Affordable Design and Implementation of a 4-Channel EEG Bio-signal Amplification System with Mobile App Visualization Interface

Laiba Farooq[1], Muhammad Danish Mujib[1], Ahmad Zahid Rao[1], Fazila Farooq[1], Abdul Wadood[1], Sijil Zehra[1], Muhammad Farooq Usmani[1], Muhammad Abul Hasan[1]

Department of Biomedical Engineering, NED University of Engineering & Technology[1]

Corresponding Email: *danishmujib@neduet.edu.pk*

Abstract

Background: Electroencephalogram (EEG) is a non-invasive, real-time visualization of the brain's electrical activity to detect any abnormalities in the nervous system before the onset of critical conditions. Therefore, this project aimed to design a cost-effective, high-accuracy, and user-friendly EEG monitoring system to monitor brain activity.

Methodology: The functional prototype was developed at NED University, Pakistan. Initially, electrodes were selected for optimal signal acquisition. An instrumentation amplifier with high differential gain was employed at the preamplification stage due to the low amplitude of the acquired signals. 5th order Butterworth Band-pass filters were designed for the filtration of the signal. Subsequently, a driving circuit was designed to reject all the common-mode signals. Upon competition of the design for all the blocks, the circuit was transferred onto a Printed circuit board for further analysis and validation of results.

Results: The developed device was able to measure brain activity accurately. Real-time data was wirelessly transmitted through Bluetooth that can be visualized on cell phones. The device was significantly cost-effective compared to commercially available products.

Conclusion: The developed system offers a cost-effective solution for real-time EEG monitoring. The final prototype successfully detected, filtered and amplified EEG signals, acquired from the body. Utilizing Bluetooth technology, the processed signals were displayed on a mobile application, thereby providing an affordable solution for monitoring brain activity.

Keywords

Brain, Encephalogram, Health Technology, Prototype.

Check for updates

Cite as: Farooq L, Mujib MD, Rao AZ, Farooq F, Wadood A, Zehra S, Usmani MF, Hasan MA. Affordable Design and Implementation of a 4-Channel EEG Bio-signal Amplification System with Mobile App Visualization Interface. Allied Med Res J. 2024;2(2):236-246. Available from: https://ojs.amrj.net/index.php/1/article/view/167/101.

DOI: https://doi.org/10.59564/amrj/02.02/026

Received: 5th February 2024 , **Revised:** 22nd April 2024 , **Accepted:** 10th May 2024

Introduction

The brain is the most complex organ, the control focus of the human body. This three-pound mass of delicate tissue inside the skull enables everything from simple movements to complex mental activities by coordinating and regulating various physical processes[1]. The brain consists of billions of neurons connected by trillions of neurotransmitters, which are conveyed through electrical and chemical signals[1,2].

The Encephalogram (EEG) records the brain's activity and collects electrical signals cooperating with different brain lobes. Following 10-20 systems, 32 electrodes are placed on specific areas of the scalp to detect and transmit electrical impulses generated in those areas. Signals from different lobes convey important information; for example, motor planning comes from the frontal lobe, sensory information from the parietal lobe, auditory processing from the temporal lobe, and visual stimuli from the occipital lobe. These signals are processed by the EEG circuit and its amplifiers, filters, and converters, reflecting different brain activity in these lobes. This technique can be used to interpret and analyze the wave patterns obtained from the brain, corresponding to the lobe's functions[1,3,4].

