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RESEARCH ARTICLE

Development of single channel EEG Acquisition system for BCI applications

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ABSTRACT:
Brain-Computer Interface (BCI) plays a major role in current technologies such as rehabilitation, control of devices, and various medical applications. BCI or brain-machine interface provides direct communication between a brain signal and an external device. In this paperwork, a detailed survey was carried out with the design of single-channel EEG system for various applications. Also, this paper mainly focused on the development of single-channel electroencephalography (EEG) signal acquisition system which includes a preamplifier, bandpass filter, post-amplifier and level shifter circuits. The design of the preamplifier and post-amplifier circuit was carried out by integrated circuits (IC) such as instrumentation amplifier IN128P and bandpass filter with the help of low power operational amplifier LM324. The developed single-channel acquisition board was tested by acquiring an electrooculogram (EOG) signal with closed and opened eye conditions. The acquired signal is displayed and stored in the computer with the help of the HBM-DAQ unit.

KEYWORDS: Electroencephalogram (EEG), Electrooculogram (EOG), Brain Computer Interface (BCI) and Data acquisition unit (DAQ).

1. INTRODUCTION:
An electroencephalogram is a method that gives the complete study of the human brain and also helps to diagnose various abnormalities related to the brain. It represents the electrical activity of the human brain called EEG. Current research is mainly focused on the brain-computer interface which acquires brain signal and converts into commands for necessary control action[1-3]. BCI technique involves the following steps such as brain signal acquisition, processing of the acquired signal, main feature extraction, classification, and control of the various peripheral devices[4].

In the case of patients affected by neuromuscular disorders such as amyotrophic lateral sclerosis (ALS), Multiple sclerosis, brain stroke, and brain damage in which they cannot control the muscle activity but their brain works in normal condition. For those patients to communicate easily with their environment by using electrical signals acquired from the brain and communicated with machine to provide the control signals is called the brain-machine interface. Our human brain controls all the internal organs such as heart rate, muscle movement, speech, emotion and memory recollection, etc[5]. The signal acquired from the brain is called EEG. In the case of patients with neurological disorders or damaged nervous system, such that the body functions may be restricted to perform muscle action. In such cases, the BCI system could offer improved communication and independence.

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Two types of EEG signal acquisition systems such as invasive and non-invasive types. Invasive type of measurement is carried out by placing a mesh of electrodes on the surface of the cortex, this method is called as Electrocorticography (ECoG) which is partially invasive type measurement. The microelectrode implanted inside the cortex is called intracortical neuron (INR) which is an invasive type of measurement. In the case of non-invasive type measurement, the electrodes were placed over the scalp to acquire brain activity. The non-invasive type is commonly used for EEG signal measurement which provides portable measurement, better temporal resolution, easy to use, and inexpensive[6].

1.1 Literature survey for design of single channel EEG acquisition unit:

In previous work, Bhagawati AJ et al. carried out a portable one channel EEG acquisition system for BCI applications. The acquired brain signals are digitized using the NI DAQ unit and analyzed using the LAB VIEW environment[7]. Minglong. Y et al. was designed an EEG acquisition system without a shielded environment which consists of hardware for EEG acquisition module, ADC sampling module, and LABVIEW software for monitoring as well as analysis purposes[8]. Xun Chen et al. was designed a wearable, wireless EEG acquisition system with data transmission and reception module for BCI applications. The proposed hardware design provides a high value of the common-mode rejection ratio (CMRR)[9]. Lin Zhu et al. designed a hardware unit for multi-channel EEG acquisition system and processed data stored in a memory card or communicated to PC by using the serial port for medical application to diagnose diseases or monitoring purposes[10]. Dias. NS, et al. carried out a wireless system for EEG acquisition by using dry electrodes. The main advantages of using dry iridium oxide (IrO) electrodes for acquiring EEG signals were it allows the subject to mobility so that the brain activity is monitored[11]. Uktveris T et al. designed a wireless modular EEG board using the ADS1298 analog front end chip that provides low power, low noise, and high sample rate[12]. Table 1 represents the literature survey for the design of the EEG acquisition system for various applications.

