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A Portable, Wireless and Low-cost Electroencephalogram Monitor using Raspberry Pi

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Research Article

Abstract:
Portable EEG devices have a great potential to become efficient computer interfaces. However, observing brain activity in real-world settings offers exciting possibilities like the support of physical health, mental well- being, and thought-controlled interaction modalities. The development of such applications is, however, strongly impeded by poor accessibility to research-grade neural data and by a lack of easy-to-use and comfortable sensors. An integrated system design is described, that combines publicly available electronics components to form an easily replicable, versatile, EEG recording system for prolonged use and easy application development. Most of the commercial EEG monitors in the market does not have wireless connection and usually serially connected with a monitor to display the data collected. A portable, wireless, and low-cost EEG system was developed by using a commercial amplifier Open BCI ganglion and a small single-board computer Raspberry Pi. The objective of this project is to design a portable, wireless, and low-cost EEG monitor, to implement Brain Flow libraries in Raspberry pi, and to display the graphs of real-time EEG, real-time power spectral density, and real-time band power. This system can acquire EEG signals through the electrode, transmit the EEG signal through the amplifier and display the signals in real-time on a touch screen. Based on the results, a mental task was given to the subject which needs concentration, the system was able to detect the targeted band which is beta, and this was supported by a previous study. Finally, the scope of this project has been fulfilled. However, the system designed still has some limitations and has plenty of room for improvement.
Keywords: Electroencephalogram; Low-cost; Medical device; Raspberry Pi

1. INTRODUCTION

With the proliferation of the concept of wearable devices, wearable technologies and solutions are targeted at addressing unmet military, automotive, and healthcare needs. Both commercial and research applications are increasingly involved in the wearable Brain Computer Interface (BCI). Observing brain activity in real-world settings offers exciting possibilities like the support of physical health, mental well-being, and thought-controlled human-computer interaction (HCI) modalities (1). Electroencephalogram (EEG) monitoring is one of the most convenient methods to investigate brain functions, and in some cases, some patients, such as epilepsy, need to be monitored in real-time, so a portable, small-sized and economical EEG device is necessary to build such a monitoring system (2).

Electroencephalography is a more comfortable way to assess brain activity than other methods, although clinical and research EEG acquisition systems are still far from portable. They rely significantly on cable transmission; they are rarely battery- powered, and conductive material between the electrodes and the scalp is frequently required to increase signal quality. Furthermore, the cost of such devices is often higher than many people's income levels, hence they cannot be termed inexpensive technologies. For non-invasive EEG to be a practical option, they must be readily available as small, wireless, portable, and low-cost systems. These systems consist of EEG amplifiers as well as a processing unit that translates brain signals into control commands for an output device. While commercial amplifier systems are available for purchase, they can be expensive and bulky. Additionally, both commercial and research amplifiers generally require a desktop or laptop computer for signal processing (3). Thus, these EEG systems are neither small nor portable and require extensive setup. The few research on EEG systems that can utilize an embedded processing unit for real-time monitoring use is expensive, overly complex, or too bulky. To meet our goals (simple, compact, portable, and low-cost), an EEG system for signal visualization that utilizes a custom 4- channel EEG amplifier and Raspberry Pi has been designed and tested.

Besides, wireless usually refers to a networked interconnection of everyday objects. It can be described as a self-configuring wireless network of sensors that has a purpose to interconnect with all things. Through a wireless network, the communication between people and objects can be realized (4). By using a wireless connection, a broad range of devices like tablets and laptops can connect cars and buildings, TVs and game consoles, smart meters, and traffic control. By enabling this, devices can communicate with each other independently without human interaction.

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Furthermore, healthcare is one of the basic needs of any person. In India, with the advent of information technology, a survey was conducted to observe the functioning of various medical centers and the progress in healthcare delivery. The survey showed that patient records were not well managed in many of the hospitals, and that patient referrals between different hospitals were based on paper notes. The survey found that with the aid of a wireless network, healthcare services can be enhanced, especially using electronic health records (EHRs) (5). The combination of Raspberry Pi and wireless connection becomes an innovative technology in the healthcare system. Raspberry Pi acts as a small clinic while it connects to some sensors (6). A popular Raspberry Pi platform offers a full Linux server on a small platform at a very low price. Raspberry allows interface services and mechanisms via the general- purpose I/O interface (7).

Commonly, EEG monitors are directly connected to a computer or a machine to analyze, interpret and display the data that is sent from the amplifier using a wired connection. Additionally, both commercial and research amplifiers generally require a desktop or laptop computer for signal processing. Thus, these EEG monitors are neither small nor portable and require extensive setup (3). Study shows that this technology has been large and bulky and limits the usage of BCI for monitoring subjects in a lab and clinic while the subject remains stationary (8). Standard EEG requires a lengthy preparation procedure which also leads to uncomfortable experiences because it involved mounting many wired sensors and connecting many electrodes to the main acquisition unit and a PC or laptop. This makes the technology far from being user-friendly, convenient and results in disapproval of users, and limits the use to clinical and ambulatory environments (9).