Brain disorders refer to many conditions that affect the function or structure of the brain and cause various cognitive, emotional, behavioral, or physical disorders. These problems can be caused by several causes, including genetic factors, injury, disease or neurochemical imbalance, and can significantly impact a person and their life. Neurodevelopmental problems such as autism spectrum disorder (ASD) and Attention-Deficit/Hyperactivity Disorder (ADHD) appear early and can affect mental and social functioning[5,6]. In contrast, neurological diseases such as Epilepsy, Multiple Sclerosis, or Parkinson's disease disrupt the nervous system and its ability, causing movement difficulties or cognitive impairment. Mental health problems such as Depression, Anxiety, Schizophrenia, and bipolar disorder can affect mood regulation and thought patterns. Traumatic Brain Injuries (TBI) and neurodegenerative diseases such as Alzheimer's disease and Parkinson's disease can also cause memory loss, movement disorders, and general impairment[7,8]. Various neuroimaging techniques like Functional Magnetic Resonance Imaging (fMRI), Computed Tomography (CT) scan, Magnetoencephalography (MEG), and Electroencephalogram (EEG) are available to monitor brain activity and are also used for diagnostic purposes of the disorders [9,10]. Moreover, EEG devices have advantages over others due to their high temporal and medium spatial resolution, mobility, and cost[11]. Further, it is a non-invasive and real-time brain monitoring technique used to diagnose various diseases by using electrodes, in comparison to other techniques. Therefore, the project aimed to create an affordable solution for brain monitoring by developing a functional prototype utilizing a 4-channel EEG Bio-signal Amplification System with a Mobile App Visualization Interface.

Methodology

Designed System

The functional prototype was developed at the Biomedical Engineering Department of NED University of Engineering and Technology (NEDUET), Pakistan.

Working Principle

Key components such as AD620IC, LM324IC, Arduino, Bluetooth modules, capacitors, and resistors were used to measure brain activity and diagnose disorders.

Construction

The device consisted of two parts, hardware and software, and was constructed using locally available components, each playing a crucial role in the system's functionality.

- It was ensured that electrodes with biocompatibility features, good conductivity, and lower skin-electrode impedance were chosen. For this reason, Ag/AgCl electrodes were the most suitable for this application. They were formed with Ag/AgCl, were wet, and required gel for the best results[12].

- The AD620 IC was used as an amplifier, playing a critical role in improving the weak electrical signals produced by the brain. These signals, estimated in microvolts, are typically weak and must be strengthened before they can be accurately analyzed and interpreted. EEG amplifiers were designed to amplify these tiny electrical impulses while minimizing interference and noise.

- Low-pass filters are widely used in EEG, ECG, and EMG systems. An EEG circuit typically uses a low-pass filter to remove the high-frequency noise. In an EEG circuit, LPF passes only a frequency range signal. An LPF with a critical frequency 38Hz and attenuation of 30 dB at 40Hz was designed using LM324 IC according to the EEG signal[4,13].

- ***Calculation of the number of poles of the circuit:***
  F= Applied Frequency
  Fc = Cut-off frequency
  Fdec = Decade frequency = Cut-off Frequencyx10

- ***For the number of poles:***
  Attenuation at Fdec = (Fdec−Fc /$F−Fc$) ∗ attenuation at F
  => ((380−38)/ (40−38)) ∗ 177.8 = 30403.8
  => In dB: 20*log (30403.8)
  => 89.65 ≅ 90 → **5 poles**

- A high pass filter blocks lower frequency signals in EEG circuits that produce artifacts and adjust the roll-off rate. LM324 IC was used for the high-pass filter because of its adjustable gain and voltage. It also offers a wide range of power consumption. An HPF with a critical frequency of 0.05Hz and an attenuation of 30 dB at 0.051 Hz was designed.

- ***Calculate the number of poles of the circuit:***
  F = Applied Frequency
  Fc = Cut-off frequency
  Fdec = Decade frequency = Cut-off Frequencyx10

- ***For the number of poles:***
  Attenuation at Fdec = (Fdec−Fc/ $Fc-F$) ∗ attenuation at F
  => ((.5−.05) / (0.05−0.049))∗ 177.8 = 80010
  => In dB: 20*log (80010)
  => 98 → **5 poles**

A driving circuit was designed using LM324 IC, capacitor (0.01uF), and resistors (1M ohm, 12k ohm, 30k ohm). The driving circuit provided electrical isolation and managed the noise between the power and the control circuit. The purpose of this circuit was to ensure the correct, reliable, and low noise measurement of the weak electrical signals generated by the brain (Figure-1 and 2).

