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A Digital Filter Design for Optimized Brainwave Reception from Central Nervous System (CNS)

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Abstract: This abstract review an original research article on the topic of digital filter design for enhanced brain wave signals reception from the central nervous system (CNS) of the brain. The paper emphases on the development of an accurate digital filter to recover the reception and processing of brain wave signals, that is being considered to play a vital role in the brain functioning and diagnosing of suitable neurological disorders. The research paper reconnoitres advanced digital signal processing techniques and several other methodologies for effectively apprehending and analysing brain wave signals, considering all their unique characteristics and challenges. In this paper various filter design techniques, including Finite Impulse Response (FIR) filters and Infinite Impulse Response (IIR) filters are examined and evaluated for their aptness in optimizing CNS signal reception. The paper presents a detailed analysis of the optimization strategies working, such as Power Spectral Density, Power Spectral Efficiency, Upper cut-off frequency, Lower Cut-off frequency, Bandwidth and Delta power parameter calculations, to enhance the performance and accuracy of the digital filter. The research paper aims at discussing the potential applications of the developed digital filter in neuroscientific research and medical diagnosis, including brain-computer interfaces (BCIs), mental state monitoring and clinical neurology. The findings of the research contribute to the existing body of knowledge by providing visions into digital filter design for brain wave reception, thus facilitating developments in the field of neuroscience and refining healthcare outcomes.

Keywords: *CNS- Central Nervous System, Finite Impulse Response (FIR) filters, Infinite Impulse Response (IIR) filters, BCI- Brain Computer Interface*

1. Introduction

Noise Filters [1] play a vital role in the brain-to-brain communication as they tend to remove the unwanted noise also termed as ripples in an impure EEG signal. The survey paper [2] had a detailed study of 25 research papers on the different filters that were used to remove the unwanted artifacts of noise from the EEG signal. The key research findings were that the FIR [3-4] filters were more preferred than the IIR filters. In the paper, after having a detailed study of all the IIR-FIR [1-2] filters, were undertaken to reach to a conclusion of selecting the best filters that would be used in this research proposal. Altogether more than twelve recent papers were studied, and a proper selection on IIR and FIR filters were achieved. A Higher Order Butterworth filter was selected for the research proposal as based on the literature review since the use of a Butterworth filter increases the overall classification efficiency of a signal. The selection of FIR filter done in the second report is Hamming Window. A proper design methodology of Graphical User Interface (GUI) is discussed in this research paper wherein the research aims to simulate the signals received from the dataset of the central nervous system. It consists of different tabs like load data, filter panel, Butterworth Filter Panel, play modes as start and stop.

The research here in this paper includes an overall time frame of eight months wherein a proper design of Digital Filter for optimized brain wave reception from Central Nervous System (CNS) has been simulated using a Graphical User Interface (GUI). In this research paper, a proper discussion on GUI creation, loading of data set in the Graphical User Interface, simulation of EEG signals received from the CNS, analysis of all the simulation outputs at different time frequencies as well as different time intervals would be undertaken. Thus, the overall paper would aim to provide simulation outputs using a mathematical tool and enable tabs for Hamming window filter thereby creating appropriate panel for the same. This will help to get validated results for different parameters of the filter with appropriate filter frequency response.

2. Literature Review

This literature review sightsees the medical field of digital filter design for optimized brain wave reception from the central nervous system (CNS). The paper focuses on the progressions in digital signal processing techniques and their applications in seizing and analysing brain wave signals. The paper highlights various methodologies employed during the design of digital filters to improve the reception of CNS signals and mainly discusses their potential applications in neuroscientific research and

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different types of medical diagnosis. The detailed study of brain waves and their analysis has grown significant attention in recent years due to their latent in understanding brain functioning and diagnosing all the neurological disorders in vegetative patients. Digital filters play a vital role in processing these brain wave signals by attenuating all the noise and artifacts, enhancing the possible signal quality, and extracting the features with the help of meaningful information. This literature review aims to consider the state-of-the-art digital filter design techniques for optimized brain wave reception from the CNS.

1. Signal Characteristics and Trials:

Brain wave signals shows specific characteristics that tend to require cautious consideration during the process of designing the filters. These signals are low in amplitude [4-6], often contaminated with excess noise, and consists of multiple frequency components. The literature view discusses the challenges associated with filtering brain wave signals and highlights the need for optimized digital filters to overcome all these challenges.

2. Filter Design Techniques:

Several digital filter design techniques have been proposed and employed for brain wave signal processing using central nervous system. The literature review investigates into commonly used methods, such as Finite Impulse Response (FIR) filters [6-8], and Infinite Impulse Response (IIR) filters solely. It states their advantages, limitations, and applications in the context of Central Nervous System signal reception.

3. Optimization Approaches:

In order to target the achievement of optimized reception of brain wave signals, different types of optimization strategies have been proposed and they include parameter tuning, coefficient optimization, Power Spectral Density, Power Spectral Efficiency quality of Upper cut-off frequency, Lower Cut-off frequency Bandwidth and Delta power approaches. The literature review presents a complete analysis of these optimization strategies and their influence on filter performance and impact on signal quality.