Thus, the current EEG systems are not well-suited for use outside the clinic or research laboratory due to their size, cost, and lengthy setup time such a clinical amplifier. In this research, a small, portable, and extremely cost-efficient EEG monitor is designed using a custom EEG amplifier (OpenBCI ganglion), and a commercial microcontroller (Raspberry Pi). In this case, the systems will be well-suited for use outside the clinic or research laboratory due to their size, cost, and concise setup time. By conducting this experiment, it is possible to further explore and determine the potential benefit of using wireless connections along with the BCI.

2. MATERIALS AND METHODS

The tools and methods that were conducted during the experiment and the details of board calibration which started with hardware connection followed by board programming to read out the data on the Raspberry Pi using BrainFlow libraries, are explained in detail.

2.1 Research Design and Procedure

As shown in Figure 1, in general, the ganglion board was connected to Raspberry Pi either through wired or Bluetooth. Ganglion is a programmable board which is designed to track brain activity using OpenBCI graphical user interface (GUI). Moreover, Raspberry Pi will be an alternative for the OpenBCI GUI. Raspberry Pi uses a different processor architecture (ARM) than most laptops, thus causing incompatible work between the GUI of the OpenBCI and the Raspberry Pi. Therefore, to collect real-time EEG to be sent to a Raspberry Pi, BrainFlow libraries were implemented.

2.2 Hardware Connection

The connection of the hardware was divided into 3 phases. Firstly, the amplifier which is OpenBCI ganglion was connected to the Raspberry Pi through a Bluetooth dongle (BLED 112) as shown in Figure 2. Some coding was required to identify the dongle as a Bluetooth device which allowed the Raspberry Pi to receive the data from the amplifier.

Secondly, the BCI libraries were implemented into the Raspberry Pi to make sure that the Raspberry Pi receive the amplifier reading. Finally, the system was connected to the whole system to test the hardware by connecting the electrodes to the amplifier. Table 1 shows the connection details of the electrodes. Next, the input switches were inverted all down which associated to channel's - input that connected to the REF pin. This action allowed to 'gang' some or all the - pins together to combine two or more of the – pins as shown in Figure 2.

Table 1. Electrodes to amplifier connection.

Electrode WireColour	Ganglion Board Pin	Function
White	REF (top pin)	Reference Pin
Black	D_G (top pin)	Noise-cancelling Pin
Purple	+2 (on top row)	Analog input
Red	+4 (on top row)	Analog input

2.2.1 Setup Process

Firstly, some dependencies were installed from PYPI includes the installment of main libraries. Prior to the installment, the Raspberry Pi packages were updated and upgraded. The modules and libraries were installed following PyQt5 module, which is one of the most used modules in building GUI apps in Python. Libatlas was automatically tuned to the linear algebra software. While PyQtGraph, a graphic and user interface library for Python provided functionality commonly required in designing science applications. Its primary goals are to provide fast, interactive graphics for displaying data (plots, video, etc.).

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Secondly, the BrainFlow library was installed which allowed communication between the amplifier and the Raspberry Pi. Since the system of the Raspberry pi was 32 bits, installing the libraries from PYPI was not possible. To overcome this situation, a code of C++ was compiled on Raspberry and python binding was installed from the local folder instead of PYPI. Moreover, a temporary folder was created in the local environment, then the library was installed from the BrainFlow github.com. Additional command lines were added to the Raspberry Pi system's text editor to make the PIP packages ready to be installed.

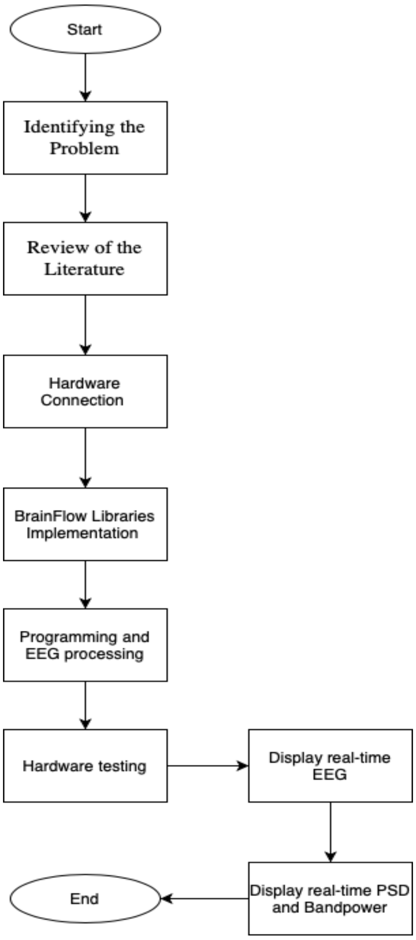

Figure 1. Project flow.

