Development of a microcontroller EEG-based system for diagnosis of autism spectrum disorder in developing countries

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Abstract: Biomedical signals consists of records of electrical activity in the human body, and they represent the health status of individuals. The biomedical signal otherwise called neural signals includes Electro-encephalogram (EEG) Signals, Electro-cardiogram (ECG) Signals, Heart Rate Variability (HRV) Signals, Electro oculogram (EOG) Signals, Electro-myogram (EMG) Signals, magnetoencephalography (MEG) signals, and electro gastrography (EGG). It is often difficult for health practitioners to visually examine these long records to diagnose a patient to arrive at conclusions. The process of classifying a biomedical signal is done by carefully attaching a signal to a disease state or healthy state and also the quality of features extracted from the signals, well pre – processed signal and the classification process determines the classification Accuracy (CA). The spectral content of the signals contains critical information on state of health of a person that can used for early detection of a particular disease. Developing an Automated system which could help in Automated classification of these signals can greatly assist the Doctors and non-technical individuals in the diagnostic process. In response to the above drawback, this paper intends to develop a prediction machine in a dual level approach using a Microcontroller EEG - based system and machine learning Algorithms for early diagnosis of Autism Spectrum Disorder using EEG signals. The performance of the proposed system will be evaluated using CA, amplitude, power frequency ratio, execution time, specificity, sensitivity, power spectral density ratio, memory usage and power consumption in a microcontroller platform time.

Keywords: Electro-encephalogram Signals, Microcontroller, Genetic Algorithm, Particle Swamp Optimization, Wavelength Packet Transform, Prediction.
1. Introduction

Autism Spectrum Disorder (ASD) is a condition whereby a child has a difficulty interacting with people, and also such child may have difficulty expressing his/herself verbally and non-verbally. They also possess odd behaviors by repeating certain actions over and over again and acting as if something does not go according to normal. ASD is one of the most prevalent neuro developmental disorders in the world today, and are characterized by delay in speaking, repeating certain behaviors, inability to make eye contact when communicating with others and they can’t understand what others are thinking because of their inability to socialize. ASD are greatly caused by the mixture of prolong labor during child birth, environmental and genetic factors. Studies have shown that ASD occur in three to six children for every 1000 that are born [5], with prevalence of about 25 to 110 per 10,000 children. It is also shown that the family members of a child with ASD will have about 2-8% higher incidence rate than in the general population. Moreover, recent studies also showed that ASD occurs more frequently in males than females [5]. The prevalence of ASD has been growing exponentially worldwide due to a few objective lab test, few diagnostic criteria and inadequate public awareness of the disorder. ASD prevalence varies in different continents as follows; Europe with a median of 18.75 per 10,000, 1.4 per 10,000 in Oman, 29 per 10,000 for PDD (pervasive developmental disorder) in the UAE, US with a median of 21.6 per 10,000, 4.3 per 10,000 in Bahrain, Saudi Arabia, there are 42,500 autism cases diagnosed, with many cases remained undiagnosed. Moreover, and China having a lower median of 11.6 per 10,000. In Gulf Cooperation Council (GCC) countries, ASD is considered as one of the most common disabilities and with studying the condition very rare [10].

Due to the prevalence of ASD and financial need associated with it, it has resulted to an economic burden on the society and the families of the affected children. There are various forms of ASD which include Asperger’s syndrome and childhood disintegrative disorder [1]. Some may live a normal life and some needs others assistance all through their lives [16]. The symptoms of ASD usually start showing between 15-18 months of age and it takes an average of four to five years age to diagnose. Due to this, a system would be needed for prompt therapies and early detection.

1.1 Causes of Autism Spectrum Disorder

ASD is believed to be predominantly caused by the combination of prolonged labor, genetic and environmental factors. Recent studies showed that prolonged labor can cause ASD due to starvation of oxygen and blood to the brain as a child head is squeezed through the vagina during prolonged labor are being done to interplay the contribution of both, others are as a result of the parent genes and environmental factors which includes parental Age, Maternal Smoking and Alcohol Consumption, Medication use during Pregnancy, Air pollution. Fetuses itself can come in contact with these environmental factors through maternal circulation and can alter normal neurodevelopment. The part of the brain called SOCIAL BRAIN that have been identify deficient in Autistic patients are the ORBIT-FRONTAL CORTEX, SUPERIOR FRONTAL SULCUS & AMYGDALA. This part of brain is responsible for social intelligence.

