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Modelling and Analysis of Brain Waves for Real World Interaction

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Abstract

The field of Brain computer interaction (BCI) has got a great momentum in recent years.Brain is a 1.5kg wetware made up of around 100 billion neurons which communicate though ion exchange at the synapses. Electrical signals are generated due to the neuronal activities. Brain emit waves of frequencies ranging from 0.2Hz to 35Hz and beyond. Several efforts have been made to extract these signals. There are many methods such as fMRI, NIRS, EEG, MEG, etc of extracting brain signals.Electroencephalography(EEG) emerges as best suitable method. This paper aims to demonstrate the use of EEG for recording brain activity. Multisim is used to simulate proposed circuit. Obtained signals are processed using TMS320C54 and MATLAB. Hardware implementation is done using ARM cortex based robot, where the speed of robot is controlled using EEG signals. A decision algorithm is proposed which is based on predefined threshold in the scale of 0-100 on PROCESSING tool. To reach to a larger audience, scope and applications of BCI are discussed at the end.

Keywords: ARM processor, Brain Computer Interaction, Brain Waves, Electroencephalography, Robotics and Artificial Intelligence, signal processing.

I. INTRODUCTION

Brain is the most complex computing device, which perform millions of calculations in few fractions of second, which our current supercomputers are unable to do. Though supercomputers are increasing their processing speed by having parallel processing, they are no match to pattern recognition and image processing when it comes to humans. This huge difference is because of the high connectivity in neurons. About 100 billion neurons each having 10,000 connections can have 100 trillion synaptic activity. These synaptic activity arise because of flow of action potential from neuron to neuron. Synaptic activity is responsible for learning and memory in all living organisms. As the synapses have electrical conduction, neurons fire at a time with a slightest delay.

" cells that fire together, wire together"[1], and these electrical properties enable brain to have rhythm in the range of frequencies from 0.2 Hz to 35 Hz and above as in[2]. These waves emitted from brain are termed as brain waves which is a layman term for electric fields detected by EEG. Around 90 years back a pioneer scientist called Hans Berger observed that the neuronal oscillations[3] can be measured through EEG. Various waves emitted from brain are listed in table 1.

TABLE I CLASSIFICATION OF BRAIN WAVES

Classification	Freq. range	remarks
Delta	0.5-3.5 Hz	Deep Dreamless sleep
Theta	3.5-7.5 Hz	Light sleep
Alpha	7.5-12 Hz	Relaxed
Beta	12-30 Hz	Focused Concentration
Gamma	31 Hz and above	Attention

Obtaining brain waves using EEG will help us in interpreting the brain disorders. If the brain is subjected to abnormal bleeding, brain tumour, brain haemorrhage, sleep disorder and migraines such abnormalities can be detected using a less expensive and non-invasive method of EEG [4-6]. In epilepsy EEG is not only used to detect but also to diagnosis and manage.

BCI is tool which enables us in controlling machines, artificial body parts, and robot navigation using our brain waves. It doesn't depend on the neuromuscular output channels of brain [7]. EEG signals obtained from brain are captured using BCI where different signal processing algorithms are used to convert these readings into control commands for different machines [8]. BCI plays an important role in rehabilitation of people with disabilities, by providing a new channel of communication.

Section II describes the proposed model for extraction and analysis of Brain waves. Section III describes the circuit simulation in 2 stages using MULTISIM. It also describes the processing of signals obtained from the simulated circuit in MATLAB. Section IV demonstrates hardware implementation of decision algorithm by controlling the speed of robot. Section V presents the obtained results. At last paper ends with applications, conclusions and future work.

II. PROPOSED SYSTEM

There are many methods of obtaining brain waves which includes invasive and non-invasive methods. An easy and less expensive way to extract brain waves is to connect electrodes on the scalp at different [9]. The EEG signals are sinusoidal waves which will be in the range of 0.5 to 100µV[2]. The electrodes collect the event retarded potential and this is sent to the input of an instrumentation amplifier.

The instrumentation amplifier acts as preamplifier which strengthens the weak input signals and aims at extracting EEG signals. An operational amplifier can be used to boost the signal.The output is passed through High pass filter (HPF) where the frequencies beyond interest which act as noise are rejected i.e. HPF will sharpen the signals. The output is then passed through Low pass filter which selects the signals of interest, by smoothening of brain waves. The problem with using electrical circuits is the inherent presence of line noise which is characterised by 60 Hz frequency. A notch filter is introduced here which will eliminate it.