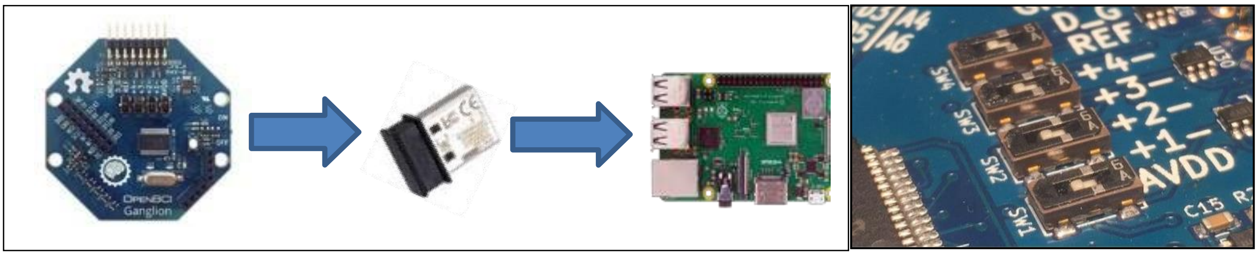

Figure 2. Connection between amplifier and Raspberry Pi (left) and amplifier switch (right).

Finally, the 4 AA batteries were installed in the battery pack, plug in the Ganglion board and the power switch was turned on. The BLUE LED blinked gently. Blinking means that the BLE radio is not connected or paired with any computer or phone/tablet. Additionally, there was a code script provided in the BrainFlow packages to test the device connectivity. Figure 3 shows the amplifier after connection where the BLUE LED stop blinked which indicated that the amplifier was connected, and the data were ready for reading.

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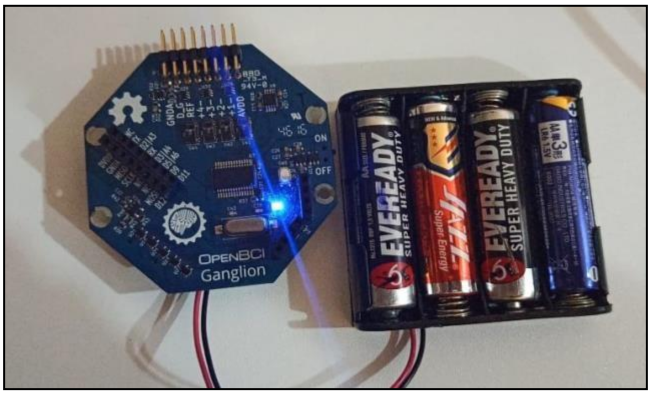

Figure 3. Amplifier after connection

2.3 EEG Data Visualization

The major library used was BrainFlow which is designed to gather, interpret and analyze EEG, electromyogram (EMG), electrocardiogram (ECG) and other biosensor data. In the BrainFlow User API, there are two main user modules: 1) BoardShim - It reads data from a board/BCI device and uses the BoardController library to call functions; 2) DataFilter - It uses the underlying DataHandler library to do signal processing such as the Fast Fourier Transform (FFT), Wavelet Transform, and so on.

These two modules of BrainFlow were installed to collect, filter and analyze the EEG data. The other interesting sub-package that was installed is the animation function of Matplotlib. BrainFlow API was used for data streaming and to perform signal processing. To connect with the board/BCI device using the BrainFlow, data acquisition API, i.e. BoardShim, a constructor and instantiate an instance of BrainFlowInputParams structure were called to hold information for the specific board/BCI device. This action allowed switchboards without any major change in the code.

There were four essential steps to visualize the real-time EEG signals included 1) Connecting - Importing the methods and classes in openBCIStream.py along with the connection via the serial port; 2) Streaming - Once the connection was established with the ganglion board, the board was started to stream and store the data in the ring buffer; 3) Polling – the used of window size 4 with the data speed of 10 ms; and 4) Stopping - The stream was stopped.

2.4 EEG Signal Processing

Data from BrainFlow comes in a 2D Numpy array which contains all the data coming from the BCI. I call this data, “raw data,” this could include EEG, EMG, Accelerometer, and Timestamp channels.Essentially, a loop through all the EEG channels is needed in the data and applies filters to each channel. If applying the same filters to each EEG channel, instead just loop through the channels normally without using enumerate and count. The filters used are bandpass and bandstop Butterworth.The power spectral density (PSD) was obtained to represent the power distribution of EEG series in the frequency domain. Moreover, to analyze EEG data by decomposing the signal into functionally distinct frequency bands, such as delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz), and gamma (30–100 Hz).