The review targeted the extensive range of methodologies applied for digital filter designing for optimized brain wave signal reception. The review discusses exact studies and research projects that have employed digital filters to enhance brain wave reception and extract relevant information. The Challenges and the futuristic picture states that despite important advancements, challenges remain in optimizing digital filters for brain wave reception. The literature review inspects these challenges, such as real time filter complexity, real-time processing requirements, and the individual differences in brain wave signal patterns. It also outlines potential future directions, including the integration of advanced machine learning approaches along with adaptive algorithms, and the development of specialized hardware for well-organized CNS signal reception. This review offers an overview of digital signal filter design [8-10] for optimized brain wave signal reception from the CNS. It highlights the implication of digital signal processing techniques in enhancing signal quality of the received signal and extracting evocative information from brain wave signals. The review emphasizes the need for further research and development to overcome existing challenges and capitalize on the possibility of optimized digital filters for neuroscientific research and clinical applications.

3. Importance of Central Nervous System (Cns) Signals

The central nervous system (CNS) is divided into two parts one is of the brain and the other part is the spinal cord. The three main basic functions of CNS are to be able to absorb the sensory information received from the central nervous system of the subject (patients), to process that received information, and then transmit the appropriate motor signals to the simulation tool. The signals received from the CNS are very important as the CNS receives sensory information from the central nervous system of the brain and controls the response of the body thus being responsible for the subject's behavioural response. The central nervous system is responsible to coordinate the activities important for the response of the body as these activities are related to day-to-day activities of the subject (person).

The CNS consist of three basic body parts: the spinal cord, nerve cells well termed as the neurons and most important the brain. The brain being responsible in undertaking control on many of the body's functions basically that includes awareness, thought process, movement in daily activities, cognizance, and reminiscence. The spinal cord is attached to brain via the stem of the brain and then moves in the downward direction through the spinal canal that is present inside the vertebra. The spinal cord is the part that transmits information from various parts of the body to the brain and from the brain. It is well known that neurons are considered as the basic building blocks of the central nervous system (CNS). Billions and trillions of these nerve cells can be found well distributed throughout the body of the human being and thus communicate with one another or each other so as to produce physical responses and actions. In the below Figure 1, a proper connection between the brain and spinal cord that make up the central nervous system is shown.

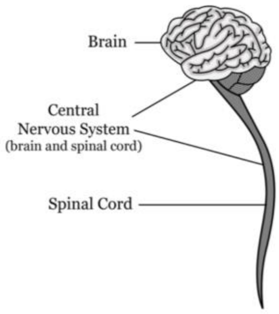

Fig 1. Central Nervous System (Courtesy: Internet)

4. Graphical User Interface (Gui) Creation

We have discussed during the progress of the research work that the dataset for the proposed design has been retrieved from an online data base that will act as an input to load data for analyzing the EEG signals. This input is further given to a mathematical modelling tool MATLAB and a Graphical User Interface is designed that would be responsible in handling the simulation of the EEG signals and thereby give effective outputs. The signals received from the online database of Central Nervous System needs to be loaded in the designed GUI. Below Figure 2 would explain the complete design of Graphical User Interface to simulate the CNS Signals.

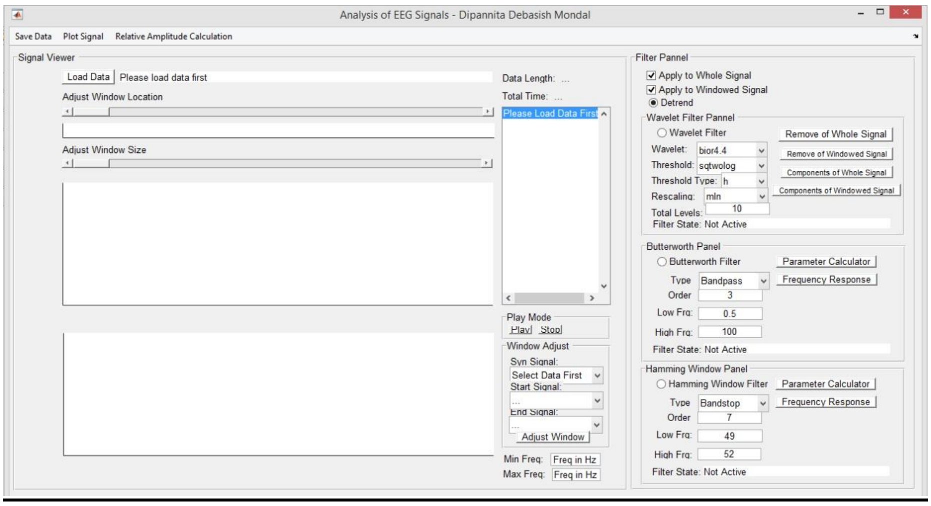

Fig 2: Creation of Graphical User Interface

As seen in the above figure, wavelet filter panel, Butterworth panel and Hamming window panels have been designed to calculate the different parameters and get the frequency response of these signals at valid interval of time. The next step is to load the CNS.mat file [data set] into this GUI as in MATLAB we require it in the .mat extension file. The online database of CNS dataset consists of data captured from Central nervous system of 19 channels altogether.