The output obtained is analogand is mixture of all EEG rhythms. We now apply the discrete Fourier transform algorithm to separate the EEG rhythms. A 12 bit ADC can be used to convert the signals into digital which are then sent to microcontroller. Microcontroller will control the speed of robot based on a predefined threshold. RS232 can be used to aid interface with computer.

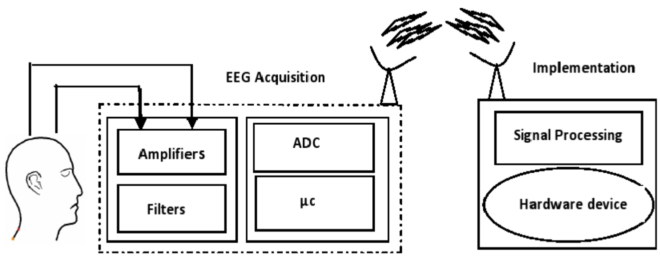


Figure 1: Block Diagram of Proposed System

In our work we have selected ARM Cortex processor which has in built ADC/DAC and different signal processing units. The arm cortex will compare the obtained signals from ADC with a predefined threshold value. If the signal is greater than threshold, it will intimate motors to increase speed, else to retard. If the threshold is selected is in the range of alpha waves, then any incoming beta/gamma wave will increase the speed. For an occurrence of theta /delta speed will be reduced.

The performance of our decision algorithm, classification, verification and validation of ARM processor can be verified using MATLAB software. Another alternative can be PROCESSING tool which not only help us to program ARM, but also presents the analysis with GUI on a PC. Here we have verified our work with software (using both MATLAB/PROCESSING) and also on Hardware using a robot.

III. CIRCUIT SIMULATION

The complete process of signal processing starting from extraction of EEG signals to translation of features into device commands can be broadly divided into two stages: Analog and Digital signal processing

A. Analog signal processing

The circuit intended to filter and amplify is implemented using MULTISIM. The circuit is divided into two stages. Stage I referred to as preamplification stage aims to extract EEG signal from raw input data which are very small and ranges in µV. It consists of an Instrumentation amplifier, virtual ground and first order HPF.

We have used AD620 instrumentation amplifier which gives very high input impedance such that it will extract all EEG signals with almost zero attenuation. The gain is selected to be about 23.To avoid the problems arising due to dual power supply we introduce a virtual ground circuit using voltage follower CA3140. Virtual ground will provide DC offset which will act as reference such that when coupled with instrumentation amplifier the single power supply will effectively act as dual power supply. High pass filter is intended to sharpen the signals by avoiding low frequency noise being propagated to further stages.

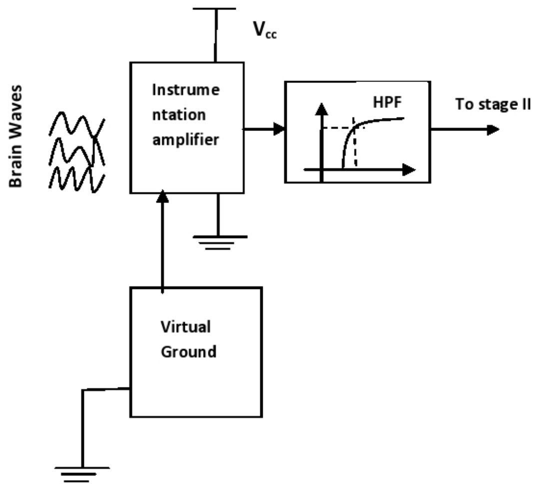


Figure 2: Preamplification stage

Stage II is called as post amplification stage, consisting of an operational amplifier, HPF and LPF. The operational amplifier CA3140 is used to boost the signals obtained from stage I. A low pass filter is coupled with op-amp to extract the frequencies of interest. The brain waves ranges from 0.2Hz upto 50Hz. The low pass filter is tuned with a bandwidth of 48 Hz. The HPF is tuned to a cut-off of 0.13 Hz and serves the same purpose as in stage I.