2.5 Experimental Setup

The OpenBCI Ganglion is a high-quality, affordable bio-sensing device, compatible with OpenBCI's free open-source software. On the input side, there are 4 high-impedance differential inputs, a driven ground (DRL), a positive voltage supply (Vdd), and a negative voltage supply (Vss). The inputs can be used as individual differential inputs for measuring EMG or ECG, or they can be individually connected to a reference electrode for measuring EEG. Data is sampled at 200Hz on each of the 4 channels.

Firstly, the electrode was placed onto the subject scalp as shown in Figure 4. The amplifier OpenBCI ganglion was amplified to filter the noises in acquiring accurate brain signal samples. The brain signals were supplemented to the Raspberry Pi with the aid of Python programming code to filter and display the EEG graphs in time series, power spectral density and band power. Figure 4 shows the overall block diagram of the BCI hardware system from the electrode placement on the subject’s head to the displayed brain signal on the monitor.

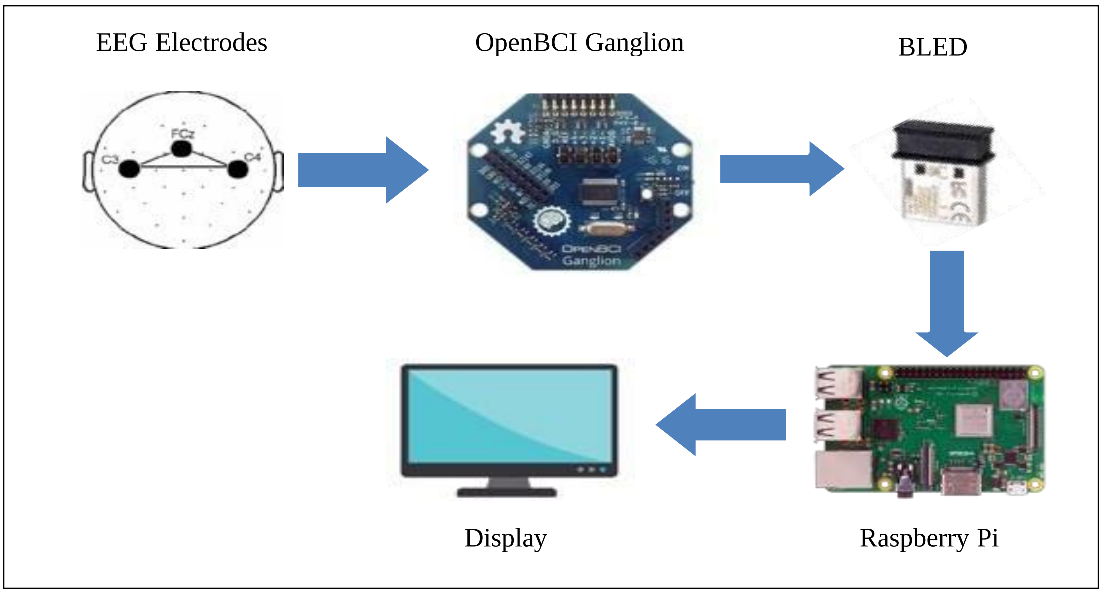

Figure 4. Overall block diagram

3. RESULTS AND DISCUSSION

3.1 Board Connection to Raspberry Pi

The codings used in the Python using the BrainFlow library are available in Supplementary 1. This coding connected the Raspberry pi with the OpenBCI ganglion using a Bluetooth connection. The BLED112 Bluetooth dongle was chosen to be implemented in this study due to the problems accounted for by the old CSR dongle and extra steps to make the system work. Additionally, the dongle is able to provide a high-speed transfer rate.

3.2 Real-time EEG Visualization Section

The last stage of this system was to get a real-time EEG signal on Raspberry pi. Figure 5 shows the results obtained from the Raspberry pi. The data collected was not stable and accurate due to environmental noises.