GUI Showing Channels After Data Load

Below Figure 3 shows GUI channels after loading of the data. As seen in Figure 2 the channel was completely empty but after loading the data set 19 channels got loaded into the GUI. So whichever channel we want to analyze we can analyze using Butterworth filter and hamming window filter and, we can analyze the synchronization level.

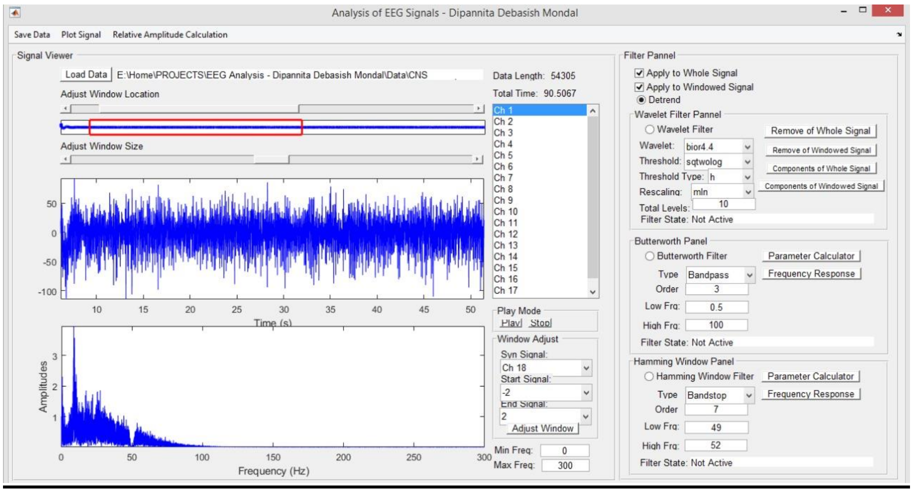

Fig 3: Loading of data set into the Graphical User Interface

5. Simulation Outputs

Based on the dataset and the simulation of the signals using the graphical user interface we have derived certain simulation outputs.

a) EEG ANALYSIS AT 1 to 2 Seconds

The raw EEG signal is the actual EEG Signal as shown in Figure 4. In the below figure we are just taking a sample of the EEG signal from 0 seconds to 10 seconds. It is an infinite time response and we can take n number of samples depending on which sampled signal we would like to analyse and here a magnification of the signal between 1 to 2 seconds is targeted. As seen in the below figure we can see the variation between alpha, beta and gamma waves. So, it represents waves that will lead to achieving of a Hybrid Filter Response as shown in Figure 5 that means when we click hybrid filter response in the GUI it generates a complete response of Hybrid Filter design for CNS signals. In below Figure 6, to convert time domain to frequency domain we have shown the output using the Hilbert Transform.