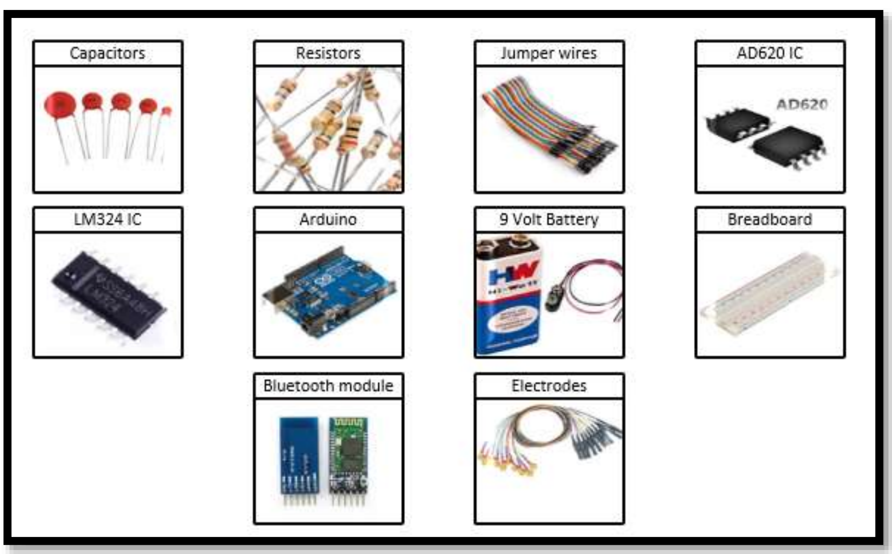

Figure-1 Components of the circuit

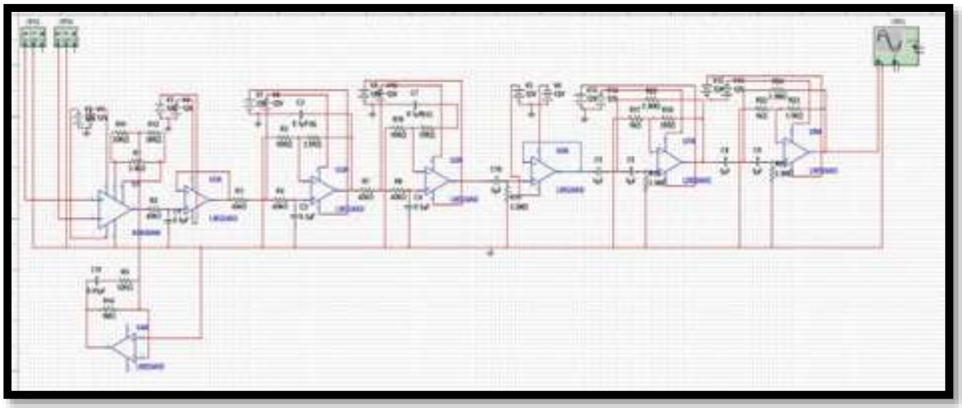

Figure-2 Schematic diagram created on Multisim

The Arduino UNO acted as the system's brain, interacting with components to receive and serve electrical signals from the oscilloscope to the mobile app. The connection of electrical components was quickly placed in a breadboard, and a jump wire was usually used to connect two points to allow electrical connection (Figure-3).

