A Low-Cost Electroencephalography (EEG) Instrumentation for Epileptic Seizure Detection

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Abstract. Noninvasive detection of epileptic seizures can help the patients to save themselves from sudden fall and assist the doctors to study the disease and treat the patient. Generally, an EEG based epileptic seizure detection system consists of EEG sensors, electronic instrumentation and a signal processing algorithm. In this paper, an EEG acquisition system (EAS) has been developed with a multi-stage amplifier and filter blocks. The instrumentation is studied, tested and evaluated with periodic signals generated with a function generator as well as the EEG-like signals simulated by virtual instrumentation (VI) developed with NI MyDAQ controlled by a Lab VIEW. The noise response of the instrumentation developed has been studied with SNR analysis. Results, obtained from the circuit simulation and experimentation conducted with EEG-like waveforms, show that the developed EAS is suitable to process the EEG signals and suitable for epileptic seizures detection systems.

1. Introduction

The human body function and activities are controlled by the central nervous system (CNS) [1] which consists of two main parts: brain and spinal cord [2-3]. Along with the brain and spinal cord the neurons network is spread over the body parts to communicate with them through the electrochemical signal communication [4-5]. To perform any task in the human body the brain sends an important physiological information which is transferred through the electrochemical activities [4]. These electrochemical activities are essential to maintain the communication between brain and the rest of the body using the neural paths developed with nerve cells called neurons [4-5]. The neurons generate electrical signals [5] during the electrochemical activities required to send and receive signals to and from all other parts of the body. As a response of the electrochemical activities inside the brain, the electrical voltage signals called electroencephalography (EEG) [6-7] are developed which can be recorded using electronic instrumentation called EEG acquisition system (EAS). An EAS is interfaced with a suitable EEG sensors [8] or EEG electrodes which are placed on the surface of the brain. As the EEG signals are generated due to the brain neural activities, it can be processed and analyzed to get a lot of information about the brain functioning which can not only be utilized to understand the brain physiology but also to diagnose and assess a number of brain diseases [6, 8] and neurological disorders [9-11]. Epilepsy [12-13] is a brain disorder or an abnormal activity of the central nervous system in which the human brain malfunctions for a certain period of time, causing abnormal movement, anomalous sensations, and sometimes loss of awareness or seizures called epileptic seizures [13]. As an epileptic seizure is found as a period of unusual symptoms excessive or synchronous neuronal activity in the brain, it always corresponds to an inconsistent electrical activity of the brain. Hence, EEG signals acquired from an epileptic patient can reveal several important information which is required for medical analysis and treatment of the disease. Noninvasive detection...
of epileptic seizures is an important role with many advantages in medical science to assist doctors to diagnose and treat the patient. EEG based epileptic seizure detection [14] is a fast technology that generally combines electronic instrumentation and the signal processing algorithm to interpret the signals and extract the information hidden inside the waveforms. In this paper, an EAS has been developed with an EEG Signal Conditioner Block (ESCB) which contains a multi-stage amplifier and filter circuits. The instrumentation is studied, tested and evaluated with low voltage, low-frequency periodic signals generated with a function generator developed with voltage controlled oscillator (VCO). The instrumentation has been tested with the low-frequency low voltage sinusoidal signal generated by VCO. The instrumentation has also been studied with the EEG-like signals simulated by virtual instrumentation (VI) developed with NI MyDAQ [15] controlled by a Lab VIEW [16-17] based graphical user interface (GUI) [17]. The instrumentation noise response is studied by measuring the signal to noise ratio (SNR) [18] of the circuit blocks using the test signals with and without noises. The SNR is obtained at each stage of the circuit blocks and the overall SNR of the EAS instrumentation is measured and compared. Results, obtained from the experimentation conducted with the real periodic signal as well as the EEG waveforms simulated by VI, show that the developed EAS is suitable for acquiring and amplifying the EEG signals and suitable for detection of an epileptic seizure.