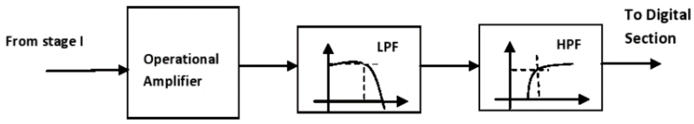


Figure 3: Postamplification stage

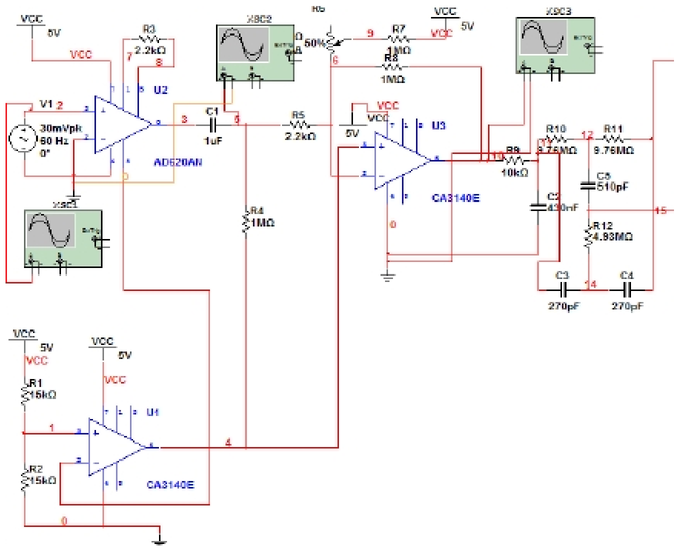


Figure 4: Multisim simulation

B. Digital signal processing

The signal processing can be segregated into two parts. First part is calculation of values related to specific features. The feature can be as simple as a potential (or frequency) or as complex as spectral coherence. Second part is a translational algorithm that assist us in translating features into commands.

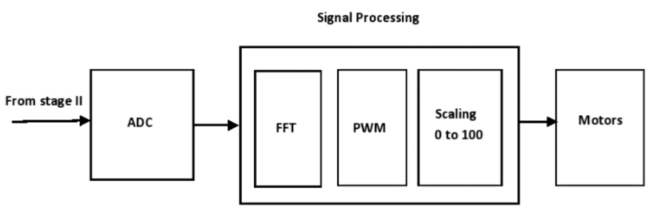


Figure 5: signal processing and implementation

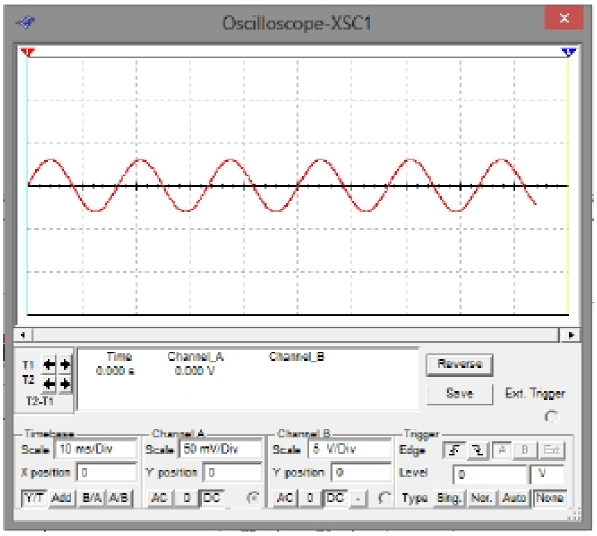
BCI uses the signal features that reflect brain events such as firing of specific cortical neuron (time domain) and rhythmic synaptic activation (frequency domain). Applying Discrete Fourier transform to the EEG signals we can extract band powers and separate the EEG rhythms. The processed output from analog signal processing block has to be converted into a digital signal for further processing. A 20 bit ADC will do the job, but care should be taken to accommodate slow varying offset due to the limitations imposed by instrumentation amplifier.

The digital output is having information about a feature which is frequency in our experiment. This feature has to be extracted to send it to translational algorithm for decision making. Since our feature is frequency, Pulse width modulation (PWM) is carried where the width of the signal is varied according to the frequency of digital output. The frequency range from 0.2Hz to 48Hz is scaled to the range 0-100. Since the width has information about frequency, the duty cycle is mapped from 0-1. For example, suppose a frequency component of 30Hz has arrived, on a scale of 0-100, it will assume a value of 60 Hz. On PWM the duty cycle scaling will be 0.6, which will be communicated to the next part i.e. translational algorithm where decision is taken.