1.2 Symptoms of Autism Spectrum Disorder

They include:

i. Communication impairment
ii. delay in language
iii. Some actions or interest are repeated severely
iv. Social skills/interaction is reduced
v. Intellectual disability, epilepsy, sleeplessness etc

2. Electroencephalography (EEG) signals:
They are neural signals used for diagnosis of diseases that occurred in the brain. EEG is a tool used to classify different neurological impairments such as Autism Spectrum Disorder, Epilepsy, sleep disorder, dementia and brain death etc. EEG has been found to contain information about patient’s psychophysiological state and also contain different pattern associated with various mental states. In Figure 1 & 2 below, sample of raw normal EEG signal and Autistic EEG signal are presented respectively.

![Figure 1 Sample of raw normal EEG signal](image1)

![Figure 2 Sample of Autistic EEG signal](image2)

2.1 Ways of Recording EEG signals
There are two major ways through which EEG signal could be recorded.

2.1.1 Non-invasive recording: This is otherwise called scalp recording. It involves mounting of an electrode on the scalp for EEG recordings. It is usually simple, harmless and easy way to record.

2.1.2 Invasive Recording: This is otherwise called inter-cranial EEG. This method of recording involves electrode being implanted on the brain or brain surface.

This model will utilize the former because of its simplicity and ease of recording. EEG signal are divided into different frequency bands such as delta which ranges between 1-4 Hz (deep sleep), theta ranges between 4-8 Hz (sleepy/sleep transition), alpha ranges between 8-13 Hz (awaken and relax while eye closed), beta ranges between 13-30 Hz (state of awake and alertness) and gamma > 30 Hz (attention). EEG signals contain high level of dynamism due to constant change of its period; amplitude, phase and frequency. They are often complex and difficult to interpret. As a result of this, a physician who will make diagnosis should be a good observer with more years of experience. A microcontroller EEG-based model for early detection and diagnosis of ASD is built in order to derive useful knowledge from records of brain electric operation. In Figure 3, a sample of electrode on scalp for EEG non-invasive method of recording is presented.
2.2. EEG signals Feature

They contain the followings:

1. Wavelength
2. Voltage
3. frequency
4. Waveform
5. Manner of occurrence (random, serial, continuous)
6. Locus
7. Reactivity (eye opening, mental calculation, sensory stimulation, movement, affective state)

3. Problem definition

Recent studies have shown the prevalence of ASD which has increased due to few objective lab tests for early diagnosis, lack of satisfactory screening tools, lack of experienced Doctors to accurately interpret EEG signals, and a huge financial burden on the family of the affected child and the society.

This model will present a generic prediction support system which supports EEG data with different characteristics (differences in devices used for data collection, data types, sampling rate) and with simple user-friendly GUI to facilitate non-technical users for the early detection, therapy and control of ASD in developing countries.

4. Literature survey

This analysis presented a non-invasive system utilizing the electroencephalography signal for detection of Autism Spectrum Disorder.