2. Materials and Methods

2.1. Electroencephalography (EEG) and Epilepsy

The body function and activities are controlled by the central nervous system (CNS) with its central processing unit called the brain. The brain generates the electrical signals to communicate with the brain cells to perform some tasks by communicating with the other parts of the body using the neural paths developed with neurons. The response of the electrochemical activities of the brain is found as an electrical voltage signal called electroencephalography (EEG) which can be recorded on the surface of the brain [19] using electronic instrumentation. The EEG signal processing and analysis can provide us a lot of signature about the brain activity as well as the information about several body functions. Therefore, the precise acquisition and accurate assessment of EEG signals is of significant interest to not only in the neuroscience studies but also it is equally important in the area of biomedical engineering research. To obtain the correct information from the EEG signal it is essential to collect the signals as accurately as possible which in turn needs a reliable, sensitive and precision instrumentation dedicated for signal acquisition, amplification, filtering, and other signal processing techniques. Using a portable EEG instrumentation, EEG has been acquired and analyzed to extract the physiological information for noninvasive diagnosis of brain disorder and diseases. Epilepsy is a brain disease or CNS-disorder which produces an abnormal brain activity, sometimes, causing seizures called epileptic seizures. Epileptic seizures may exist several minutes and generally are accompanied by a period of unusual behavior, abnormal sensations, and loss of awareness. Though the primary diagnosis of epilepsy is clinical but electroencephalography (EEG) can be applied as a noninvasive diagnostic procedure to detect and assess epilepsy and epileptic seizures. Analysing and comparing an EEG with the normal one it is possible to detect the abnormal features present in the EEG signal which can be correlated and identified as the signature of epilepsy and seizures. Therefore, by the feature extraction process, an epileptic seizure could be detected using an EEG signal acquisition cum analysing system that could be developed with electronic instrumentation based EEG signal recorder and a software-based EEG feature extractor and information interpreter.

2.2. EEG Measurement Procedure

EEG signal is developed inside the brain and the potential is distributed inside the body tissue and hence these electrical signals are available on the surface of the brain or head. In general, the EEG signals are recorded from the surface of the scalp using the sensors called EEG electrodes [19]. As the amplitude of the potential developed by neural activity is very small the amplitude of the EEG signals is also very small, generally in order of microvolts (µV). The EEG signals recorded on the scalp surface contain different waveforms with different frequencies each reflecting particular neural activity/activities. For human subject, the major waveforms present in their EEG signals are Delta (0-
3.5 Hz) [20-21], Theta (3.5 -7.5 Hz) [20-21], Alpha (7.5 -13 Hz) [20-21] and Beta (greater than 13 Hz) [20-21]. EEG electrodes or electrode array [22] used for EEG acquisition could be made up of gold (Au), silver (Ag) or silver-silver-chloride (Ag/AgCl). Electrodes are placed over the scalp at some predefined positions [23] and connected to the electronic hardware dedicated for signal recording and processing. The electrode arrangement can be made as per the standard EEG electrode placement protocol [24] which are considered as the international standards. As for example 10-20 system [24] refers to an international standard in which the number “10” and “20” refer to an electrode placement protocol. In 10-20 system, the actual distances between two adjacent electrodes are either 10% or 20% of the total distance between the “front to back” or “right to left” of the skull of the subject under test (Figure 1a). The specified positions of the electrodes are represented with letters and numbers such as the letters “F” and “T” indicates the “Frontal” and “Temporal” lobes of the brain respectively whereas the and odd and even numbers denote the “left side” and “right side” of the head (Figure. 1b).

2.3. EEG Acquisition System (EAS)

EEG signal is developed with the electrochemical activity of the neurons inside the brain and hence it is found with very low amplitude and low-frequency voltage signal. As shown in the Figure. 1b, an EAS generally contains an electrode array (EEG sensors) and electronic instrumentation called EEG signal conditioner circuit (ESCB). To acquire the low frequency, low voltage EEG signals, the ESCB is developed with, generally, several amplification blocks and filter blocks. In the proposed project, the EAS system has been developed with an ESCB and a Data Acquisition System (DAS). As shown in Figure 2 the ESCB has been developed with several filter blocks and amplifier blocks. As shown in the Figure 2, in ESCB, the EEG signals collected from the EEG sensors, are fed to the low pass passive filters and then the signal has been passed through an instrumentation amplifier. The output of the instrumentation amplifier is fed to a bandpass filter (BPF) developed with second-order low pass filter and second-order high pass filter. The output obtained from the BPF is supplied to the gain controller block which is developed with two non-inverting amplifiers (Figure 2). At the last stage, the amplified and filtered signal is passed through a 50 Hz notch filter. All the circuit blocks, except the passive filter block, have been developed with OP07 Op-Amps (Analog Devices Inc., USA) [25] connected with high precision passive components (resistors and capacitors) as shown in the Figure. 2. The proposed ESCB circuit is developed on the breadboard (Figure. 3a) and tested with the signals generated by a voltage controlled oscillator (VCO). The VCO is developed as a Wien Bridge Oscillator (WBO) circuit which is developed with OP07 ICs. The ESCB has also been simulated in NI Multisim software (National Instruments Inc., USA) [26] to test and assess the circuit performance and its noise response. The EAS has been developed with NI MyDAQ hardware interfaced with graphical user interface (GUI) developed (Figure. 3b) with NI LabVIEW 2019 (National Instruments Inc., USA). The EAS has been tested with low frequency low amplitude EEG like signal and the signal acquisition process is assessed (Figure. 3b).