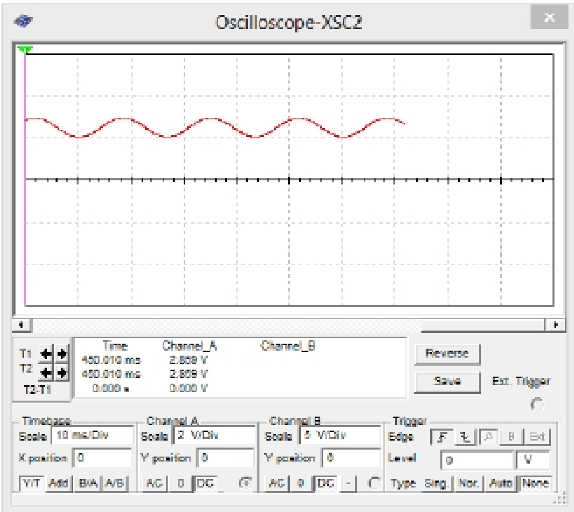
The decision is to determine whether the speed of a robot has to be increased or decreased. This is decided based on the scaled value of duty cycle. The scaled value is compared with a predefined threshold, and speed is increased if the value exceeds threshold. In the considered example where the scaled duty cycle value is 0.6 and if the predefined threshold is 0.3 then the motor is triggered to increase rotations and thereby increasing speed.

IV. RESULTS

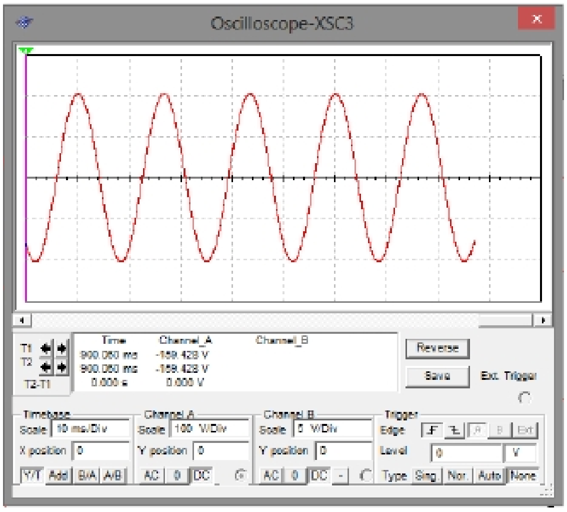
We have used MULTISIM simulation for the initial processing of the brain waves. As modelling the input is provided with a frequency of 30 Hz, as shown in fig. 6.a., and the output is amplified by a gain of 23, because of the instrumentation amplifier, as shown in fig. 6.b. The output of stage I is fed to stage II where it is amplified with a gain of 65, thereby making overall gain of about 1500.



(a) Input waveforms



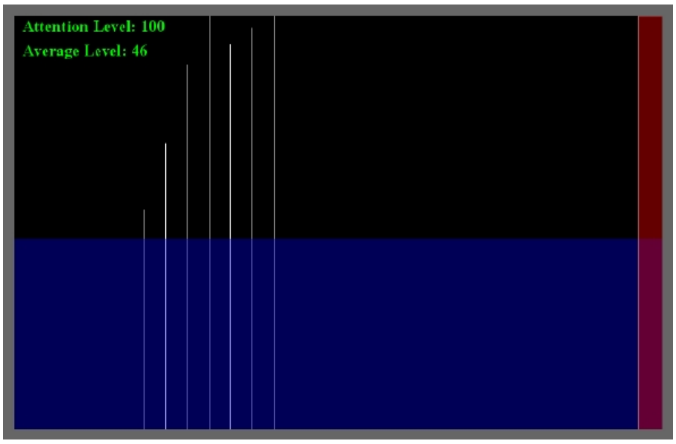
(b) Output waveforms of Stage I



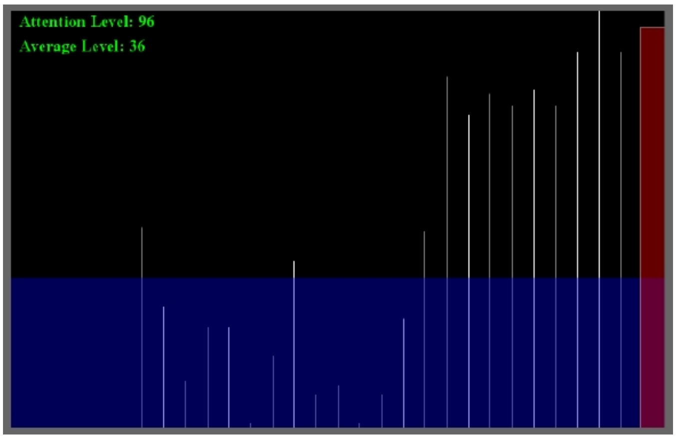
(c) Output waveforms of Stage II

Fig. 6. Showing waveforms of MULTISIM, input, output at stage I and stage II.

