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Curation of A Low-Cost Scalable BCI System

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Abstract— **EEG (Electroencephalography) is a non-invasive technique through which brain impulsive activity can be recorded. There are various invasive techniques which are used to record the brain activity by measuring the individual neuronic impulses and analyzing them by placing electrodes by penetrating in the scalp. Our aim is to design a low-cost EEG** system **which measures the Electroencephalograph of pulses as an application of the Brain Computer Interfacing (BCI). For doing initial testing, we preferred designing our system using an Arduino platform along with a signal conditioning mechanism and shields employing (Digital to Analog Converter) DAC along with minimal external hardware. The conceptualization behind this system was giving it the ease of access so that its replication by students can be done seamlessly. Emulation of results from the above system are compared to professional grade equipment and achieved results close to it.**

Keywords: EEG, BCI, Arduino, Mental Ailments

I. INTRODUCTION

A Brain-computer interface is a technology which enables brain signals to be read and analyzed by a human interaction machine. The growth in research in this field has been exponential and has attracted attention from researchers all over the world. Its application primarily lies under biomedical instrumentation which has an integration of computer science. This technology employs the ideology that human brain signals can be quantified and measured. This collected information can be processed and then used to command the computer perform actions accordingly. This communication bridge is the underlying principle on which BCI functions.

There are various invasive techniques which are used to record the brain activity by measuring the individual neuronic impulses and analyzing them by placing electrodes by penetrating in the scalp. Post-synaptic summation of impulses from thousands of neurons are analyzed to conclude various parameters. There are various obstacles in the form of hair, skull and tissues that act as an interface between the source of the electric energy and the electrode terminals that cause high impedance.

We aim to design a low-cost EEG system using Arduino, low-cost electronic amplifiers, and MATLAB processing. And we demonstrate here the results of our work, comparing it with a high-end laboratory device.

II. MATERIALS AND METHODS

The acquisition of the signal is done through Ag-AgCl electrodes, placed directly on the scalp, using Electrolyte paste for EEG for fixation and better conductivity. The placement of the electrodes is very important because if its poorly placed it can highly decrease the signal-to-noise ratio. The signal is then amplified, the amplifier used in this project is a Single Lead Heart Monitor AD8232[2], which is a sensor for Electrocardiogram (ECG), but can serve the same purpose as an EEG sensor. Three electrodes are wired in it. One for the signal, one for reference, and another for ground, the placement of these electrodes will depend on the intended application.

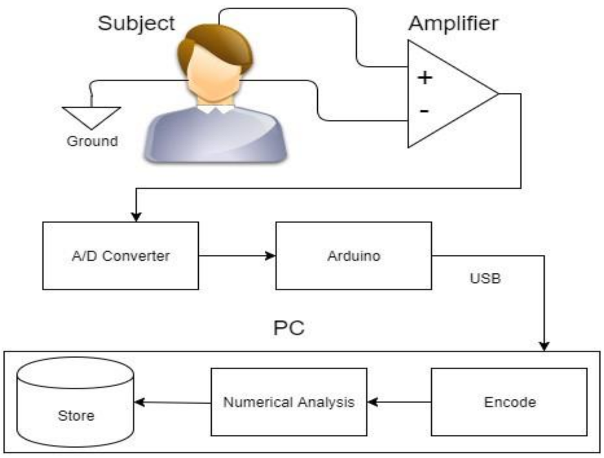

Figure 2: System Diagram

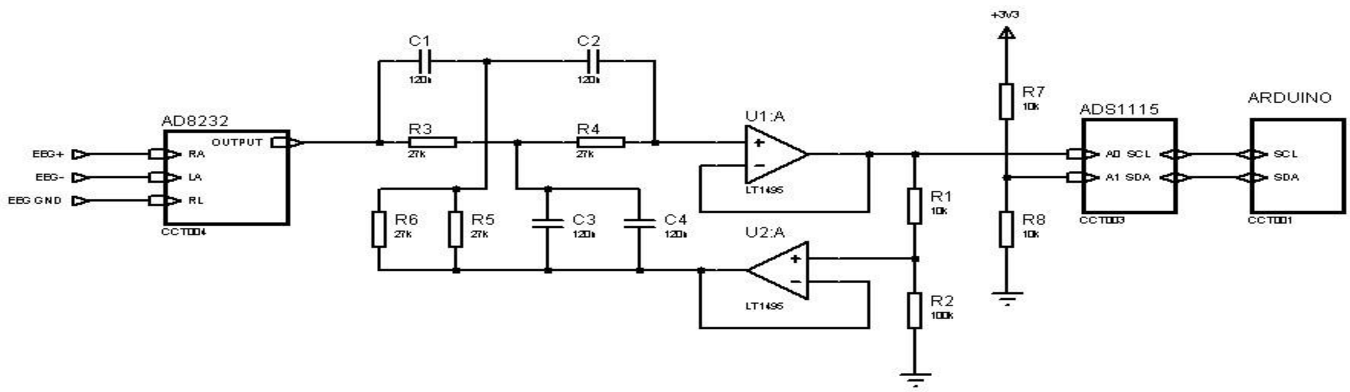

Figure 1: Circuit Diagram[2]