Table 1: Literature survey for the design of EEG signal acquisition system

Sl. No	Author name and Year of publication	System/Approach	Technique
1	Bhagawati AJ et al, 2016	Single channel portable EEG system for BCI applications	Design carried out with using instrumentation amplifier as IC INA 128P, operational amplifier LM 358P. Output signal analyzed with using NI DAQ unit.
2	Minglong. Y et al, 2012	EEG signal acquisition unit designed of unshielded environment.	The design consists of EEG signal conditioning module and ADC sampling module with using MSP430. Data acquisition using lab view software to view and store in PC, finally EEG analysis carried out by Matlab tool.
3	Xun Chen et al, 2011	Wireless single channel EEG system.	The design of wireless system carried with using op-amp as OPA333 and instrumentation amplifier using INA333. ADC and Zigbee module used for wireless communication with PC.
4	Lin Zhu et al, 2009	Portable multi-channel EEG acquisition system	Circuit design carried out with low power ICs such as AD623 for instrumentation amplifier, TLC27L4 for op-amp. MSP 430 used for A/D conversion and transmitting digitized data to PC through serial communication.
5	Dias. NS et al, 2012	Wireless EEG acquisition system using dry electrodes	Wearable cap which consist of dry electrodes and radio frequency transceiver used for transmitting the acquired signal to PC.
6	Uktveris T et al, 2018	Design of low cost wireless EEG acquisition board.	High performance up to 64 channel EEG acquisition system with using ADS1298 analog front end chip.

Ravikumar et al carried out development of brain computer interface by using machine learning algorithm [13]. Keshava murthy et al carried out a detailed review on cognitive attention was measurement from human by extracting EEG signals.[14] EEG based BCI for various medical applications and treatment for motor impairment patients review article by Lazarou Ioulietta et al[15]. Ganesan et al carried out the brain tumor detection and classification using support vector machine (SVM)[16]. Grace kanmani prince et al identified epileptic seizure detection by using EEG signals with supervised learning algorithms[17]. Harikumar rajaguru et al classified epilepsy detection from acquired EEG signals by using wavelet neural networks[18].

2. SYSTEM OVERVIEW:

To acquire the brain activity, biopotential electrodes placed on the scalp. In the case of non-invasive type EEG signal acquisition, gel-type disposable electrodes were used. The EEG signal acquired from the scalp has very low amplitude and noise in nature. So after the acquisition of the EEG signal proper signal treatment was carried out. The main blocks in the EEG acquisition system consist of a preamplifier, unity gain bandpass filter, post-amplifier, and level shifter circuit followed by DAQ unit to display the output or connected to Arduino Uno controller for further processing is shown in figure 1. The main use of Arduino Uno microcontroller board has inbuilt analog to digital converter (ADC) module for converting the analog signal in to 8 bit digital data that can be viewed by using serial monitor option and its waveform plot can be viewed in serial plot in the Arduino IDE software.

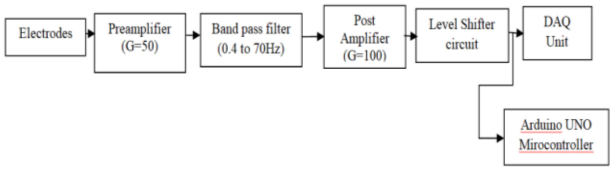

Figure 1: Block diagram of single channel EEG acquisition system

2.1 Electrodes and preamplifier:

In the development of a single-channel EEG acquisition unit, the normal disposable type electrodes were used for testing and acquiring the signals. Using leads the electrodes were connected and another end of the leads connected to the preamplifier circuit. The acquired signal is amplified with a preamplifier using an instrumentation amplifier with IN128P[19]. The main features of INA128P provides low offset voltage of 50µV maximum, low drift voltage with respect to temperature, low input bias current, high CMRR of 120dB minimum, operates with a wide supply voltage as ±2.25 V to ±18 V and high gain with wide bandwidth. The gain of the preamplifier is variable by a 10KΩ potentiometer connected between the pins 1 and 8. If the gain of the preamplifier taken as G=50 then R_G value can be calculated as

The gain equation for INA128P is given by

$$G=1+ (50K\Omega) / R_G \quad (1)$$

$$R_G=50K / (G-1); \quad \text{if } G=50 \text{ then } R_G=1.02K\Omega \quad (2)$$

2.2 Band pass filter:

The acquired EEG signal from the preamplifier is contaminated with other frequency noise signals. Also, it is overlapped with low-frequency noises and baseline drift. To remove those noises a bandpass filter has to be designed with lower cut off frequency and upper cut off frequency of 0.1Hz and 70Hz respectively. The output of the preamplifier circuit is connected to the bandpass filter. The circuit uses infinite gain multiple feedback type active bandpass filter is shown in figure 2. It uses unity gain and second-order active filter. The op-amp used for the bandpass filter is LM324 low power quad-operational amplifiers[20]. It provides high gain, wide bandwidth of 1MHz, wide supply voltage of Single Supply 3 V to 32 V, or Dual Supplies ±1.5 V to ±16 V with low offset voltage.

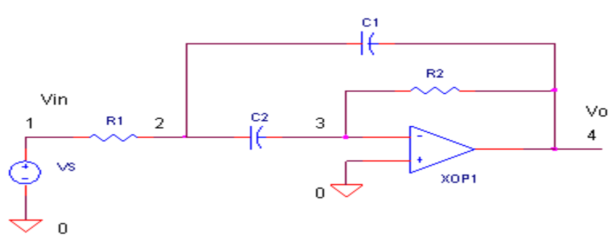

Figure 2: Infinite Gain Multiple Feedback second order active Band pass filter.

