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Embedded Implementation of Brain Computer Interface Concept Using FPGA

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Abstract: ***The brain computer interface (BCI) is a fast growing technology which aims to build a direct communication pathway between brain and external device. The motivation behind this concept is to restore the capabilities of humans with severe motor disabilities and improve physical easiness in life. This work aims to develop a new System on Chip (SoC) that can be used for controlling electronic devices using EEG signals under various mind set of people with disabilities. The EEG signals obtained through the electrodes are filtered using EEG filter block implemented through Verilog, extraction of useful features from it, and to perform the corresponding activity which is intended by the person with disabilities.***

Keywords: brain computer interface (BCI), System on chip (SoC), EEG, Verilog, Extraction

1. Introduction

In 1924, Hans Berger discovered the electrical activity of human brain. At that time, Acquisition of brain data and it's processing to help a person with a motor disability was a distant thought. Today with the availability of low cost electronic systems and powerful processing tools has eased the bio-signal processing. These factors currently opened up the possibility of developing a system that allows restoration of person's capabilities with severe neuromuscular disorders and also makes their easier. A system which allows interfacing brain signals with computers is known as Brain computer interface (BCI).

Jacques Vidal [1] gave the first peer-reviewed publication about brain computer interface (BCI) in 1977. BCI is a communication technology, in which the humans can control various devices by using his or her imaginations [3]. This work aims to develop a System on Chip (SoC) technology which can be used for controlling electronic devices using EEG signals under various mind set of people with disabilities.

2. Brain Computer Interface

Electroencephalographic (EEG) measures of brain function and provide a new alternative channel for providing commands and messages to the external world. EEG signals from the brain are acquired by electrodes on the scalp and extract specific signal features that reflect the task-specific information by feature extraction. These signal features are translated into commands using classification scheme which operate a device.

2.1 Basic Components of BCI

A brain computer interface system has four components: (1) signal acquisition, (2) feature extraction, (3) feature classification, and (4) output device. The basic design and operation of a BCI system is represented in the Figure 1.

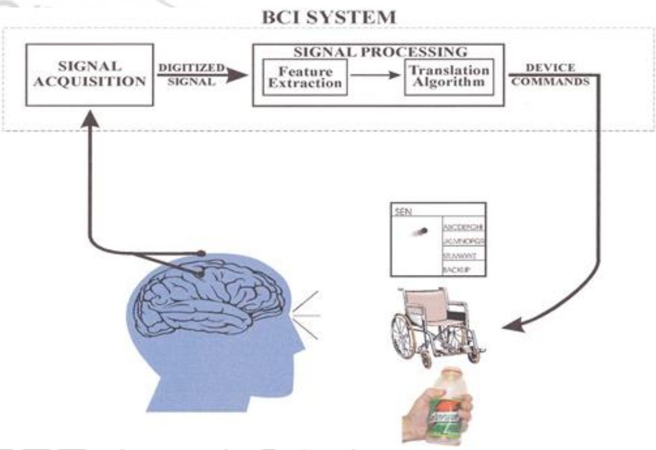

Figure 1: Basic design and operation of any BCI system

The signal acquisition is carried out by the EEG recorder. Such signals are amplified to a particular level which is suitable for signal processing, then it is digitized and transmitted to a computer for further processing. The digitized EEG signal is processed in frequency domain for feature extraction.

The resulting signal features are then passed to the translation algorithm, which converts these signal features into device commands orders that will perform the patient imagination. For example, a P300 potential translated into selection of the letter, or a power decrease could be translated into the displacement of a computer cursor [2]. The algorithm used in this work is flexible to adapt spontaneous changes in features and the user's possible level of values must cover the level of device control.

In a BCI system, the output device is a screen of a computer and the output is the icons presented on it, letters [5], or selection of targets [4]. Output is indicated in various ways such as cursor movement toward the item prior to its selection, or the feedback that the brain uses to maintain and improve the accuracy and speed of communication and some output is the user's own hand. The device operation gives feedback to the human, thus completing the control loop.

2.2 Brain Wave Patterns

The EEG is typically described as rhythmic activity and is divided into bands by frequency, they are called wave patterns and these patterns within a certain frequency range was noted to have a certain biological significance or a certain distribution over the head. Different types of wave patterns is indicated in Figure 2.

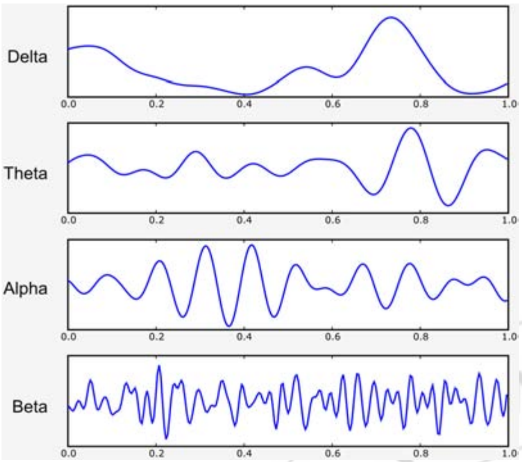

Figure 2: EEG wave patterns

2.2.1 Delta Waves

Delta is the frequency range up to 4 Hz depicted in Figure 2. It is known as slowest waves and its amplitude is the highest among other waves. It may occur in general distribution with deep mid line lesions, diffuse lesions and focally with sub cortical lesions.