After amplification of the signal, it must be transformed in order to be able to be processed by a computer. Thus, an ADC (Analog to Digital Converter) is needed. In this project, an ADS1115 16-bit ADC 4-channel chip was used [3]. This chip also includes a programmable 16x amplifier. The conversion can be made in two ways: single-ended input or differential input. When using differential input, only two channels are available at a resolution of 16 bits. The total gain was set to 85 db. An additional Twin-T notch filter, as shown in Figure 1, is added between the amplifier and the ADC. This filter is needed because otherwise, depending on the noise levels in the environment, we would result in a signal with amplitudes greater than supported by the ADC, therefore distorting the signal.

The data rate in serial was 57600 baud, while the ADS1115 analog conversion rate operated at 600 samples per second as the maximum rate resulted in inaccurate results. As each sample amounts to 16 bits of data, the maximum throughput of this communication, for a single channel, will be less than 14000 bits per second, which is supported. In Figure 1 we have the electronic circuit diagram and in Figure 2 we have an overview of the system. The Arduino captures the data bit by bit at approximately 200 samples per second and feeds the data to the MATLAB through serial connection with a computer. It is also worth noting that the system was enclosed in an aluminum box for additional electromagnetic insulation.

III. MATLAB AND ARDUINO ALGORITHMS

The use of the Arduino in this project is very simple, and it can be exchanged by many other platforms, its function is just to send the data acquired in the ADC via serial communication to the computer. The acquiring of the ADC signal is done within a specified time period, so that the reading frequency remains constant. The readings are sent one by one through the serial connection. The MATLAB code captures these samples and arranges them into a vector in the memory. It applies then a lowpass filter to clean the signal and accordingly, a notch filter is used at 50/60Hz to filter the line noise from the power supply. This filter applied to completely eliminate the line noise from the FFT spectrum, as some still remained even with the analog filter. Afterwards, it applies an FFT analysis to identify patterns and perform signal processing.

IV. RESULTS

A series of tests have been conducted for analyzing performance and comparing it to high-end laboratory equipment.

Amplifier Evaluation - To establish our device as a suitable system for the measurement of EEG signals we gathered the parameters for the gain and the common mode rejection ratio (CMRR), which are the most basic parameters for a bio-amplifier system.

Theoretically, calculated gain of the circuit is 84.8 dB, with low pass cut frequency of 41.09Hz and a high pass cut frequency of 0.48Hz. The frequency characteristics of Gain and CMRR of this amplifier are shown in Figure 3 and Figure 4, respectively. The CMRR is calculated dividing the common mode gain by the differential mode gain. The common mode gains are measured by applying the same signal in both EEG+ and EEG- inputs and driving EEG GND to ground.

Comparison tests - Figure 3 shows the comparison between the signals acquired by our prototype device and a high-end device used in the laboratory for research. The comparison is made using only one channel. Both signal electrodes are put near the CZ zone (center behind the cranium), with 1 centimeter of distance from each other on the scalp. The negative electrodes are put near them, while the ground electrodes are put on each mastoid.

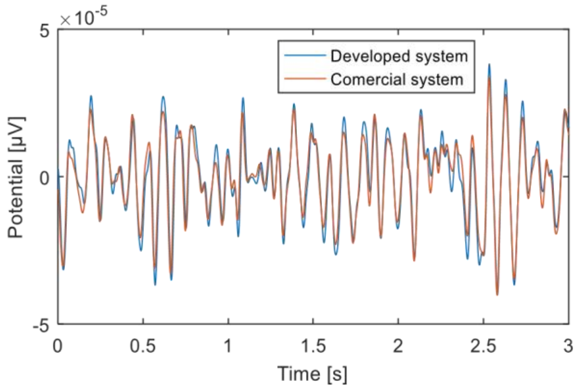

Figure 3: Sample signals acquired by developed system (blue) and commercial system (red).

The acquisition started unsynchronized, and the data is synchronized later by visual inspection, using the evoked potential caused by the opening of the eyes as reference, which is clear on both data sets.

The data is acquired by measuring the activity of the brain with both the commercial and our own amplifier system. We measured during 100 seconds with multiple activities such as blinking and moving arms, then the data is filtered within the 1 and 30 Hz frequencies, using a third order digital Butterworth filter, as this is the frequency range we want our system to be applied, if we consider a wider frequency range the performance may be different, because both systems have different analog filters. The data is then synchronized, normalized and compared. On figure 3 we can see a 3 seconds sample of the data acquired by both systems.

The correlation between the amplitude of the EEG and the movement artifacts in both signals is similar, the frequency spectrum presents the same peaks and both signals have very similar components and behavior. A correlation coefficient of 0.9586 is calculated between the two 100 seconds samples, therefore we can consider it to be equivalent for most intended applications.