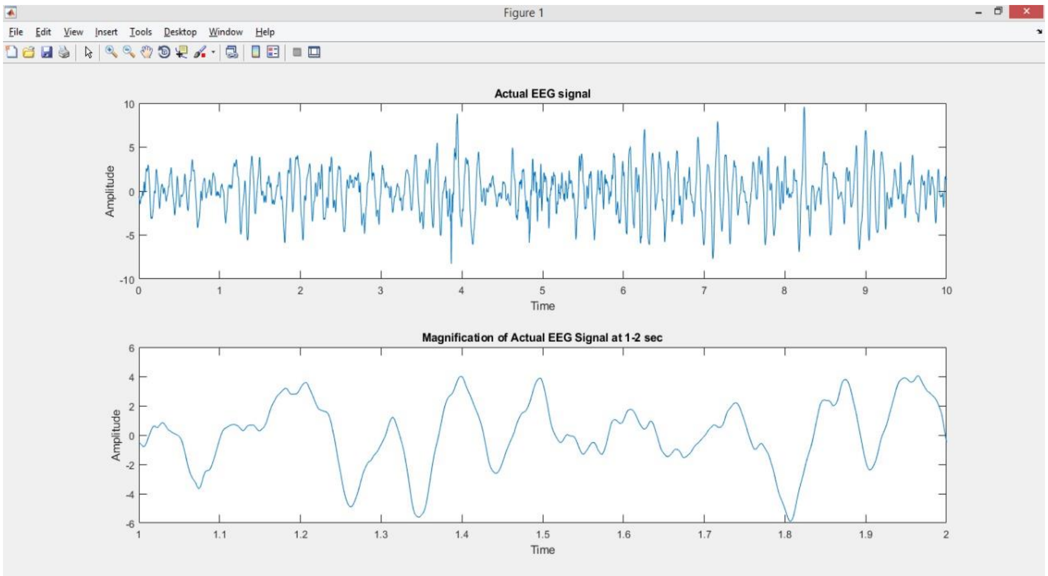

Fig 4: EEG signal magnification at 1 to 2 Seconds

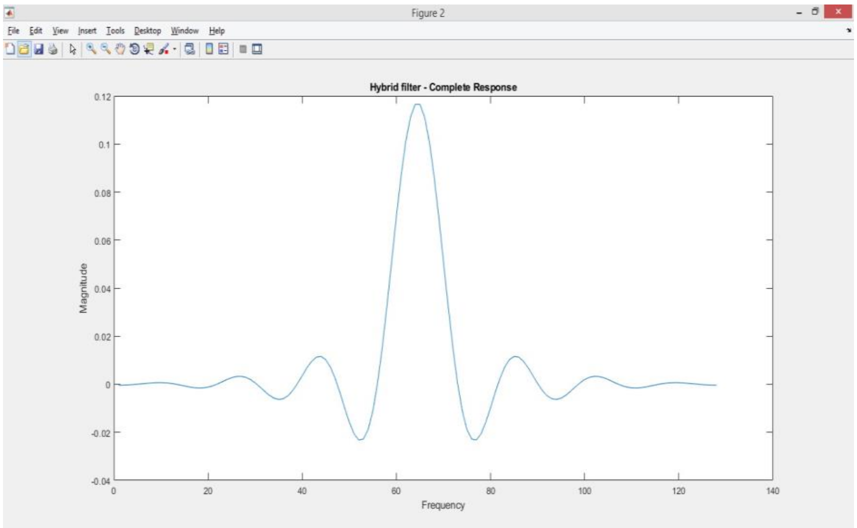

Fig 5: Hybrid Filter- Complete Response

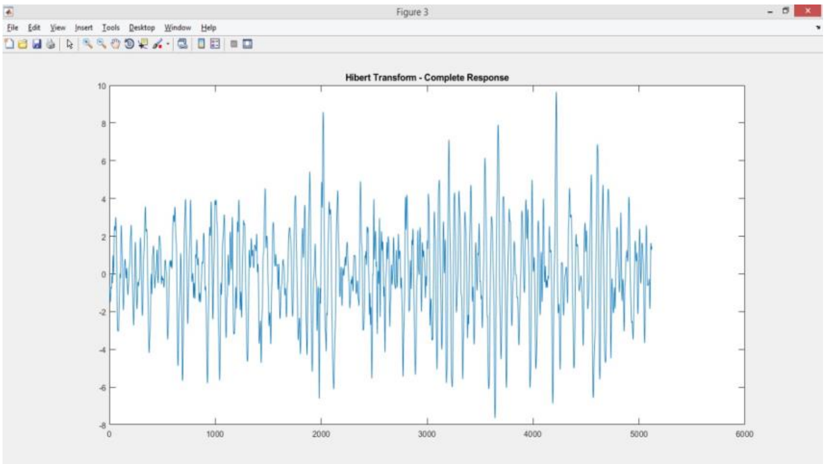

Fig 6: Hilbert Transform- Complete Response

As shown in the below Figure 7, the power spectral density (PSD) of the signal is calculated using two methods that is Welchs method and Periodogram method. The hybrid filter design for both has been generated with appropriate signals at 60 Hz for both Welchs method and Periodogram method and power spectral density has been estimated. Here we are taking four intervals.

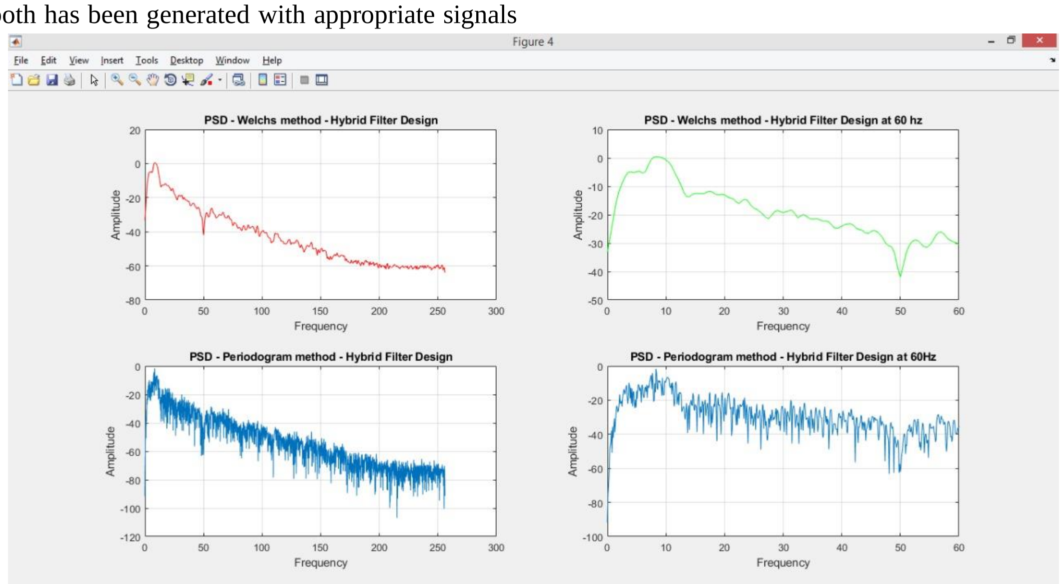

Fig 7: PSD using Welchs Method and Periodogram method at 60 Hz

Below are some of the EEG signal analysis done at different time intervals with PSD estimation using welchs and Periodogram methods.