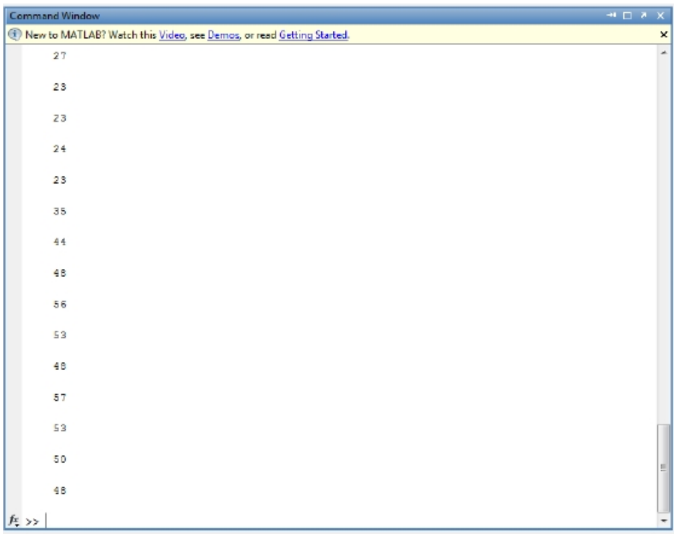
The processing software is used to implement the decision algorithm. Where a predefined cut-off is compared with the incoming signal. The signals shown in fig.7 (a) are of full attention, and (b) shows both attention and drowsiness signals where average is being calculated.



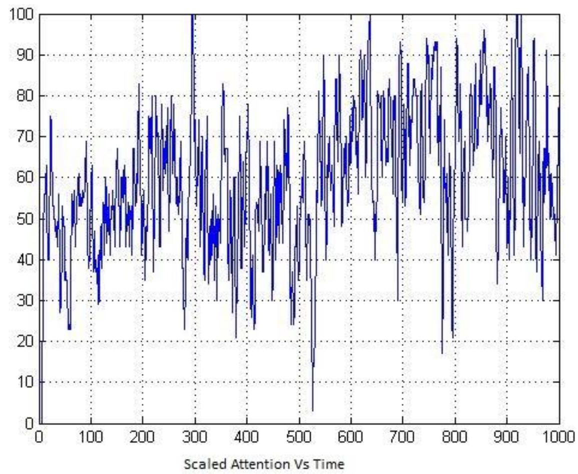
(a) Signals with high attention only



(b) Signals with average attention



(a) Attention values obtained in Matlab



(b) Attention values scaled from 0-100 plot

Fig. 8. Matlab readings obtained from wireless transfer of Brain waves after processing.

A. ***Discussion***

The extraction of brain waves with EEG have following challenges. EEGs are noisy and are sensitive to any frequency. They are non-stationary signals which need to be filtered. Electrodes are non-invasive i.e. they are placed on the skull and are unable to receive all brain signals. Still this technology is under development and ethical issues hamper the growth of this method[10]. Issues such as safety and long term stability are of main concern.

B. ***Applications***

EEG signals can be used in security purposes such as Bio-metric user identification, medicinal applications such as control of artificial devices for physically disabled people, communication channel for patients with paralysis and Neural disorders. This work can also be used to control wheel chair, to detect attention of students in a classroom environment, by which we can understand their learning styles and in robotic control for navigation. This technology has a potential market in Gaming industry. Drowsiness can be detected in a driver and can be used to avoid accidents.

V. **CONCLUSIONS**

The work demonstrates use of EEG for extracting brain waves. Obtained signals are amplified and processed using MULTISIM AND MATLAB. Processing software is used to program the hardware. Hardware implementation of decision algorithm is demonstrated using a robot. Attention level decides the speed of the robot.

This work can be extended to detect the drowsiness in a driver to avoid accidents. This can also be used in speed control of a wheel chair.

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