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A Detailed Study on IIR-FIR Filters and Design of a Graphical User Interface for Simulation of EEG Signals

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Abstract

Electroencephalography (EEG) plays a pivotal role in accepting brain activity and identifying neurological disorders. The precise analysis and explanation of EEG signals require the solicitation of digital signal processing techniques, such as Infinite Impulse Response (IIR) as well as Finite Impulse Response (FIR) filters. This paper investigates into a complete exploration of IIR-FIR filters and their application in EEG signal processing. The first part of this research paper involves a detailed examination of IIR and FIR filter types, their mathematical foundations, pros, and cons. Various filter design methods, such as Chebyshev, Butterworth and Elliptic filters, are discussed as well as compared through literature survey. Speculative aspects, including filter design, transfer functions, and frequency responses, are presented in a clear and much accessible manner. The second phase of the study introduces the design of a Graphical User Interface (GUI) on mathematical modelling tool aimed at enabling EEG signal simulation and analysis. This GUI is designed to enable users, including researchers and clinicians, to generate synthetic EEG signals with controllable parameters, apply IIR-FIR filters in real-time, and thereby visualize the filtered signals. The interface offers user-friendly controls for customizing filter characteristics, such as filter order, cutoff frequencies, and filter type. To validate the efficiency of the designed GUI and the selected IIR-FIR filters, general simulations are conducted using EEG datasets. The results showcase the GUI's efficacy in real-time EEG signal processing, demonstrating its prospective in research, clinical diagnostics, and educational settings and many areas. In summary, this paper presents a full investigation into IIR-FIR filters, proposing insights into their theory and practical application for EEG signal processing. The development of a intelligible GUI for EEG signal simulation and study further enhances the approachability of these mathematical modelling tools to a wider audience, eventually contributing to progressions in the field of neuroscience and brain signal analysis.

Keywords

Electroencephalography, Infinite Impulse Response, Finite Impulse Response, Computer Vision

1. INTRODUCTION

Filters play an important part as they tend to remove the noise in an impure EEG signal. Earlier, a detailed study of all the IIR-FIR filters were undertaken to reach to a conclusion of selecting the best filters that would be used in this research proposal. More than fifteen recent papers were studied, and decision related to the filter that can be used was compared and discussed.

The research here in this paper includes an overall time

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frame of six months wherein the IIR-FIR filters have been studied and since any signal cannot be noise free so an overall selection of the type of filters to be used in extracting the pure EEG signal is carried out in this paper. A trial to undergo complete study is done on filters such as IIR and FIR filters also known as digital filters and the filter that is required to design the hybrid digital filter is undertaken. Literature surveys were used to identify the type of IIR filter and FIR filter to be used in the research proposal. The first progress paper described the literature review of almost twenty-five papers studied based on the different filters used in various papers, pros/advantages of those filters, cos/disadvantages of using such filters along with different challenges faced by the researchers and the uses of these filters in real life scenarios. This paper would aim to discuss and suggest the type of IIR-FIR filter that needs to be used while working on the EEG noise filtering mechanism. The paper is planned such that before designing the hybrid digital filter effective care is taken by studying the filters to move ahead and thus select a proper IIR-FIR filter. The hybrid digital filter would be a combination of two or more filters and thus selection of a proper filter is essential to guide the research proposal towards its required directions.

Thus, the overall research paper would aim to select the IIR-FIR filter and provide the base for such selection with the help of certain advantages of those filters. The paper further discusses the design of a Graphical User Interface (GUI) to analyze the EEG signals and the anticipated outcomes of the complete six-month study. In the below Figure 1, a proper EEG noise filtering mechanism is explained using an appropriate block diagram.