(b) EEG ANALYSIS AT 2 to 3 Seconds

The below samples have been collected for duration 2 to 3 seconds.

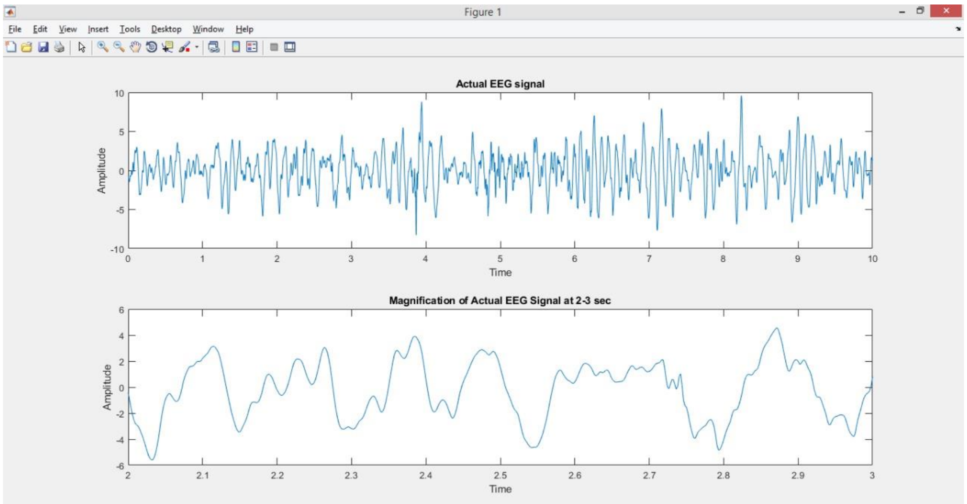

Fig 8: EEG signal magnification at 2 to 3 Seconds

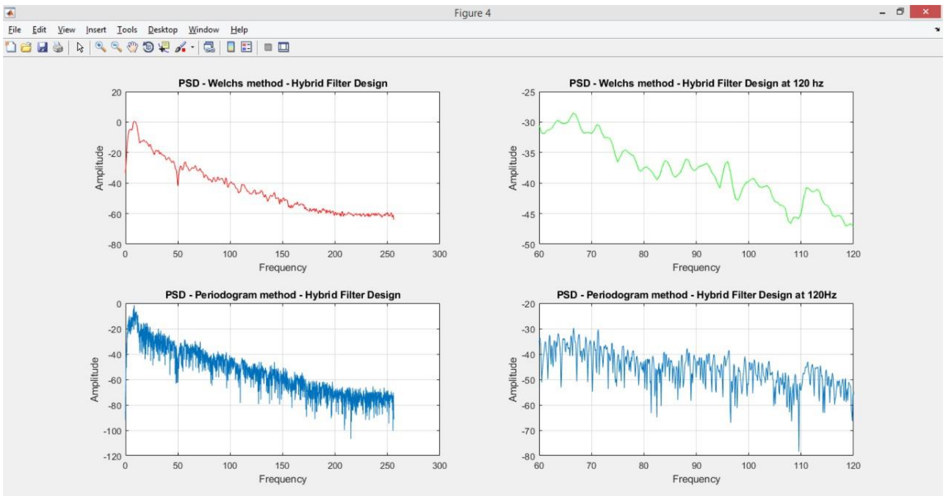

Fig 9: PSD using Welchs Method and Periodogram method at 120 Hz

(c) EEG ANALYSIS AT 3 to 4 Seconds

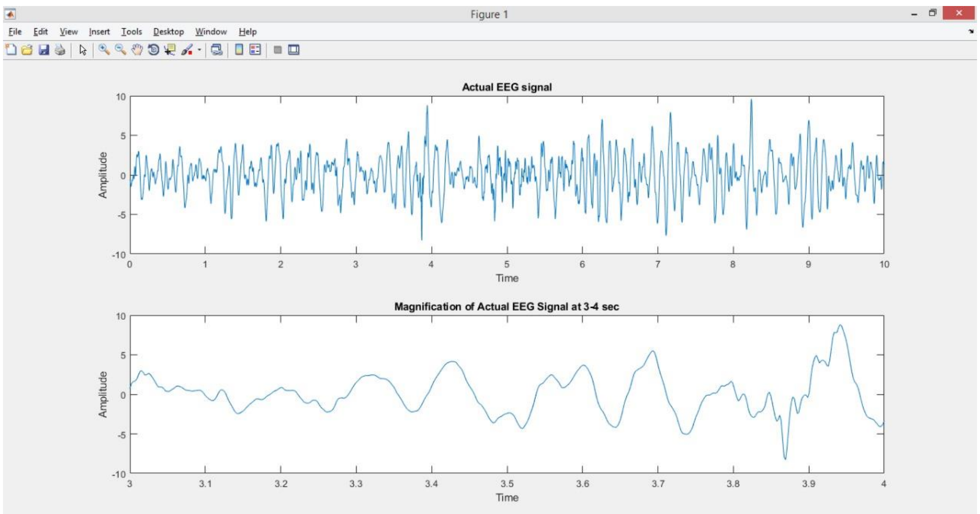

Fig 10: EEG signal magnification at 3 to 4 Seconds

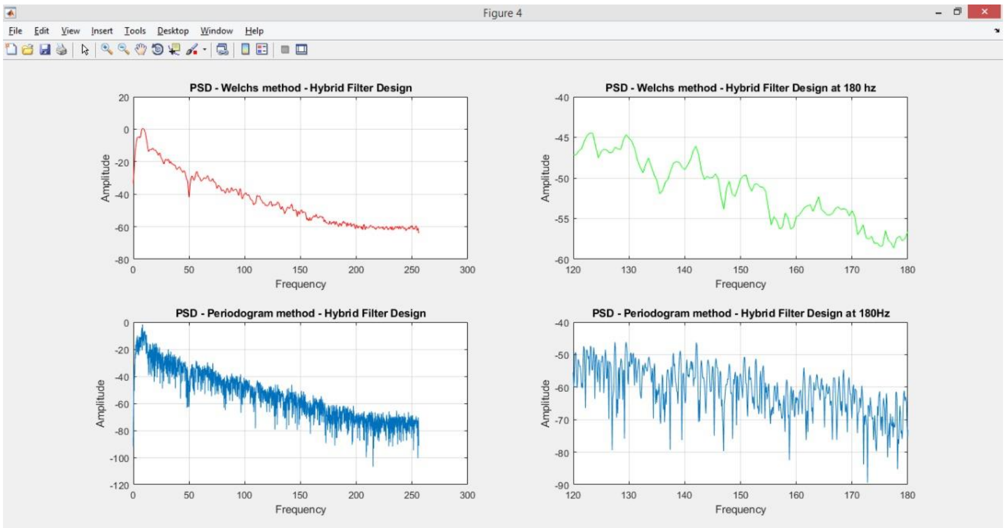

Fig 11: PSD using Welchs Method and Periodogram method at 180 Hz

(d) EEG ANALYSIS AT 7 to 8 Seconds

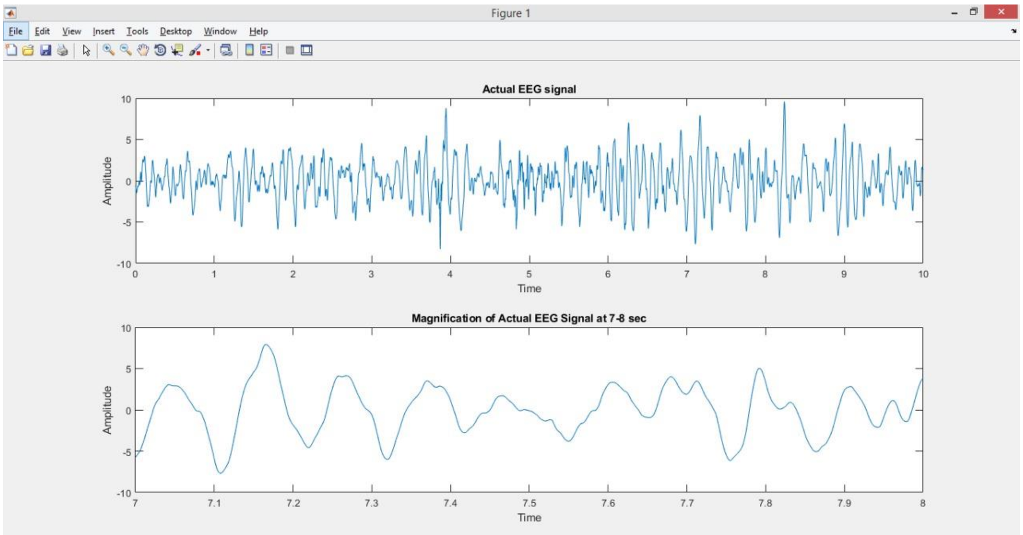

Fig 12: EEG signal magnification at 7 to 8 Seconds

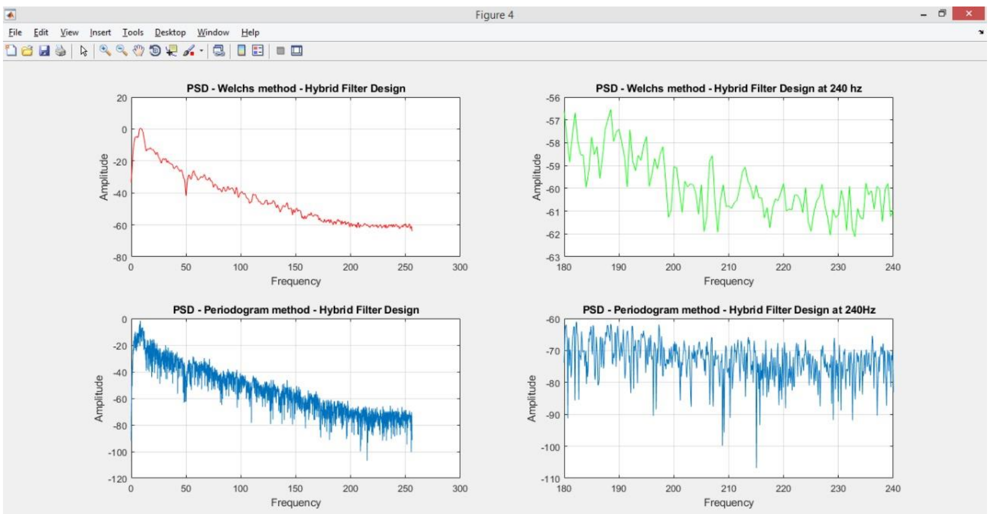

Fig 13: PSD using Welchs Method and Periodogram method at 240 Hz

6. Tabulation Results

Below is a table of calculations of different parameters that are calculated at different time intervals. The table consists of EEG analysis in various time and frequency components in terms of power spectral density, power