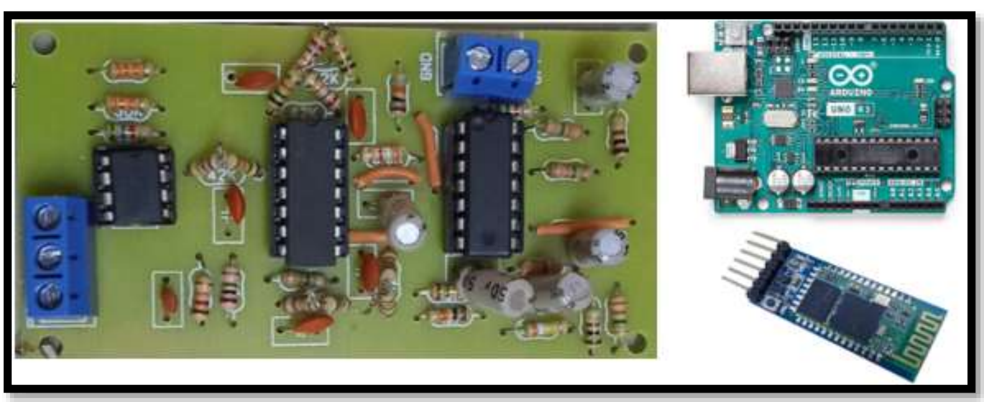

Figure-3 Hardware components of the system

Application Design

While developing the app in MIT App Inventor, its visual and user-friendly programming interface was utilized to create the user interface quickly, and the components were designed to simplify the user experience. The system utilizes a 4-channel set-up, allowing the amplifying bridge to collect brain information accurately. Sensor and signal processing components were integrated seamlessly into the app using MIT App Inventor, enabling real-time amplification and bio-signal reception. The mobile phone's user interface incorporated graphic display and data logging features with graph controls to enhance user interaction and user controls to improve mobile responsiveness. This may result from the MIT App Inventor's event-driven programming model method (Figure-4).

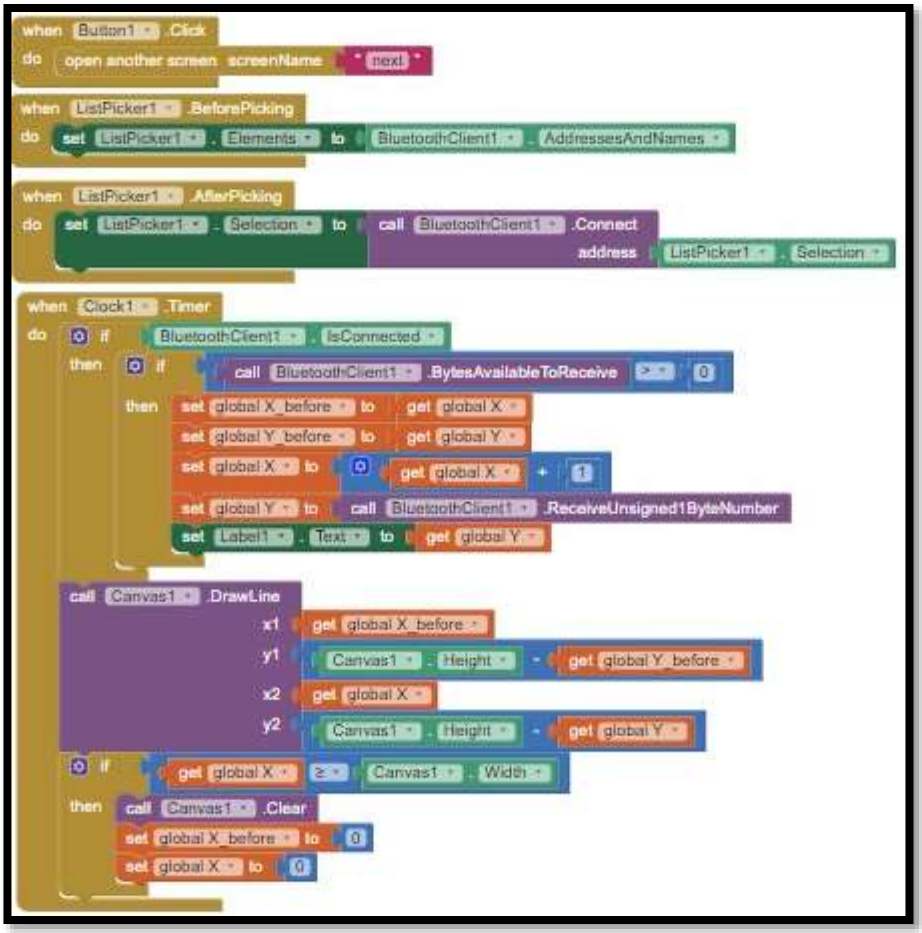

Figure-4 Component of backend program of MIT App Inventor

Results

Figure-5 displays the output of an EEG device, showing a continuous brain wave pattern on an oscilloscope screen. The waveform appears stable and clear, indicating that the device is successfully capturing and amplifying brain signals. The screen shows a relatively flat baseline with minor fluctuations, suggesting that the device is effective in filtering noise and accurately representing real-time brain activity. This visual representation confirms that the EEG device developed is capable of reliable brain activity monitoring, with data being easily interpreted by the end-user.