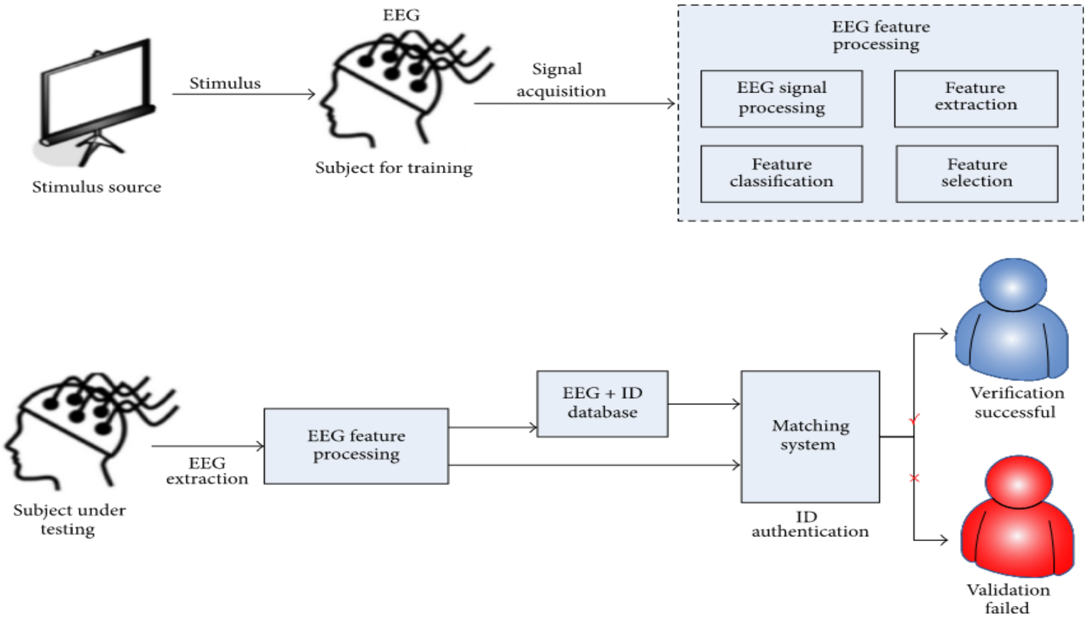

Figure 1. EEG Noise Filtering Mechanism (Courtesy: Internet)

2. Literature Review

This research paper is going to emphasize the real benefits that AI has brought to the field of medication delivery and design, as well as the method of "how AI helps in the drug discovery" through a detailed assessment of current research and success stories.

An overall review on filters is jotted below for the undergoing research work that is happening in the field of noise filters used for extracted EEG signals and their analysis related to brain wave communication. A proper table consisting of different methodologies used, the advantages, disadvantages, challenges, and future scope has been reviewed so as to proceed towards a better research agenda.

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Table 1: Description of test papers for literature review

Filter used	Pros/Advantages	Cons/Disadvantages	Challenges	Uses
[1] Survey on BCI filters and review on different filters	Restoration of communication between doctors and DOC patients	Analyzing the EEG signal using proper filtering mechanism	Designing a highly efficient filter that would help analyze EEG signal	The need to design a digital filter better than an analog filter
[2] Noise cancellation adaptive filters	Normalization helps in less computational complexity	EMG signal removal artifacts are an important issue.	Recording of cortical signals in EEG signals as they are weak	Improves EEG signal quality
[3] FIR and IIR Filter	Provides better harmonization of signals	It does not behave the same in all cases of intrinsic features	Analyzing the signals between healthy, epileptic and autism subjects	Used in signal extraction for BCI systems
[4] Digital band pass filter	It is suitable for the analysis of alpha wave signals with fast dynamics.	FIR requires large computational effort	Amplitude estimation is challengeable	Used in clinical practices
[5] Digital Filter both FIR and IIR filters	Significant improvement in delay and consumption of power	IIR filters are less effective in computations	FIR filters are more stable than IIR filters	Hybrid adder and booth multiplier
[6] FIR and IIR filters	Minimizes stopband energy, ripple, and interference	Transition bandwidth is more	Maintaining the algorithmic complexity	Can be used in future wireless communication
[7] Univariate filter, Wrappers and Common Spatial Pattern (CSP) filters	Improves performance and reduces the computational complexity	Signal loss due to signal transformation	To find the exact filter that could transform signal into 1D space	Used in applications of motor imagery devices
[8] High pass and low pass filter	Portable, low-cost simple use	Limited spatial resolution	Noise removal in acquired signal	Monitoring patients in ICU
[9] Efficient digital filter	Eliminates random noise in EEG data	Arithmetic calculations require speed and more power	Applying a filter design on real time EEG signal	To identify associated cognitive workload
[10] Digital filter	Increases stability and accuracy along with reliability	Classification in data set to extract the exact feature	Reduction in task irrelevant information	BCI systems and disability products
[11] IIR digital filter	IIR filter design performance is more promising	Filtering effect is poor	Wide transition band cost	Intelligent filter in EEG
[12] Butter worth filter, Chebyshev filter, FIR bandpass filter and Elliptic filter	Improving the classification accuracy	100% accuracy is not achieved	Difficult to get 100% classification accuracy under unsupervised condition.	Can be used in various BCI systems