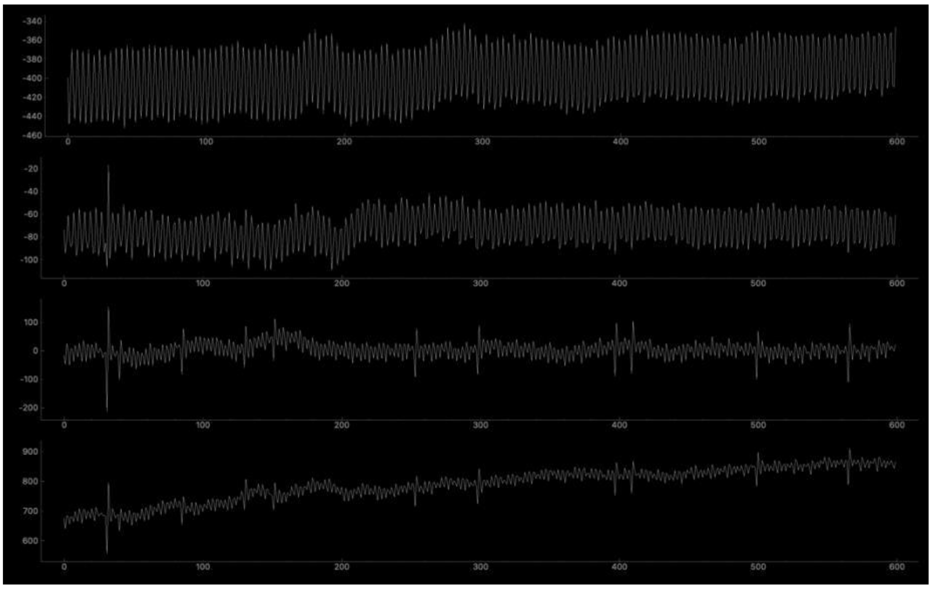

Figure 5. Brain_Flow coding for hardware connection.

The noises were filtered with a bandpass and band stop Butterworth, to show the high and low frequencies (Figure 6). Finally, the signal bands were processed. Supplementary 2 presents the coding that was developed to compute the power spectral density of the average band power.

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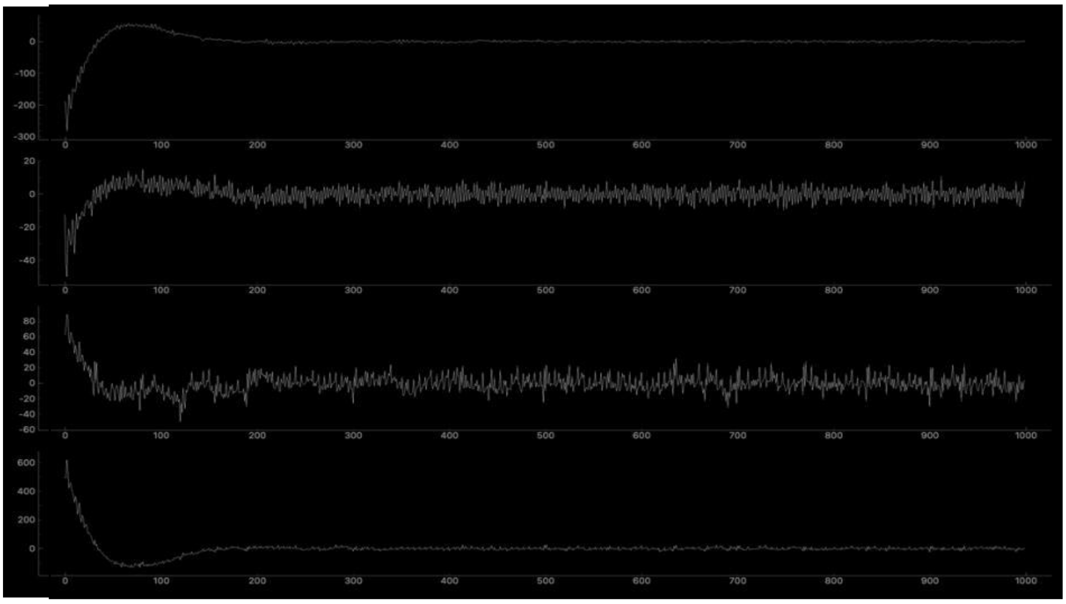

Figure 6. Filtered EEG signals.

Figure 7 shows the EEG signals and bands monitoring. The bands from the left to the right: delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz), beta (12–30 Hz), and gamma (30–100 Hz). The system indicated the band's variation. The graph shows the reading of four different channels and, since the amplifier board support only up to four channels which mean only for electrodes can be placed at the same time beside noise-canceling and reference electrodes, each channel was defined by a color which allowed tracking the needed channel in the PSD graph. The PSD graph described the changes over the four channels in the frequency domain. Furthermore, the band power graph shows how strong the band is. The bands are delta, theta, alpha, beta, and gamma left to right, respectively.