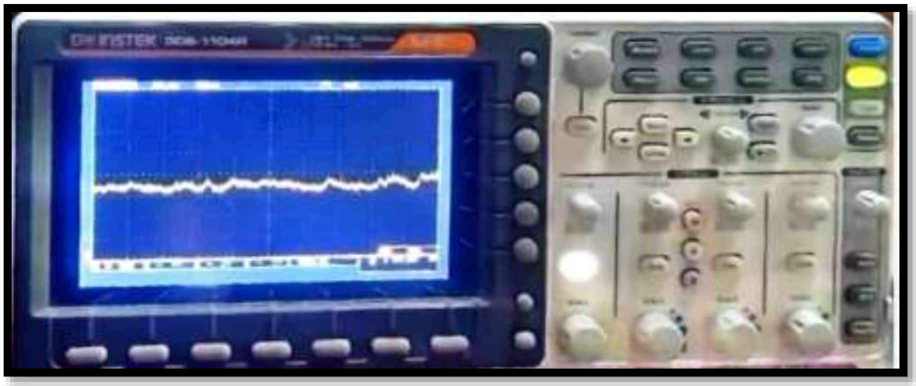

Figure-5 EEG output on Oscilloscope

Cost Comparison

Table-1 below shows the cost comparison of multiple devices available and the developed device:

Table-1 Cost comparison

Device	Description	Approximate Price ($)
Muse S EEG Brain Sensing Headband	Portable EEG headset with 4 channels, sleep tracking, and meditation assistance.	400
Muse 2 EEG Brain Sensing Headband	Measures physical activity, and promotes calmness, and emotional control.	200
g.Nautilus	Mid-range 8- channel EEG system for research applications.	7000
Semi Active Two	High-end research-grade 32-channel EEG system.	6000
BrainMaster Discovery 24E	Mid-range 4- channel EEG system suitable for neurofeedback	6000
NeuroSky MindWave Mobile 2	Affordable 1- channel EEG headset for basic applications.	200
OpenBCI Ultracortex Mark IV	8 to 16 channels, research-grade EEG headset.	400
Brainlink Lite V2.0	Measures different states of mind (focus, calm, excitement) with various apps.	400
MYNDPLAY MyndBand	Neurofeedback training with virtual reality compatibility.	400
Neeuro Senzeband 2	Widely used for the purpose of neurofeedback, relaxation, and focus enhancement.	400
Bio-Signal Picker (BSP)	Affordable, easy for consumer use, provides real-time brainwave data streaming and analysis.	90

Characteristics Comparison

Table-2 shows, a characteristics comparison of multiple devices available with our device.

Table-2 Characteristic comparison

Device	Channels	Setup Time (minutes)	Accuracy %	Portable	Wireless	Light Weight
NeuroSky Mind Wave Mobile	1	1-3	83.33	P	P	P
Muse 2	4	3-5	83.80	P	P	P
EPOC+	14	10-15	78.34	×	P	P
Open BCI Cyton Biosensing Board	16	10-15	60.00	×	×	×
BrainBit EEG Headset	4	5-10	81.56	P	P	P
BSP (Bio-Signal Picker)	4	1-3	75.00	P	P	P

Upon evaluation, the device proved significantly cost-effective compared to commercial alternatives, as shown in Table-1, highlighting its affordability and accessibility. Further, it contains all those parameters compared to high-cost devices, as shown in Table 2; for example, our device's set-up time is (1-3) minutes, while Muse 2 takes (3-4) minutes. Furthermore, in the market, some devices are high-cost but not portable, while our device is mainly designed for user comfort, wireless, and lightweight. This achievement aligns with our overarching goal of broadening access to diagnostic technology, particularly in low-resource settings where specialized operator training and high initial costs pose significant barriers[14].