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[13] Digital Filter	Reliability, Accuracy, stability, compact size, easy to get interconnected	Removing unwanted signals is difficult	Accuracy needs to be checked on WT and ICA methods	Intelligent home appliances
[14] Spatial filter	Increases EEG signal quality	Limited research in BCI problems	Featured data sets showed poor performance	Used in BCI systems
[15] Non-uniform digital FIR filter	The design is computationally efficient thereby compensating the loss in hearing	Computational cost increases due to FIR filters since number of multipliers get added	Full band spectrum is compromised in this case	In hearing aid applications

3. Selection Of IIR-FIR Filter

A detailed study of the IIR and FIR filters were undertaken from the above literature survey and selection of the below filters for the analysis of the EEG waves were decided based on certain advantages and importance.

A. IIR Filter

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. A further advantage of this Butterworth filter is that Butterworth filters always tend to have a more linear phase response in the pass-band cycle than the types such as the Chebyshev or elliptic filters. Thus, the Butterworth filter can render better group delay performance, along with a lower level of overshoot.

The frequency response of the Butterworth filter has absolutely no ripples in the passband as well as the stopband. Therefore, it is generally called as a maximally flat filter. Butterworth filters are considered to provide smooth, monotonically decreasing frequency response in the transition region.

B. FIR Filter

There are certain disadvantages of IIR filters that are overcome by the FIR filters. IIR filters are always difficult to control, and these filters have no phase, on the other side FIR filters make a linear phase always possible. IIR is not as stable as FIR. IIR, can have limited cycles, but FIR has no limited cycles. IIR is derived from an analog history, whereas FIR has no analog history. IIR filters undertake polyphase implementation possible, but FIR can always be made casual.

The selection of FIR filter here is Hamming Window. The advantages of using this type of filters are that a taper is formed by using a raised cosine that consists of non-zero endpoints, needed to optimize so as to minimize the nearest side lobe.

C. EEG CAP AND ITS ADVANTAGES

The vital role of an EEG cap is to collect the brainwaves called as EEG signals using an EEG cap. The collection of EEG signals from brain needs an EEG test. Thus, this EEG test uses this special cap fitted with electrodes to detect all the electrical activity related to the brain. In the field of medicine, the EEG test is considered as one of the best diagnostic tools for diagnosing epilepsy and any type of other seizure disorders. Doctors are seen using an EEG alongside the imaging scans, such as MRI scans or CT scans. Below Figure 2 indicates a plot diagram for an EEG cap used for recording EEG signals.

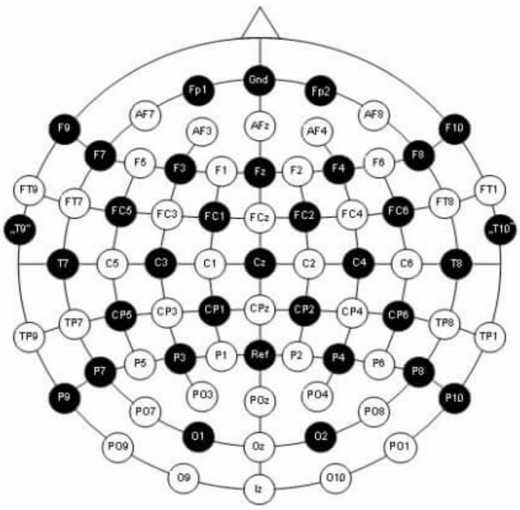

Figure 2. EEG CAP (Courtesy: Internet)

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In the above figure, the C1, C2 etc. are the different channels that record the brain signals from Central Nervous System (CNS). Depending upon the cap, we can have different number of channels to record different EEG signals from Central Nervous System (CNS), Peripheral Nervous System (PNS) and Respiratory Signals (RS). In hospitals, this type of EEG cap is used to record the EEG signals of a diseased subject. In the earlier research papers, mostly the brain signals were captured using invasive techniques by operating the brain with electrical rods that used to result into many types of brain infections resulting damage to the scalp tissues. The EEG cap is another way of capturing the brain signals but in this case only non-invasive way is used. Its just a cap that a subject needs to wear to get his brain signals recorded.