2.2.2 Theta Waves

Theta is the frequency range from 4 Hz to 7 Hz depicted in Figure 2. Normally it is seen in young children, in meditation, may be seen in arousal in older children and adults, and in drowsiness. It can be seen as a focal disturbance in focal subcortical lesions, also it is formed in person of relaxed, meditative, and creative states. It may be seen in diffuse disorder or deep midline disorders or metabolic encephalopathy or some instances of hydrocephalus. Excess theta for age shows abnormal activity.

2.2.3 Alpha Waves

Alpha is the frequency range from 8 Hz to 12 Hz depicted in Figure 2. Hans Berger who initiated the study of rhythmic activity and he named it as "alpha wave". This is EEG activity in the 8–12 Hz frequency range seen in the posterior regions of the scalp on both sides of the brain and higher in amplitude on the dominant side. Closing the eyes and relaxation are the main situation of this activity and this rhythm is actually slower than 8 Hz in young children.

2.2.4 Beta Waves

Beta is the frequency range from 12 Hz to 30 Hz depicted in Figure 2. It is seen mainly on both sides and is most evident frontally. These activity is mostly happening during motor behavior and is attenuated due to active movements. Active, busy or anxious thinking and active concentration are the main reasons for this activity and it is a low amplitude with multiple and varying frequencies. Sometimes rhythmic beta is associated with drug effects and various pathologies, especially benzodiazepines. Beta is the dominant rhythm in patients who are anxious or alert or who have their eyes open and may be reduced or even absent in areas of cortical damage.

2.2.5 Mu rhythms

Mu rhythm is alpha frequency range activity that is normally seen over the sensorimotor cortex is depicted in Figure 3. It attenuates with movement of the arm or motor imagination of movement of the arm.

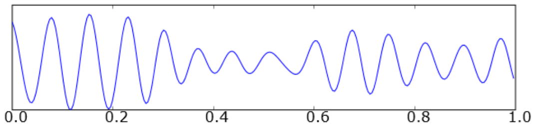

Figure 3: Mu rhythm wave pattern

2.2.6 Gamma Waves

Gamma is the frequency range approximately 30–100 Hz is depicted in Figure 4. Gamma rhythms are thought to attenuate with sudden motor sensory stimuli.

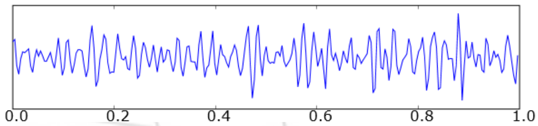

Figure 4: Gamma wave pattern

Out of these wave patterns, we use the beta and Mu rhythms in the proposed system. Because these signals are produced in brain while thinking of movement actions such as left, right hand movements or movement of tongue and legs etc.

3. Embedded Implementation of the Brain Computer Interface

In this work it is proposed to build a new communication pathway between the brain and electronic devices in order to restore the capabilities of patient with severe motor disabilities. It consists of four phases which includes EEG signal acquisition, filtering section, feature-extraction process and classification.

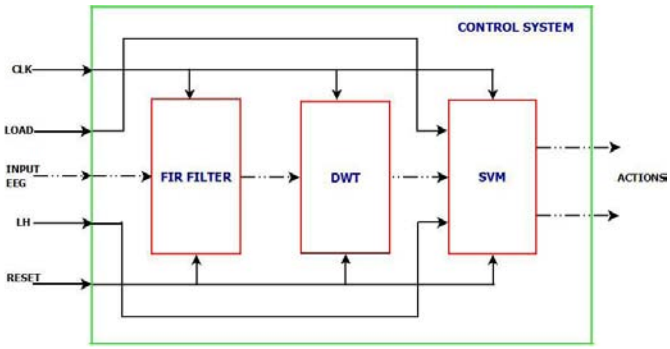

Figure 5: System block diagram

In the first phase, data set has to be read from the input source. System block diagram is depicted in Figure 5. During second phase, the unwanted data or noises are removed using filtering process. The filtering is carried out by using FIR Filters, as it is simpler and more convenient for programming on dedicated digital signal processing platform. In the third step, the required features are extracted using feature extraction process from the obtained signals by using wavelet analysis, discrete wavelet analysis (DWT). In the final phase, the data is classified based on the features using Support Vector Machine (SVM) and is used to control devices. The SVM provide facility for huge data space to incorporate the collected data. This technology comes in handy when a variety of data to store or if anything to compare which is a must in our case.