![Figure 1. (a) 10-20 standard of EEG electrode protocol, (b) Schematic of an EAS developed.](image)

3. Results and Discussion

The circuit is tested and analyzed in NI Multisim software before proceeding for real circuit development. The circuit simulation has been conducted with the circuit developed with OP07 ICs.
The transient and frequency responses of the circuit have been studied. The circuit is tested with different gains and it is found that the overall gain of the proposed circuit could be obtained as \(10^{4}\) for 1 mV (RMS), 100 Hz sinusoidal input signal. Transient analysis of the input (Figure 4a) and output (Figure 4b) signals are also studied in Multisim and the stable signal has been found after 50 ms. The frequency response of simulated ESCB circuit demonstrate that the ESCB is suitable for EEG signal processing (Figure 5). The circuit simulation has been conducted for different EEG signals such as alpha (\(\alpha\)), beta (\(\beta\)), theta (\(\theta\)) and delta (\(\delta\)). For the ESCB circuit developed in the NI Multisim, the high SNR values are found at different frequency levels corresponding to \(\alpha\), \(\beta\), \(\theta\) and \(\delta\) waves. At 5 Hz, 10 Hz, 25 Hz, 50 Hz, the SNR is found as -90.57dB, -89.69 dB, -84.81 and -75.07 dB respectively.

![Figure 2. Schematic of the EEG Signal Conditioner Block (ESCB) circuit proposed](image)

![Figure 3. Experimental setup (a) signal conditioner circuit, (b) NI MyDAQ based EAS](image)

The breadboard based ESCB has been tested with real low frequency low amplitude signals generated by WBO. The output signal amplitude and the frequency of the WBO circuit are varied with the variation in the control resistor and capacitors to generate low amplitude (0-75 mV) and low frequency (0-100Hz) signal. The gain of the instrumentation amplifier, non-inverting amplifier 1 and non-inverting amplifier 2 are controlled with variable resistors. Trimmer potentiometers are used as the variable resistors and they are set to obtain the gains of the instrumentation amplifier, non-inverting amplifier 1 and non-inverting amplifier 2 as 10, 10 and 10 producing an overall gain of 1000. The WBO output signals generated for different amplitudes and frequencies are tested in digital storage oscilloscope (DSO) and found suitable for performance assessment of an EEG signal conditioner. The WBO output signals generated for different amplitudes and frequencies are fed to the ESCB circuit and ESCB output signal are tested in DSO. It is observed that the WBO is suitable for generating low-frequency (10 Hz-100 Hz) and low voltage (1 mV-100 mV) sinusoidal signals. The WBO is tested for 1mV, 25 mV, 50 mV, 75 mV (Figure 6a) and 100 mV using DSO (TDS1001B, Tektronix Inc., USA). All the signals are also generated and tested at different frequencies varying between 10 Hz to 100 Hz. As shown in Figure 6b, for a test signal of 1mV (RMS), 100 Hz sinusoidal voltage signal applied to the input of the EAS circuit, the output of the EAS is found as 1.01V (RMS) which indicate the gain of 1000. The frequency response of the ESCB circuit shows that the proposed ESCB is suitable for acquiring low voltage signals of different
frequency bands corresponding to the standard EEG waves such as α, β, θ and δ. The developed circuit is also studied with an EEG signal generated by an NI MyDAQ based EEG signal generator (Figure 7). The generated EEG signal is found as a real electrical signal voltage representing the EEG waveform. A simulated EEG signal is developed by using a virtual instrumentation (VI) in NI LabVIEW and the simulated signal has been converted to a real signal through NI MyDAQ hardware. Figure 7 shows the simulated EEG signal obtained in the front panel of the LabVIEW based VI. The NI MyDAQ based data acquisition system is tested with 1 V, 100 Hz sinusoidal signal with a sampling rate of 1 kHz and 100 number of samples to read. The acquisition is conducted using the A/I channel A0 with respect to an analog ground pin.

Figure 4. Transient analysis of the input and output signal studied in NI Multisim

Figure 5. Frequency response of the EEG instrumentation simulated in Multisim for δ-θ signals

Figure 6. (a) 1mV (RMS), 100 Hz signal generated for EAS testing, (b) amplified signal.

Figure 7. Simulated EEG signal generated in LabVIEW based virtual instrumentation
4. Conclusion

An EEG acquisition system (EAS) has been developed with a multi-stage amplifier and filter blocks called ESCB to study the epileptic seizure. The ESCB has been simulated in NI Multisim and its frequency response and the noise response have been studied. Results obtained from circuit simulation shows that the ESCB is suitable for EEG signal conditioning. The breadboard based real instrumentation is studied, tested and evaluated with low voltage, low-frequency periodic signals generated with a function generator developed with the Wien Bridge oscillator circuit. The instrumentation has also been studied with the EEG-like signals generated by NI MyDAQ based virtual instrumentation (VI) controlled by a LabVIEW based graphical user interface (GUI). The instrumentation noise response is studied by measuring the SNR of the circuit blocks using the test signals with and without noises. High SNR is obtained at each stage of the circuit blocks and the overall SNR of the ESCB is found varying from -90.57 dB to -75.07 dB within a frequency range of 5 Hz to 50 Hz. Results, obtained from the experimentation conducted with the real periodic signal as well as the EEG waveforms simulated by VI, show that the developed EAS is suitable for amplifying, filtering and acquiring the EEG signals. Therefore, it is anticipated that the proposed EAS system could be applied for detection of EEG during normal condition or during epileptic seizure.

