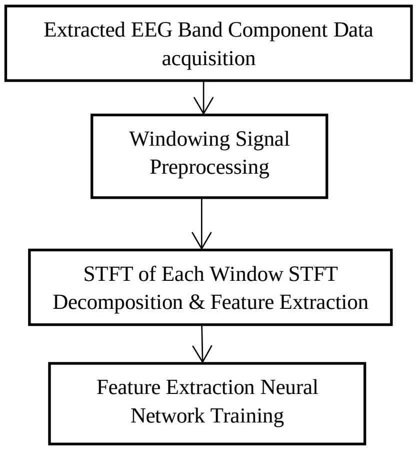

Figure 3: Process of signal decomposition and feature extraction

E. Neural Network

For classification of the analyzed signal, multilayer perceptron neural network is designed. It consists of three stages which is an input layer, hidden layer and output layer. An input pattern is inserted into the input layer, pass through the hidden layer and the result shown in output layer by setting different parameters [14]. From the experiment, we found that 8 hidden layers give the highest accuracy of classification. The mean squared error of the network is calculated using Equation (3). Mean squared error allows us to measure the quality of the network with the application of the settings.

$$MSE(t)=\frac{1}{n}\sum_{i=1}^{k} f_i(x_i-t)^2 \qquad (3)$$

F. Graphical User Interface (GUI)

A GUI is designed to integrate the developed algorithm to ease the non-professional personnel in carrying out the signal classification. The designed GUI is user-friendly and able to save and show the result in simplest form by analyzing and classifying the EEG signal which obtained from the sensory stimuli.

In this study, the GUI in designed to integrate both analysis and classification of EEG signal. The analyzed signal is processing in the same path with the classification to ease the user in the medical process. The integrated system is named as autiSmart. It is user friendly and provides fast response. The flow of the autiSmart is shown in Figure 3 which includes the integration between analysis and classification of EEG signal. The main page of the autiSmart is shown in Figure 5 which load the patient's data while Figure 6 shows the summary of patient's data and the result from signal analysis and severity classification.

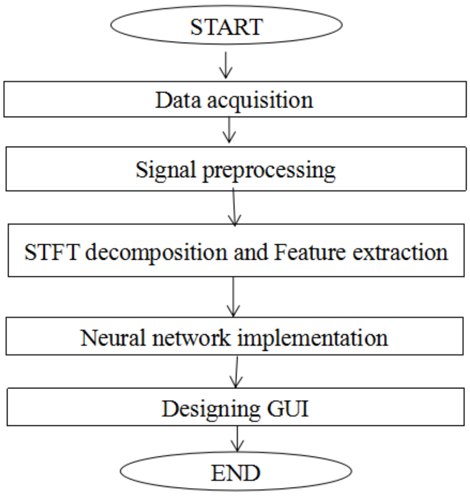

Figure 4: Flow of autiSmart

Figure 5: Main page of autiSmart

Figure 6: Result and summary of patient's data

IV. RESULT AND DISCUSSION

The raw signal obtained from the patient has undergo the signal preprocessing. The artefact of the signal is removed and sent to the process of feature extraction.

In this study, there are 26 subjects used in training, validation and testing for the neural network training. There are 17 subjects used as training samples, 6 subjects as validation samples and 3 subjects as testing samples. The architecture of the training network is shown in Figure 7. The parameters are set to give the greatest performance in classification of analysed signal.

Table 3
Setting Parameters for Neural Network Training

Parameter setting	
Training percentage	65%
Validation percentage	25%
Testing Percentage	10%
Hidden neurons in hidden layer	8

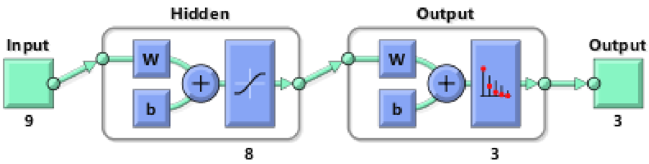

Figure 7: Architecture of neural network

By setting the parameters of the neural network as in Table 3, the result yields an accuracy of 96.2%. Mean squared error obtained from the network is 0.0336 which is quite high due to larger amount of features of the signal. The best performance from validation obtained at epoch 17 which shown in Figure 8. The cross-entropy achieved by the network is 0.21697.

There are 4 samples reserved to test with the trained neural network system. These signals undergo the same flow of signal preprocessing, feature extraction, signal decomposition. The decomposed signals were classified by using the trained neural network and the results of classification are shown in Table 4. All the four subjects get the same output result as the expected severity.