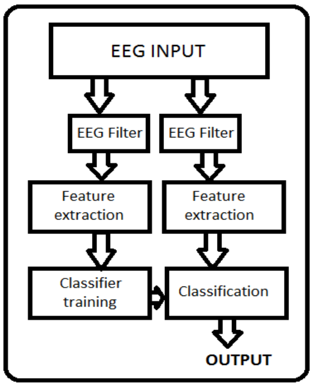

Figure 6: Flow diagram

The implementation of the above has two parts; the training part and testing part depicted in Figure 6. Training part is used for creating the database of the features and then EEG signals are recognized using these database in the testing part. Each part will be filtered through EEG filter block and then necessary features are extracted through the feature extraction by DWT.

3.1 FIR filter implementation

The EEG signals obtained through the electrodes are filtered using EEG filter block. The simulation of filter has been carried out using FIR concept. A finite impulse response (FIR) filter is a filter structure is used to implement the frequency response digitally. An FIR filter is usually implemented by using a series of delays, multipliers, and adders to create the filter's output.

In this work, two different order of FIR filters were used for comparison in order to recognise the effectiveness of increasing the order. The simulation results shows encouraging results and motivated to choose a band pass filter of 64 order which enhance the accuracy. The filter coefficient needed was obtained from the mat lab by using required filter specification for both 4 order and 64 order FIR filters.

3.2 DWT implementation

The wavelet transform has achieved widespread acceptance in signal processing and image processing. The discrete wavelet transform (DWT) has been established as a highly flexible and efficient method for sub-band decomposition of signals. At present, DWT considered as a key operation in EEG signal processing. DWT of an EEG signal are calculated by passing it through a series of filters. The EEG samples are passed through a low pass and a high pass filter simultaneously, giving detail coefficients and approximation coefficients as outputs. According to Nyquist's rule half the samples can be discarded because half the frequencies of the signal have been removed in the above process. One level decomposition is represented in the Figure 7.

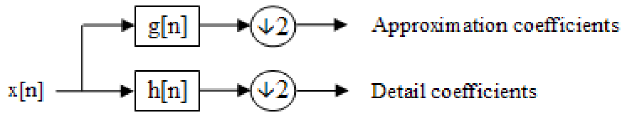

Figure 7: One level of transform

This decomposition is repeated further to increase the frequency resolution and the coefficients decomposed with high and low pass filters are then down sampled. Here, the DWT is extended to 8-levels and this 8 output are used for the detailed analysis.

3.3 SVM implementation

SVM is a kind of margin classifier that performs classification tasks by creating hyper planes in multidimensional space that separates features of different class labels. It is a divider which best segregates the two actions and also it is a linear machine learning method where the objective is to find a line of control between two classes that is suitable for differentiating the training data. SVM operation is depicted in Figure 8.

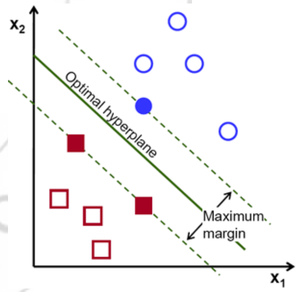

Figure 8: SVM classification scheme

4. Experimental Results

The proposed system is designed using Xilinx ISE Design suite. The input EEG signal form the BCI competition is scaled to suitable form for the easiness of implementation. Unwanted noises are removed using FIR filter. The implementation of FIR filter is carried out using direct form 64 order filter, then 8-level DWT is used for detailed analysis of EEG signals. Features such as variance, standard deviation, frequency, mean, large and small amplitude are calculated. The SVM will classify the desired action using the best feature.

Figure 9 shows the system output which indicate that the system correctly identifies the user's intended action for moving left or right movement.

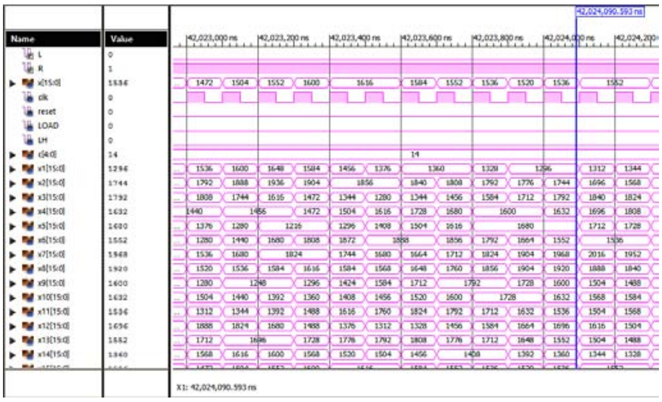

Figure 9: System Response to an EEG signal

5. Conclusions

Brain computer interface (BCI) allows a person to communicate with or control the external world without using the brain's normal output pathways of peripheral nerves and muscles. BCI is a collaboration in which a brain accepts and controls a mechanical device as a natural part of its representation of the body. They are designed to restore sensory function, transmit sensory information to the brain, or stimulate the brain through artificially generated electrical signals.

The EEG signals obtained through the electrodes are filtered using EEG filter block and necessary features are extracted using DWT. Based on extracted features, the classification module identifies the user intention. The working of the system is verified using simulation analysis. The result obtained indicates that the system correctly identifies the user's intended action. The system developed through this work could be utilized for patients with severe motor disabilities at home and even for office automation.

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