Choose C $=C_1=C_2$,

$$Fr = 1/2\pi\sqrt{R1R2C1C2} \quad (3)$$

$$Q=F_r / BW =1/2\sqrt{(R2/R1)}; \quad (4)$$

Bandwidth (BW) $=F_2-F_1$, where F_1 and F_2 are lower and upper cut off frequency respectively.
For unity gain Av=1; Av=1= $-2Q^2$; Q=0.707, Assume C $=C_1=C_2=1\mu F$
R1=21KΩ and R2=42KΩ.

2.3 Post amplifier and level shifter circuit:

The output of the bandpass filter whose amplitude is low so that it can be amplified by the post-amplifier circuit. The gain of the post-amplifier circuit is 100, using INA 128P the gain resistance of R_G=500Ω used. The output of the post-amplifier is connected to the level shifter circuit before connecting to a microcontroller unit to avoid the negative value of output given to the ADC module in arduino microcontroller. Using op-amp with fixed reference dc voltage is added to the post-amplifier output so that the output shifted to the desired positive voltage. The sample output results obtained by connecting the HBM-DAQ unit in different stages of acquisition module such as preamplifier, bandpass filter, and post-amplifier. The HBM-DAC system provides 16 channels with a 24-bit resolution output. For testing the hardware acquisition module, the EOG signal was measured by placing the disposable electrodes above and below the eyes for vertical eye movement recording purpose with the third electrode connected in forehead serves as common ground act as a reference electrode. The placements of electrodes for EOG signal measurements as shown in figure 3 below.

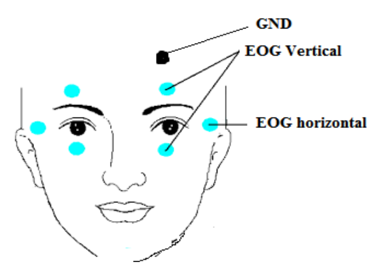

Figure 3: Placement of Electrodes for EOG signal acquisition

3. RESULT AND DISCUSSION:

The output across different stages of the acquisition module such as preamplifier, bandpass filter, and post-amplifier under closed and opened eye situations represented in the below figure 4 to figure 6 using the HBM-DAQ unit. The electrodes were placed above and below in the left eye were recorded for 10 seconds under open eye condition shown in figure 4. For closed eye condition, the EOG signal was recorded for 10 seconds and continuous blinking of the eye were shown in figure 5 and figure 6 respectively.

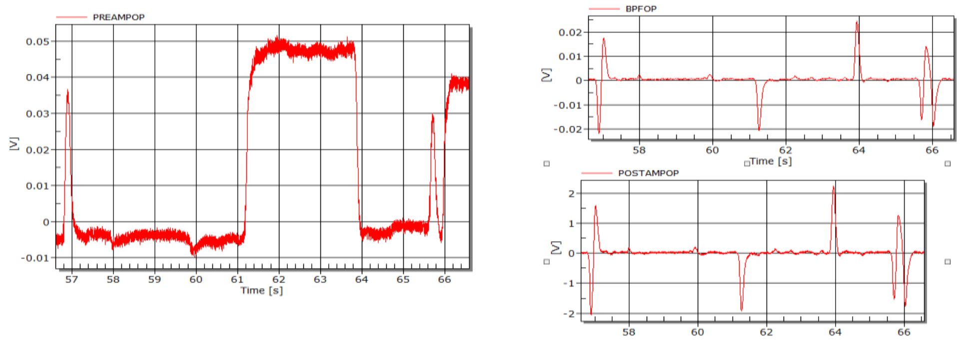

Figure 4: EOG measurement output across pre amplifier, band pass filter and post amplifier under open eye condition

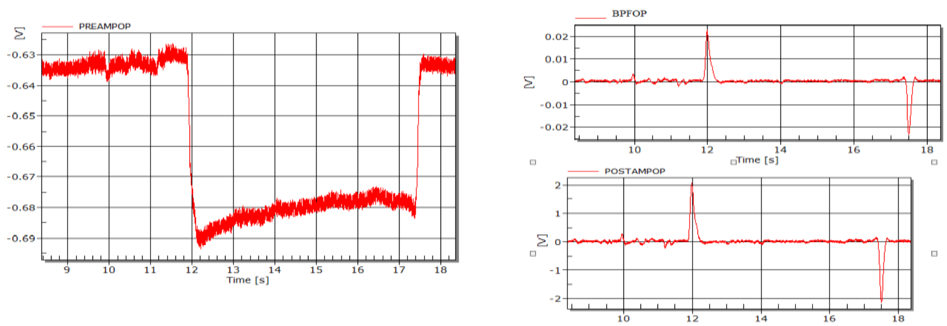

Figure 5: EOG measurement output across pre amplifier, band pass filter and post amplifier under closed eye condition