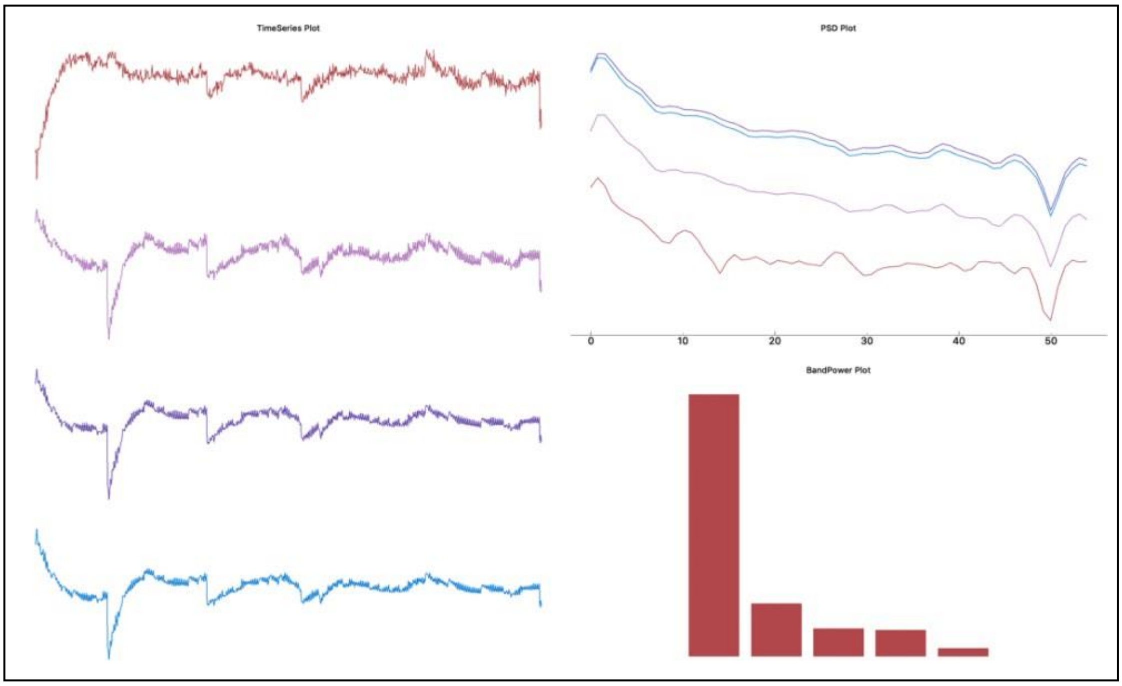

Figure 7. Final output which shows the EEG signals and bands monitoring.

Finally, a touch screen was added to the system and a power bank was used as the power supply to make the system portable and ready to use anywhere and anytime with no limitation to a specific place and time (Figure 8).

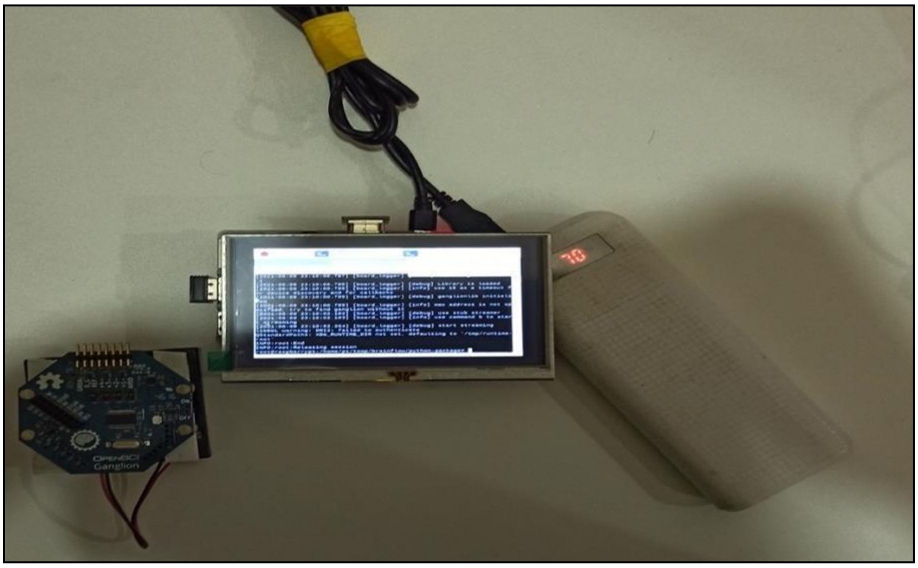

Figure 8. Touch screen to display the output.

3.3 Prototype

Figure 9 shows the prototype wireless EEG monitor was attached to the subject. A headband was attached to the subject's head to reduce artifact noise. For this prototype, the amplifier board that was attached to the subject shoulder was not very stable and needed to have a casing to hold the board. A casing was required to support the board. While the electrodes were organized for more accurate reading and no artifact movement. There were four electrodes that were placed in the correct place. The first electrode was the purple electrode, which was placed on the scalp of the patient. The red electrode was placed on the back of the head. While the white and black electrodes which are the reference and the noise-canceling were placed on the earlobes.