In the work presented by Nair et al [3] carried out an experiment to classify Autism through brain MRI analysis, the dataset is collected from ABIDE database that consist of human brain image data which is affected by Autism. The brain images are downloaded in 3D format and using MRI slicer the 3D images are sliced and converted to 2D form. The pre-processed image is segmented in order to extract feature, segmentation is executed using Otsu segmentation technique. The white matter region is segmented and the feature is extracted using PCA technique. The features like Mean, RMS, SD, energy, homogeneity features are extracted and classify the image based on the extracted feature using naïve Bayesian technique to get accuracy up to 88.3%. In [4] researcher, carried out a review of processing and
classification methodologies for Autism Spectrum Disorder from 2010 to 2018, datasets of different file format such as vhdr, vnrk, .edf) signals were sampled using various frequencies of 128hz, 250hz, 256hz and 500hz. The methods are divided majorly into four phases namely data collection, pre-processing, feature extraction and classification. The present study examines numerous pre-processing techniques and tools, feature extraction and feature collection, classification, and measurements for analyzing the model with the strengths and disadvantages of the studied techniques and tools. Dan Liu et al[7] performed a Surface EEG Signal Quality Assessment Analysis focused on a Fuzzy Detailed Evaluation, the evolved model employs Amplitude, Power Frequency Ratio, and PSD (Power Spectral Density) Alpha Band Resting EEG Signal as Performance Assessment Indicators, and conducts a quantitative Signal Quality Assessment. The model is capable of assessing the EEG signal strength with low computational complexity, and is also capable of displaying the results of the EEG quality measurement in real time. The limitation is that the model is not applicable to non-resting EEG signalsIn [8], the Assessment of feature extraction methods for the Internet of Things Electroencephalograms was performed out using three (3) Feature Extraction Techniques, namely Filter (FIR), FFT (Welch Method), DWT and Microcontroller (MSP432P401R). The three (3) feature extraction techniques are applied on EEG signal and the results of each passed to Microcontroller for evaluation based on the following performance evaluation metrics, they are execution time, memory usage & power consumption. Welch's method and DWT worked slightly better than FIR after evaluating each of the parameters in a particular way, in terms of the time of service. For the usage of memory, the extraction of features was separately tested by Flash and SRAM. DWT and FIR displayed strong Flash memory usage results, although FFT Welch's approach worked better for the SRAM. For any of the methods, power consumption is comparable, and energy was also calculated to prove that the effects are comparable with respect to implementation time. Better than FIR, the FFT (Welch's method) and DWT do. The outcome demonstrates that power usage relies on the time of implementation. In [13], the author optimizes the PSO BPNN parameter for EEG signals in which EEG signal data reports are retrieved from the clinic. At a sampling rate of 256 Hz, the data was collected. Discrete Wavelet Transform (DWT) is applied to patients with normal epilepsy and brain death for reported EEG signals obtained from the clinic for feature extraction. Back Propagation neural network (BPNN) optimized by particle swarm optimization to reduce training time is used for classification. The hybridization of ANN and PSO for classification produced an improved accuracy which later dropped as the number of hidden layers of ANN increases.

5. Proposed Methodology

The aim of this research is to develop a model for the early diagnosis of Autism Spectrum Disorder for Doctors and non-technical users as illustrated below. The system consists of four main steps. The first step is the Signal acquisition; the second step is preprocessing to remove the noise and artifacts (unwanted signals). The third step is feature extraction from the EEG signals. The fourth step is classification of the signal to be either Autistic or non-Autistic. The Figure 4 below show the block diagram of the proposed system.
1.1. **Data Acquisition**

Acquisition of EEG Signal segments: The first step in the classification methodology is the data acquisition with emphasis on the technical details of EEG data collected and on its metadata. These determines the next phase of classification process.

The metadata details are:

a. Electrodes number  
b. The locations of electrode: EEG output are generated based on a reference point  
c. EEG montage: gives information about reference point  
d. The rate at which the frequency is sampled  
e. The duration of the recording  
f. The activities of the subjects during recording and the data types.

There are different kind of meta data file format such as (.vhdr, .vmrk, .eeg), European data format (.edf) one of which will be used with International 10-20 system recognized electrode placement standard in this research.

5.2 **Pre-processing stage**

This stage involves Dimension Reduction and Artifacts removal: This stage is important so as to keep the integrity of the signal and to eliminate noise. This is to be achieved by

(i) Signal amplification using AD8421 amplifier: The amplifiers function is to increase the signal strength to a level useful information can be dealt with. Bio-signals are usually known to have a very low amplitude say μV and signal-to-noise ratio (SNR).

(ii) Filtering (low and high pass filter; Least Mean Squares (LMS) adaptive filter): This is done to limit the frequency band of the signal to desired band of interest to primarily eliminate noise. The high - pass filter provides details coefficients and low - pass filters provides approximation coefficients.