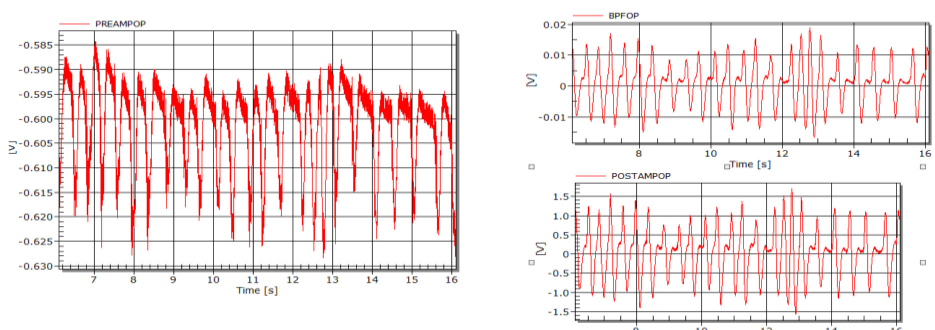

Figure 6: EOG measurement output across pre amplifier, band pass filter and post amplifier under continuous blinking of eye

The output signal of the bandpass filter can be viewed and analyzed using a DAQ unit or analog form of the signal can be converted into digital form by using the ADC module in the Arduino Uno microcontroller and the data serially transferred to a memory storage device. To convert negative value of the EOG signal into digital form a level shifter circuit was introduced after the post-amplifier circuit. The positive and negative peak in the output shows that the eye movement in the up direction, down direction, and voluntary eye blink status. The schematic circuit design and printed circuit board (PCB) layout for the acquisition module was obtained by using the Easy EDA tool. The schematic circuit diagram and two-layer PCB layout for acquisition module which has preamplifier, filter, post-amplifier, and level shifter with header pins for electrode lead input and header pins for individual circuit output were shown in figure 7 and figure 8 respectively.

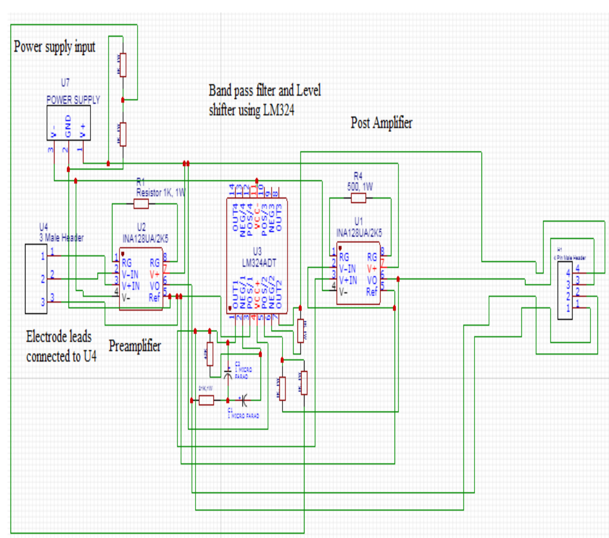

Figure 7: Schematic circuit diagram of the acquisition module.

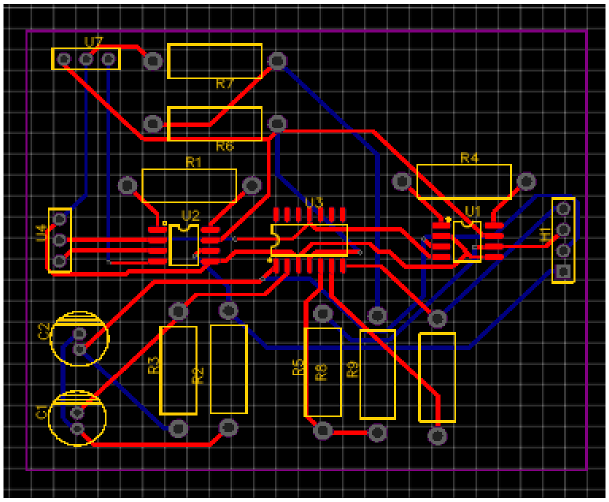

Figure 8: Two layer PCB layout for the acquisition module.

4. CONCLUSION:

In this paper, a detailed literature survey related to the design of various EEG signal acquisition unit for various applications was carried. A low-cost EEG signal acquisition unit for BCI applications was developed. The hardware design of a single-channel EEG acquisition module which consists of preamplifier, bandpass filter, post-amplifier and level shifter circuit tested by acquiring the EOG signal under closed and opened eye condition with disposable electrodes used for measurement.

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