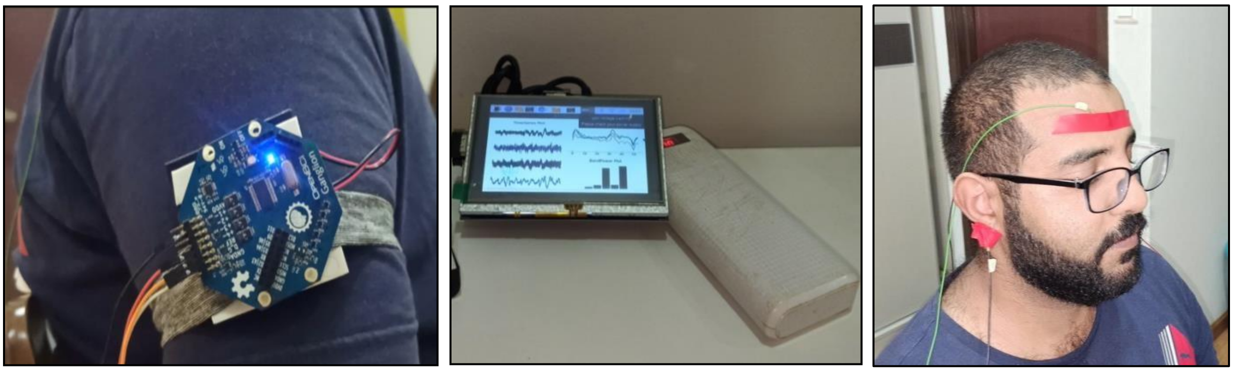

Figure 9. System prototype and electrode placement.

3.4 System Validation

As a validation, the subject was asked to solve a mathematical problem, to see the system reading. As shown in Figure 10, the system indicated beta signal, which means that the system gives the correct reading. A study done by Gola *et al*. (10) showed a similar result when studying the EEG beta-band activity. The data collected were presented in real-time graphs that show the live EEG, and to provide an initial overview. Distributions of the EEG frequencies were reported in the form of power spectral density (PSD) distributions for each condition. These allow assessing changes in frequency bands by experimental condition visually (Figure 11 and 12).

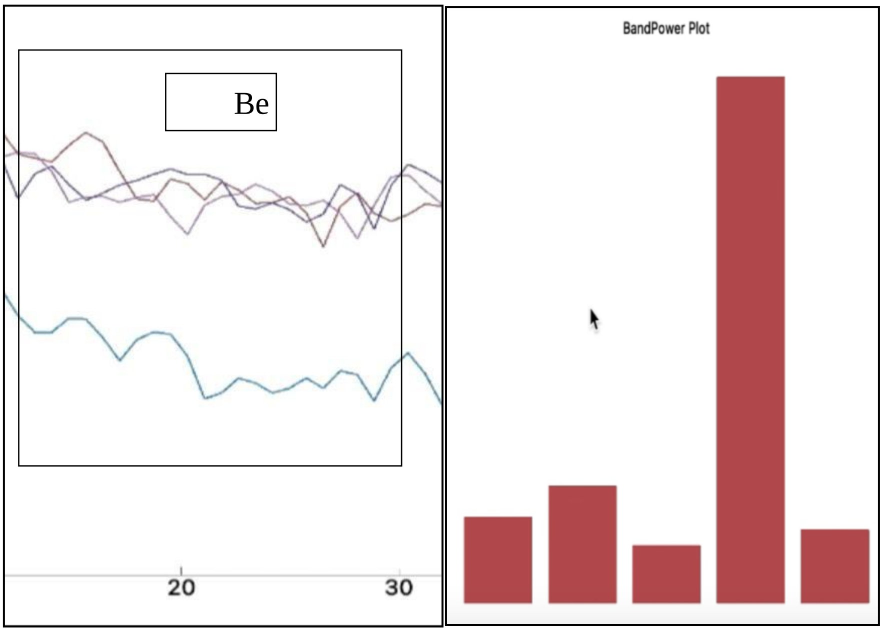

Figure 10. PSD and band power reading.