***Feature detection* -** To test its functioning as an EEG measuring device, set of experiments is conducted which is suited for BCI and same experiment is conducted with the high-end amplifier and compare the results.

By measuring only one channel, with the electrode placed in the Cz zone of the scalp, it is possible to detect whether the subject is with closed or opened eyes. By analyzing the sampled signal in the frequency domain, applying a Fourier Transform, we can detect different frequency peaks for "eyes closed" and "eyes opened". This is possible because the brain emits different types of brain-waves for different states of brain activity. For instance, it produces higher frequencies when the eyes are opened and there is high activity.

For that purpose, we measured the EEG for 30 seconds, with the open eyes, and another 30 seconds with the closed eyes. The data is then evaluated by performing and FFT on the signal, so that we can have a clear visual understanding of the result, shown in Figure 6 and Figure 7. In these cases, we have a window of 10 seconds of data sampled at 600Hz, giving an DFT resolution of 0.1 Hz. It becomes very clear that this is an application where a single channel in our system is perfectly able to detect, as there is a clearly noticeable spectral difference.

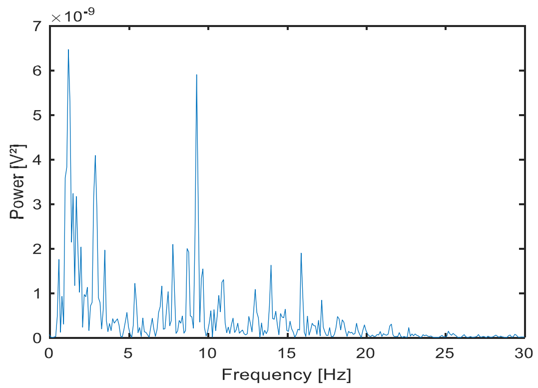

Figure 4: EEG Spectrum during eyes opened.

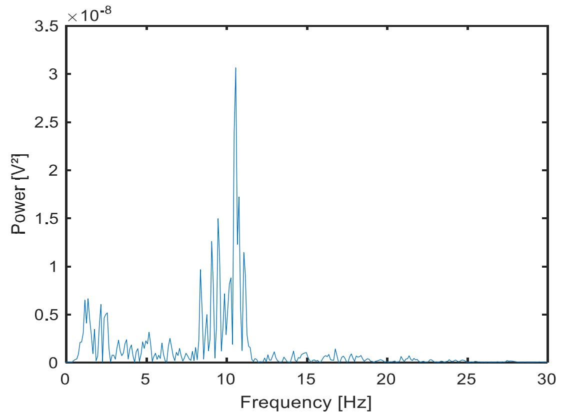

Figure 5: Spectrum of EEG during eyes closed.

SSVEP - Another very popular task performed by BCI systems is the detection of Steady-State Visual Evoked Potential (SSVEP), that are brain signals generated in response to visual stimuli such as

blinking light [4]. We performed such an experiment by using a MATLAB Toolbox called Psychtoolbox-3 [5] which is used to generate precise visual stimuli, blinking the screen black and white with a frequency of 15Hz, interleaved every 5 seconds stopping the blinking so we could observe the difference in the spectrum, this frequency is limited by the monitor refresh rate. By using this toolbox, we could also easily synchronize the stimuli and the signal acquisition.

We visualize the results of this experiment through a spectrogram, in Figure 8, we use a window of 4 second with 3 seconds of overlap, where we can clearly see the distinctive frequencies varying along the time of the experiment, switching behavior every 5 seconds.

V. DISCUSSION

The proposed system is a viable alternative to expensive EEG measurement systems. As shown in the results, we can achieve a very good amplification using inexpensive electrodes. And besides being cheap, it is very easy to build, the proposed system can be easily replicated by researchers and students that face the same limitations regarding the availability of these more expensive systems.

Of course, it still has many limitations, such as acquisition rate and frequency range, but if we think about simple applications it is giving good results. The system is also modular, means we can substitute many of its parts for others if needed, or more parts being attached. In this system, a single channel of the ADC is used, but we can easily increase it by adding more amplifier channels, or even more ADC's, as it uses I2C, it is easy to expand. It would also be interesting to make it communicate wirelessly with the computer, so we can even further reduce the noise in the system that can be done by using a Bluetooth module in the Arduino.

VI. CONCLUSION

With this proposed system, we are able to achieve a gain of 85dB and a CMRR of more than 100dB, which makes it a suitable amplifier for use in applications such as EEMG. When comparing it with high-end devices we can achieve a correlation in results as great as 0.9586, that proves our initial point that the results observed by our system can be considered equivalent to the ones provided by the high-end devices, enabling it's application in scientific and educational purposes without any considerable loss in the results, while keeping an affordable budget. Although trying to work with limited budget and equipment, it is possible to acquire very high-quality data samples from where we can extract features and information from the brain. EEG devices are still very delicate to handle, due to its high interference sensibility and the complexity of diminishing impedance (mainly avoiding the hair and cleaning the scalp).

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