Discussion

The project, undertaken at NED University, Pakistan, in 2024, aimed to develop an affordable 4-channel EEG bio-signal amplification system with a mobile app interface to enhance accessibility to brain disease monitoring. A functional prototype addressed small bio-signals, noise interference, and high costs. The system effectively captured brain activity, providing real-time data visualization while ensuring accurate measurement. Its success relied on carefully selecting electrodes, incorporating amplification and filtration circuits, and integrating calculated low-pass and high-pass filters. These components enabled the system to record EEG signals efficiently. The circuit is designed up for the signal of very low frequency from range of 0.05 Hz to 45 Hz where the signals of all bands of EEG will be gained. The noise in the circuit is quite minimal and the setup time is quite low as compare to the others it is also compact in size, portable, wireless, user-friendly which can be used by the medical staff, researchers and patients. The circuit is mainly comprised of the instrumental amplifier, high and low pass filters, notch filters. The ICs we used are widely available and has the all-basic parameters and characteristics [15–18].

Diseases like Epilepsy, Alzheimer, brain ham-rage and others which are most common in the current generation but the people are unaware about them and not get proper treatment which effects the patient’s life so for that reason we have used the software. So, for the aid of the society and new researches in the field of medical, neuro will be flourished by using this device. There are multiple researches worked on this problem statement. Also, it helps in the data collection, storing and analyzing [19–22]. The Bio-Signal Picker (BSP) is developed with very minimal cost and provide 4-channels and has meet all the necessary parameters of the current devices available in the market. The vital part is that the device is highly compact in design with the wireless and portable in nature. The other part is that it can provide the real time signals which helped out the doctors to diagnose the patients well from distinct areas and the provision of aid is made possible[23]. This system can be integrated with neuromuscular therapy devices such as Binaural beat[24], Transcutaneous electrical nerve stimulation[25], transcranial direct current stimulation, neurofeedback[26], in conjunction with machine learning techniques[27], to facilitate personalized therapeutic approach.

Conclusion

The developed system offers a cost-effective solution for real-time EEG monitoring. The final prototype successfully detected, filtered and amplified EEG signals, acquired from the body. Utilizing Bluetooth technology, the processed signals were displayed on a mobile application, thereby providing an affordable solution for monitoring brain activity.

Acknowledgments
None.

Conflict of Interest
None.

Grant Support and Funding Disclosure
None.

References

1. Belanger HG, Vanderploeg RD, Curtiss G, Warden DL. Recent neuroimaging techniques in mild traumatic brain injury. J Neuropsychiatry Clin Neurosci. 2007;19(1):5–20.
2. Siuly S, Li Y, Zhang Y. Electroencephalogram (EEG) and its background. In: EEG Signal Analysis and Classification. Cham: Springer International Publishing; 2016. p. 3–21. doi:10.1007/978-3-319-47653-7_1.