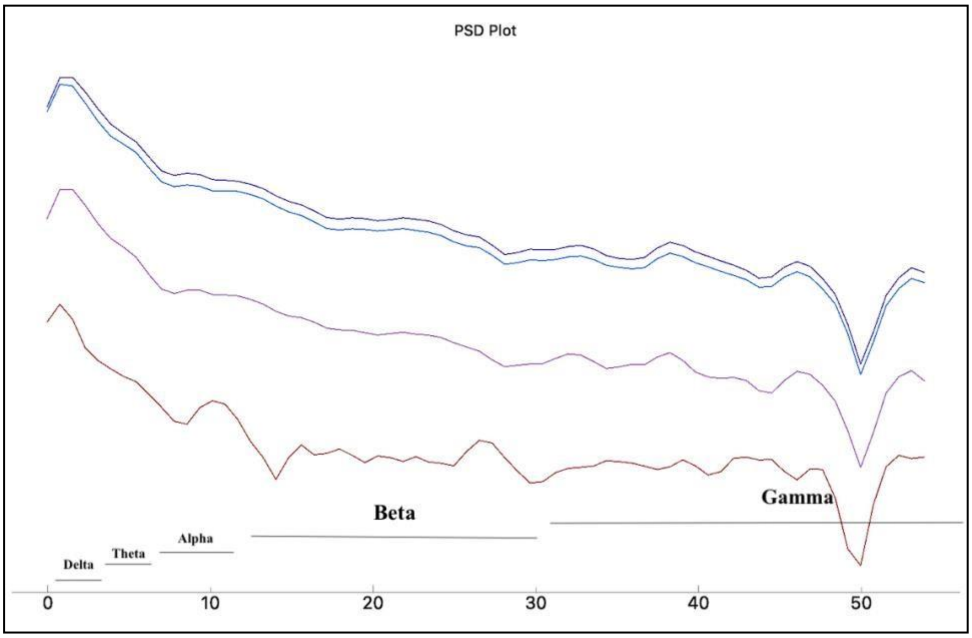

Figure 11. Grand average PSD distributions showing changes in EEG frequency power by experiment condition. Extracted frequency band ranges are shown by black lines below the PSD.

EEG systems are neither small nor portable. Standard EEG requires a lengthy preparation procedure, and current EEG systems are not well-suited for use outside the clinic or research laboratory. The problem was solved throughout this study by using an affordable amplifier and good quality microcontroller connector wirelessly. Finally, Raspberry Pi is 32-bit and has an ARM processor instead of x86, which means that libraries should be compiled for ARM. To install the libraries C++ code should be compiled on Raspberry and install python binding from the local folder instead of PYPI. This justifies the long process and time taken to connect the amplifier to the Raspberry Pi. The hardware needs to be stable, so it can be placed on a small and slick casing that can be attached to the patient's head for more comfort in wearing. 3D printed case can help to stabilize the system. Moreover, an ideal electrode organization is needed to avoid artifact noises that came from the patient's movements and can give more freedom to the patient to move.

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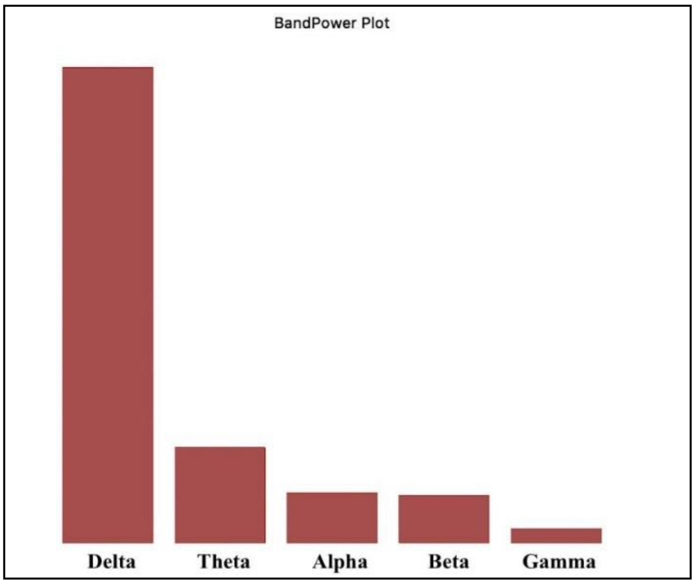

Figure 12. Powerband variation based on PSD.

4. CONCLUSION

In conclusion, EEG signals are generated by the neurons of the brain, which can tell us about the brain and human activity. A portable, wireless, and low-cost EEG system can be designed by using a commercial microcontroller and an affordable amplifier using a Bluetooth connection to get a fast and accurate data reading without data loss. The data can be displayed in a Raspberry Pi which is connected a to touch screen, so the user can see the displayed data in a small device without needing a bulky monitor that is attached to the patient. BrainFlow library was installed to allow the communication between the Raspberry Pi and OpenBCI ganglion, other libraries were used to display the real-time power band variation. A Wearable EEG device that utilizes wireless technology can be developed to the user's convenience throughout the monitoring process. The user can also move freely during the recording with the designed system. Thus, the objectives of this research were accomplished.

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CONFLICT OF INTEREST

The authors have no conflict of interest.

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