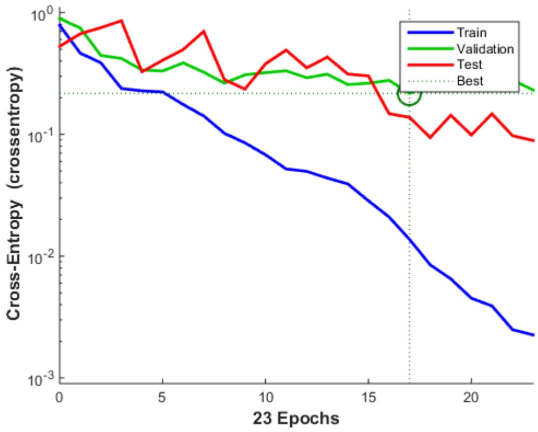

Figure 8: Plot of the best validation performance

Table 4
Result of Classification Testing

Subject	Expected severity	Classification Output (%)		Result of severity
6	Mild	Mild	54.35	Mild
		Moderate	24.74	
		Severe	20.91	
10	Moderate	Mild	8.56	Moderate
		Moderate	48.07	
		Severe	43.37	
26	Severe	Mild	7.40	Severe
		Moderate	42.78	
		Severe	49.82	
36	Severe	Mild	0.02	Severe
		Moderate	3.00	
		Severe	96.98	

V. CONCLUSION

The different sensory signal is obtained to process in this study. STFT able to decompose the EEG signal into different frequency band which is representing different brain activity. STFT helps in the process of feature extraction which extracted the Alpha band of the autistic patient's EEG signal. Training neural network with the extracted signal from STFT shows that the result of accuracy reaches 96.2%. The testing data was classified correctly by the trained network.

In the future, researchers might build a hardware model for this system, including analysis and classification of EEG signal by using Field Programmable Gate Array (FPGA).

ACKNOWLEDGMENT

The author would like to express the appreciation to Universiti Teknologi Malaysia for funding the research under research university grant scheme vote number 12J09.

REFERENCES

[1] C. L. Chuin, "Electroencephalograph Signal Classification for Autistic Spectrum Disorder using Multilayer Perception," *Final Year Project Report*, Universiti Teknologi Malaysia, Malaysia, 2015.

[2] S. S. Hussin and R. Sudirman. "Sensory response through EEG interpretation on alpha wave and power spectrum," in *Malaysia Technical Universities Conference on Engineering & Technology 2012*, Perlis, 2012, pp. 288-293.

[3] R. Vigario, J. Sarela, V. Jousmaki, M. Hamalainen, and E. Oja, "Independent component approach to the analysis of EEG and MEG recordings," *IEEE Transactions on Biomedical Engineering*, vol. 47, no. 5, pp. 589-593, 2000.

[4] N. N. Boutros, R. Lajiness-O'Neill, A. Zillgitt, A. E Richard and S. M. Bowyer. "EEG changes associated with autistic spectrum disorders," *Neuropsychiatric Electrophysiology*, vol. 1, no. 3, pp. 1-20, 2015.

[5] S. S. Hussin and R. Sudirman, "EEG interpretation through short time fourier transform for sensory response among children," *Australian Journal of Basic and Applied Sciences*, vol. 8, no. 5, pp. 417- 422, 2014.

[6] M. Okamoto and I. Dan, "Functional near-infrared spectroscopy for human brain mapping of taste-related cognitive functions, "*Journal of Bioscience and Bioengineering*, vol. 103, no. 3, pp. 207-215, 2007.

[7] A. Hyvärinen. "Fast and robust fixed-point algorithms for independent component analysis*". IEEE Transactions on Neural Networks*, vol. 10, no. 3, pp. 626-634, 1999.

[8] S. Reynolds and S. J. Lane, "Diagnostic validity of sensory over-responsivity: a review of the literature and case reports," *Journal of Autism Development Disorder*, vol. 38, pp. 516- 529, 2008.

[9] A. Sheikani, H. Behnam, M.R. Mohammadi and M. Noroozian, "Analysis of EEG background activity in Autism disease patients with bispectrum and STFT measure", in *11th WSEAS International Conference on Communications*, Agios Nikolaos, Crete Island, Greece, 2007, pp. 318-322.

[10] M. K. Kiymik, I. Guler, A. Dizibuyuk and M. Akin, "Comparison of STFT and wavelet transform methods in determining epileptic seizure activity in EEG signals for real-time application," *Computers in Biology and Medicine*, vol. 35, no. 7, pp. 603- 616, 2005.

[11] A. Delorme and S. Makeig, "EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis," *Journal of Neuroscience Methods*, vol. 134, pp. 9-21, 2004.

[12] S. K. Pal and S. Mitra, "Multilayer perceptron fuzzy sets, and classification", *IEEE Transactions on Neural Networks*, vol. 3, no. 5, pp. 683- 697, 1992.

[13] S. Chauhan and S. Dhingra, "Pattern recognition system using MLP neural networks," *International Journal of Engineering Research and Development*, vol. 4, no. 9, pp. 43-46, 2012

[14] M. G. Bello, "Enhanced training algorithms, and integrated training/architecture selection for multilayer perceptron networks", *IEEE Transaction on Neural Networks*, vol. 3, no. 6, pp.864- 875, 1992.