References

[1] Davis, J. Mark, and Stephen P. Bailey. Possible mechanisms of central nervous system fatigue during exercise. Medicine and science in sports and exercise 29.1 (1997): 45-57.
[2] Carpenter, R., and Benjamin R. Neurophysiology: a conceptual approach. CRC Press, 2012.
[3] Johnston, D, and Samuel MSW. Foundations of cellular neurophysiology. MIT Press, 1994.
[4] Bucher, Elizabeth S., and R. Mark Wightman. Electrochemical analysis of neurotransmitters. Annual review of analytical chemistry 8 (2015): 239-261.
[5] Brazier, M. A. B. Electrical activity of the nervous system. London: Pitman Medical, 1977.
[6] Bera, Tushar Kanti. Noninvasive electromagnetic methods for brain monitoring: a technical review. Brain-Computer Interfaces. Springer, Cham, 2015. 51-95.
[7] Blinowska, Katarzyna, and Piotr Durka. Electroencephalography (EEG). Wiley Encyclopedia of Biomedical Engineering (2006).
[8] Chi, Yu Mike, et al. Dry and noncontact EEG sensors for mobile brain-computer interfaces. IEEE Transactions on Neural Systems and Rehabilitation Engineering 20.2 (2011): 228-235.
[9] Wells, C. E. Chronic brain disease: an overview. The American journal of psychiatry (1978).
[10] World Health Organization. Neurological disorders: public health challenges. WHO, 2006.
[11] Zigmond, Michael J., Joseph T. Coyle, and Lewis P. Rowland, eds. Neurobiology of brain disorders: biological basis of neurological and psychiatric disorders. Elsevier, 2014.
[12] Penfield, Wilder. The evidence for a cerebral vascular mechanism in epilepsy. Annals of Internal Medicine 7.3 (1933): 303-310.
[13] Engel Jr, Jerome. Seizures and epilepsy, Vol. 83. Oxford University Press, 2013.
[14] Tzallas, A.T., Markos G.T., and Dimitrios I.F., Epileptic seizure detection in EEGs using time-frequency analysis. IEEE Trans Inf Technol Biomed. 13.5 (2009): 703-710.
[15] Meng-Jun, L. Application of NI myDAQ in practical education of electronic circuit engineering. Journal of Hebei North University (Natural Science Edition) 6 (2011).
[16] King, Robert H. Introduction to data acquisition with LabVIEW. McGraw-Hill Science/Engineering/Math, 2008.
[17] Bera, TK, Nagaraju J, and Lubineau G. A LabVIEW-based electrical bioimpedance spectroscopic data interpreter (LEBISDI) for biological tissue impedance analysis and equivalent circuit modeling. Journal of Electrical Bioimpedance 7.1 (2019): 35-54.
[18] Bera, TK, and J. Nagaraju. Studies on thin film-based flexible gold electrode arrays for resistivity imaging in electrical impedance tomography. Measurement 47 (2014): 264-286.

[19] Teplan, M. Fundamentals of EEG measurement. Meas. science review 2.2 (2002): 1-11.

[20] Michel, C. M., et al. Localization of the sources of EEG delta, theta, alpha and beta frequency bands using the FFT dipole approximation. Electroencephalography and clinical neurophysiology 82.1 (1992): 38-44.

[21] Zietsch, Brendan P., et al. Common and specific genetic influences on EEG power bands delta, theta, alpha, and beta. Biological psychology 75.2 (2007): 154-164.

[22] Pisarski, L. Head harness for EEG electrodes. U.S. Patent No. 3,735,753. 29 May 1973.

[23] Koessler, Laurent, et al. Spatial localization of EEG electrodes. Neurophysiologie Clinique/Clinical Neurophysiology 37.2 (2007): 97-102.

[24] Valer J., Tsuzuki D, and Dan I., 10/20, 10/10, and 10/5 systems revisited: their validity as relative head-surface-based positioning systems. Neuroimage 34.4 (2007): 1600-1611.

[25] Datasheet, OP07 Op-Amps, Analog Devices Inc., USA

[26] Instruction Manual, NI Multisim software, National Instruments Inc., USA

[27] Instruction Manual, NI LabVIEW software, National Instruments Inc., USA

[28] NI MyDAQ Manual, National Instruments Inc., USA