spectral efficiency, upper cut-off frequency, lower cut-off frequency, bandwidth, and delta power. As seen in Table 1, the power spectral density decreases with increase in frequency similarly the power spectral efficiency decreases with the increase in the time and frequency component. The upper cut-off frequency increases with the increase in time and frequency component similarly the lower cut-off frequency increases with the increase in time and frequency component. The bandwidth at Time: 3-4s, Freq 120-180Hz is the lowest when compared to other frequencies and the bandwidth at Time: 2-3s, Freq- 60-120Hz is highest amongst all. The delta power is increasing from Time: 1-2s, Freq- 0-60Hz to Time: 7-8s, Freq- 180-240Hz. Thus below is a complete statistical analysis of the signals received from the central nervous system.

Sr. No	EEG Analysis in various TIME and frequency component	Power Spectral Density	Power Spectral Efficiency	Upper cut-off frequency	Lower Cut-off frequency	Bandwidth	Delta power
1.	Time: 1-2s, Freq- 0-60Hz	0.67	99.06	58	12	46	0.0064
2.	Time: 2-3s, Freq- 60-120Hz	0.59	87.22	119	68	51	0.0864
3.	Time: 3-4s, Freq- 120-180Hz	0.51	75.39	168	132	36	0.1664
4.	Time: 7-8s, Freq- 180-240Hz	0.47	69.48	234	192	42	0.2064

Table 1: EEG Analysis in various time and frequency component

7. Comparison Chart

The below Figures 14-17, will highlight the bar graphs for the above tabular calculations that include the EEG analysis in various time and frequency component. The Figure 14 is showing the bar graph for the power spectral density for various time and frequency component. The Figure 15 is showing the bar chart for the power spectral efficiency for different time in seconds and different frequencies in Hertz. Figure 16 is comparing the upper cut-off, lower cut-off and the bandwidth of the received signals and different time and different frequency components. Figure 17 is depicting the Delta Power for various Time and Frequency Component. Here the different time and frequency components considered for sampling are:

1. Time: 1-2s, Freq- 0-60Hz
2. Time: 2-3s, Freq- 60-120Hz
3. Time: 3-4s, Freq- 120-180Hz
4. Time: 7-8s, Freq- 180-240Hz

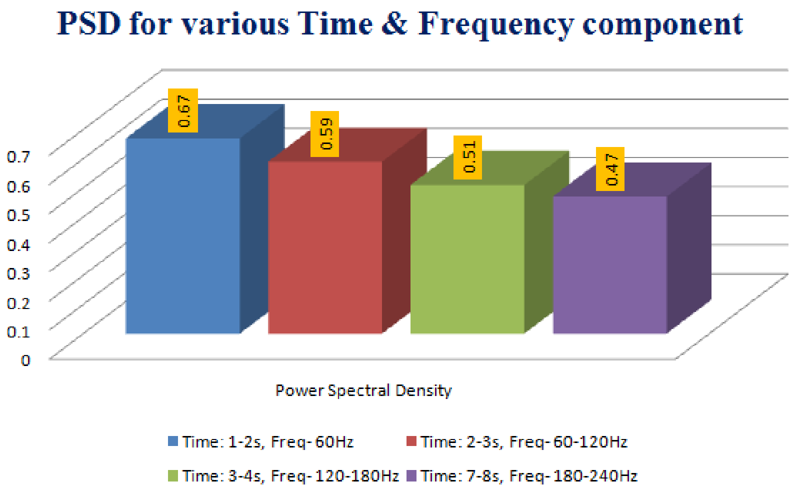

Fig 14: PSD for various Time and Frequency Component

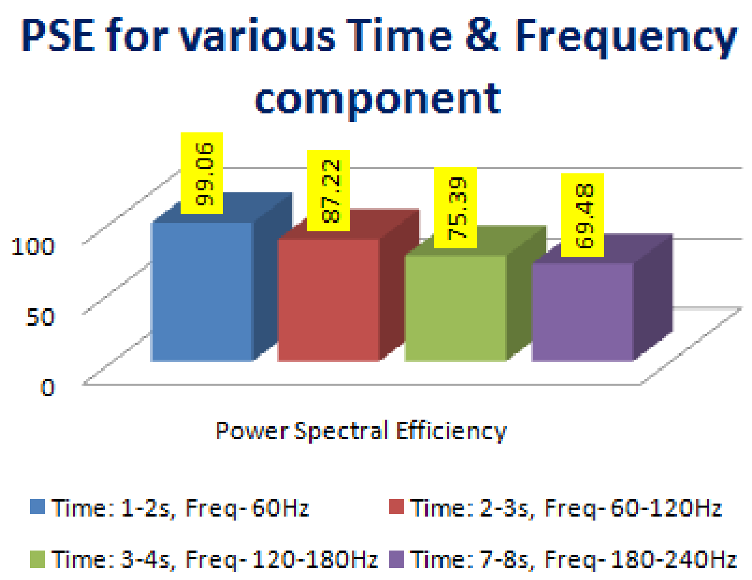

Fig 15: PSE for various Time and Frequency Component

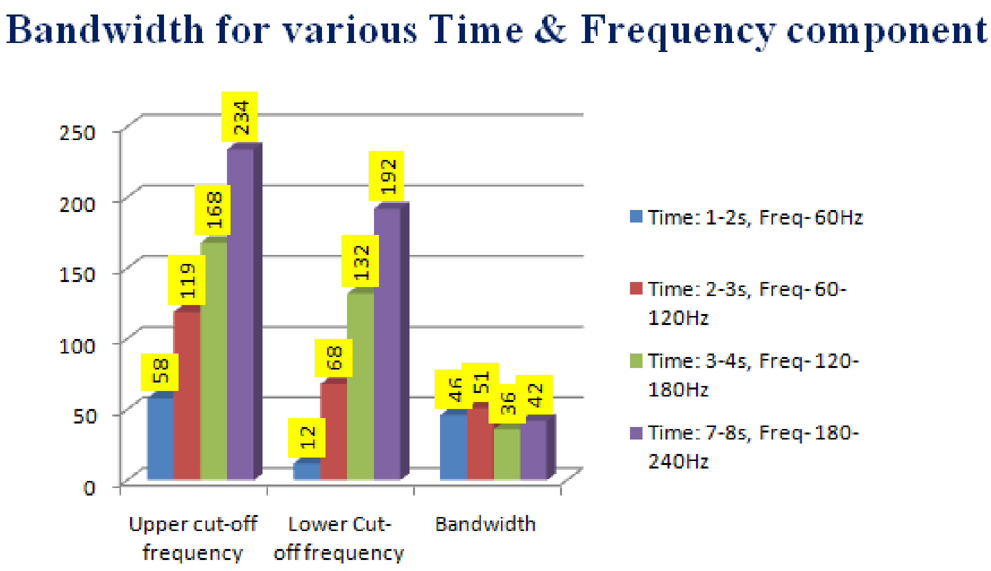

Fig 16: Bandwidth for various Time and Frequency Component

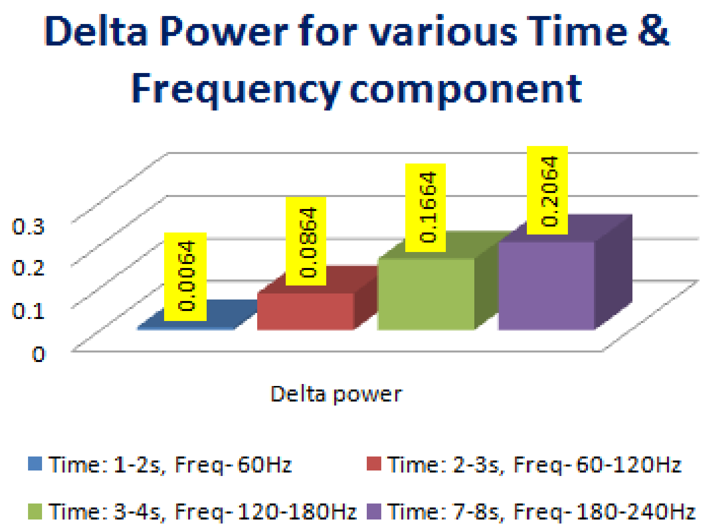

Fig 17: Delta Power for various Time and Frequency Component

8. Conclusion

The conclusion for this research article would indicate the status at which the design is currently being worked upon and the research findings based on the survey that is carried out by analyzing the signal that is received from the central nervous system indicating the key findings of this research paper. At the end it would describe in the future scope the next steps to comment on the direction the research is moving forward to. The design in this progress research paper analysed the signals received from Central Nervous System as collected through the online data base. Here the dataset of CNS is simulated and validated results for different parameters of the filter with appropriate filter frequency response is estimated. This paper has a detailed study of different calculations to estimate the parameters like Power Spectral Density, Power Spectral Efficiency, Upper cut-off frequency, Lower Cut-off frequency, Bandwidth and Delta power. The key findings are as the time interval increases the power spectral density decreases with increase in power spectral efficiency.

9. Future Scope

The next step is to simulate the dataset for PNS and get validated results for different parameters of the filter with appropriate filter frequency response. Also, to compare the CNS and PNS parameters to understand as to which signal will help to filter the noise in an effective way.

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