3. Sahin ME, Ucar Y, Temurtas F. An implementation of analog portable EEG signal extraction system. In: 2015 9th International Conference on Electrical and Electronics Engineering (ELECO). IEEE; 2015. p. 1126–31.
4. Tchiotsop D, Kanaa T, Fogue M, Njomo AFT, Zana KK. Low cost and low power ECG recorder suitable for low incomes populations. Int J Electron Commun Comput Eng. 2015;6:558.
5. Bosetti C, Ferrini L, Ferrari AR, Bartolini E, Calderoni S. Children with Autism Spectrum Disorder and abnormalities of clinical EEG: A qualitative review. J Clin Med. 2024;13(2):279.
6. Lenartowicz A, Loo SK. Use of EEG to diagnose ADHD. Curr Psychiatry Rep. 2014;16(11):498.
7. EEG Signal Processing for Alzheimer's Disorders Using Discrete Wavelet Transform and Machine Learning Approaches [Internet]. Available from: https://ieeexplore.ieee.org/abstract/document/9857825
8. Ianof JN, Anghinah R. Traumatic brain injury: An EEG point of view. Dement Neuropsychol. 2017;11(1):3–5.
9. Nilawati S, et al. Unraveling emotional regulation through multimodal neuroimaging techniques. BrainBridge Neurosci Biomed Eng. 2024;1(1):1–26.
10. EEG-based functional connectivity analysis of brain abnormalities: A systematic review study. Inform Med Unlocked. 2024;47:101476.
11. Mullen TR, et al. Real-time neuroimaging and cognitive monitoring using wearable dry EEG. IEEE Trans Biomed Eng. 2015;62(11):2553–67.
12. Fatoorechi M, et al. A comparative study of electrical potential sensors and Ag/AgCl electrodes for characterising spontaneous and event related electroencephalagram signals. J Neurosci Methods. 2015;251:7–16.
13. Whitchurch AK, Abraham JK, Lonkar MA, Varadan VK. Design of a compact amplifier and signal conditioning module for wireless EEG monitoring. In: 2007 IEEE Region 5 Technical Conference. IEEE; 2007. p. 153–6.
14. Tallgren P, Vanhatalo S, Kaila K, Voipio J. Evaluation of commercially available electrodes and gels for recording of slow EEG potentials. Clin Neurophysiol. 2005;116(4):799–806.
15. Dilmaghani R, et al. Design and implementation of a wireless multi-channel EEG recording. In: 2010 7th International Symposium on Communication Systems, Networks & Digital Signal Processing (CSNDSP 2010). IEEE; 2010. p. 741–6.
16. An EEG analysis approach towards brain-to-brain synchronization | IEEE Conference Publication | IEEE Xplore [Internet]. Available from: https://ieeexplore.ieee.org/abstract/document/9411590
17. NeuroSpy: A low-cost portable IoT enabled EEG and ECG data processor | IEEE Conference Publication | IEEE Xplore [Internet]. Available from: https://ieeexplore.ieee.org/abstract/document/9357429
18. Kumar N. Design of Non Invasive Wireless EEG Recording System. 2015.
19. EEG Recording and Online Signal Processing on Android: A Multiapp Framework for Brain-Computer Interfaces on Smartphone - Blum - 2017 - BioMed Research International - Wiley Online Library [Internet]. Available from: https://onlinelibrary.wiley.com/doi/full/10.1155/2017/3072870

20. Frontiers | The Acceptability, Feasibility, and Utility of Portable Electroencephalography to Study Resting-State Neurophysiology in Rural Communities [Internet]. Available from: https://www.frontiersin.org/articles/10.3389/fnhum.2022.802764/full
21. Liu C, et al. Complex brain network analysis and its applications to brain disorders: A survey. Complexity. 2017;2017:8362741.
22. Melinda M, Arnia F, Yafi A, Andryani NAC, Enriko IKA. Design and implementation of mobile application for CNN-based EEG identification of Autism Spectrum Disorder. Int J Adv Sci Eng Inf Technol. 2024;14(1):57.
23. NeuroPhone | Proceedings of the second ACM SIGCOMM workshop on Networking, systems, and applications on mobile handhelds [Internet]. Available from: https://dl.acm.org/doi/abs/10.1145/1851322.1851326
24. Mujib MD, Hasan MA, Qazi SA, Vuckovic A. Understanding the neurological mechanism involved in enhanced memory recall task following binaural beat: A pilot study. Exp Brain Res. 2021;239(9):2741–54.
25. Mujib MD, et al. Comparative neurological and behavioral assessment of central and peripheral stimulation technologies for induced pain and cognitive tasks. Biomedicines. 2024;12(7):1269.
26. Ather M, et al. Efficacy of audiovisual neurofeedback training for attention enhancement: A multimodal approach. NeuroReport. 2024;10:1097.
27. Rao AZ, et al. Sensor fusion and machine learning for seated movement detection with trunk orthosis. IEEE Access. 2024;12:41676–87.

AUTHORS' CONTRIBUTION

The following authors have made substantial contributions to the manuscript as under:

Conception or Design: Farooq L, Mujib MD, Rao AZ, Hasan MA

Acquisition, Analysis or Interpretation of Data: Farooq L, Mujib MD, Rao AZ, Farooq F, Wadood A, Zehra S, Usmani MF

Manuscript Writing & Approval: Mujib MD, Hasan MA

All the authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.