(iii) Analogue to Digital Converter (ADC): The recorded EEG signal is a successive transformation of analog to digital signal which is necessary for digital conditioning of the signal. This transformation is necessary to provide signal for efficacious signal processing and serve as input signal to the microcontroller.
(iv) **Microcontroller (PIC16F877A):** Microcontroller already contains all components which enable it to operate stand-alone and it has been designed in particular for monitoring and control tasks. In consequence, in addition to the microprocessor, it includes memory, various interface controller, one or more timer, an interrupt controller and general purpose I/O pins which allow it to directly interact with its environment. It shall be used in this research for spectral analysis for information identification, analogue–digital signal conditioning, digital signal processing, transmission time reduction and signal compression.

### 5.3 Feature Extraction

The feature extraction could be described as the transformation of one or several EEG signals into a feature vector using:

(i) **Wavelength Packet transform (WPT):** WPT is a variation of Discrete wavelength transform (DWT) which decompose the signal into detail coefficient provided by high-pass filter $h(n)$ & approximation coefficients provided by low pass filter $g(n)$ to obtain a first level of decomposition for time–frequency decomposition. In this work a multi-level WPT decomposition with *Daubechies–four* (db4) mother wavelengths will be used in order to extract five EEG sub bands and to achieve better results in feature extraction stage using the following performance metrics such as CA of the model, Power frequency ratio, Amplitude of the signal, Power Spectral density ratio, Specificity (False acceptance rate), Sensitivity (True rejection rate), time of execution, memory requirement and power consumption in a microcontroller platform Time.

The selected feature extraction technique will be implemented using a development kit MSP432P401R Launch pad from Texas Instrument. The EEG test signal will be provided as input to WPT code and the output will be extracted from the Microcontroller. The extracted signal will be imported to MATLAB for simulation. Figure 5 below show the Multiple WPT decomposition of signal.

![Multiple WPT decomposition of a signal](image)

**Figure 5.** Multiple Level Discrete Wavelet Decomposition of a signal

$g[n] = \text{low-pass filter}$

$h[n] = \text{high-pass filter}$
(ii) Back propagation Neural Network (BPNN) will be enhanced using Particle Swamp Optimization (PSO) during training and testing of the system as a result of large time duration of BPNN learning and rehearsing during EEG classification. This aforementioned defect will be eliminated by PSO. The BPNN comprises of one input layer, one or more hidden layers and one output layer. BPNN is a supervised learning algorithm that is capable of checking if the input information that is sent to the hidden layers is different from what is expected at output layer. Then, the output error will be calculated and the weight between the neurons of all the layers is modified and adjusted to minimize the error. By this, the network is said to be rehearsed for the given data or application. During the rehearsing, lengthy time is involved. In order to combat this drawback, PSO algorithm is applied in feed forward neural network to enhance the learning process by detecting numbers of neurons in the hidden layers, and estimate the optimum value for initial weight and biases for BPNN which enhance the convergence rate and classification accuracy.

5.4 Classification
This is the task of resolving class of variable. In other word is the task of predicting the category of the target variable as Autistic or non-Autistic. This involves predicting the class of Autism Spectrum Disorder based on EEG signal parameters. For this task an evolutionary algorithm named Genetic Algorithm (GA) will be used to evaluate

(a) Developed System: Performance Analysis: Evaluate time and Quality response of the proposed System considering different parameters using tables and graphs. In Figure 6 below the proposed model is presented.

![Proposed Model Diagram](image-url)

Figure 6. The proposed model

Conclusion
In this research a Microcontroller EEG –based system is proposed using (Amplifier, low & high pass filter, ADC, Microcontroller) for dimension reduction and Artifacts removal from multiple EEG signal
segments, Wavelength Packet Transform (WPT) for feature extraction, PSONN for training the model for discriminant sequence subset that becomes the optimized parameter used by GA for Prediction/Diagnoses of Autism Spectrum Disorder. It is expected that the proposed system will help in designing decision support system that support EEG data with different characteristics and with a simple user-friendly GUI device that can be used by Doctors and non-technical users in developing countries to detect, diagnose Autism Spectrum Disorder, therapy and remedy.

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