On studying the above research papers, the possible research questions were mostly focusing on the advantages and disadvantages of using different digital filters in the EEG filtration process. The questions mainly focus on the accuracy and performance that were of prime concern but the computational complexity while designing an effective filter played a vital role in selecting the filter that can prevent the unwanted noise. So, in short, the major research problem is finding an operative graphical user interface that can make these filters simulated so that they are able to provide 100% accuracy in terms of filtration performance.

Designing a proper Graphical User Interface (GUI) that can effectively extract the noise from the EEG signal is the need of the present research situation. In this research, the main contribution is to aim to create a digital noise filter which will help acquire the brain waves in a better way with reduced noise as compared to Analog Filter. This will help in the overall restoration of communication between the DOC patients and doctors thereby helping them for a better recovery and a better life. This research will be providing an input filter to the BCI System for future studies and serve as a platform to help the coma patients get back to their normal lives using their communication mode.

4. Design Methodology- Graphical User Interface(GUI)

After the selection of IIR and FIR filters, designing a proper Graphical User Interface to simulate the EEG signals plays an important role. GUI is vital if the proposed proposal needs to simulate the EEG signals on a proper mathematical tool. In this case the graphical user interface is designed in MATLAB tool. Since the proposal works for EEG signals received from Central Nervous System (CNS), Peripheral Nervous System (PNS) and Respiratory Signals (RS), here the data set comprises only of recordings taken from CNS. So, if the dataset can be loaded in GUI for the CNS, then same method can be used for PNS and RS.

Below Figure 3 shows the visual designed for GUI. It consists of different tabs like load data, filter panel, Butterworth Filter Panel, play modes as start and stop.

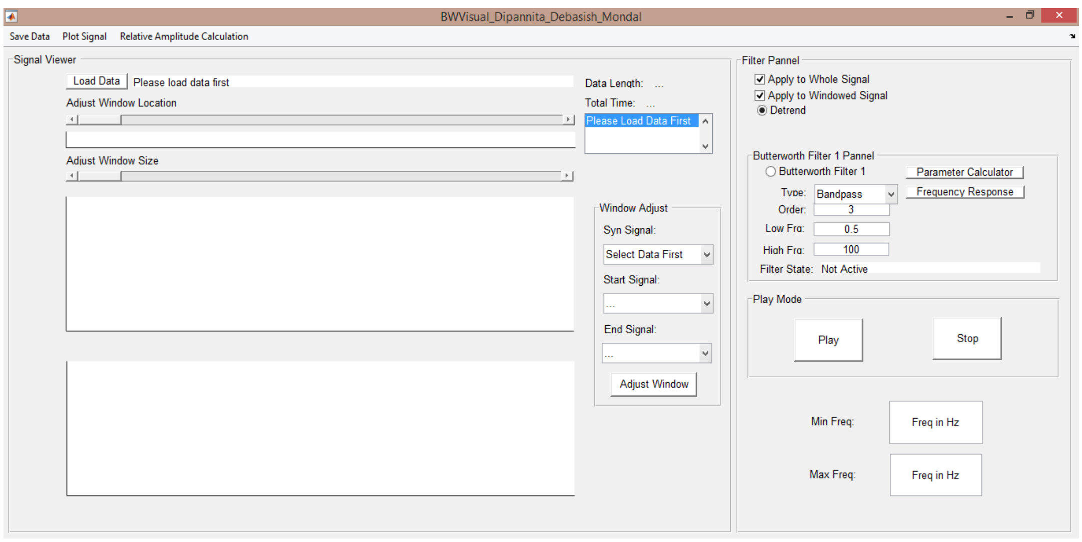

Figure 3. Visual of Graphical User Interface

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Below Figure 4 shows the different ranges of gamma, beta, alpha, theta and delta that is received from brains.

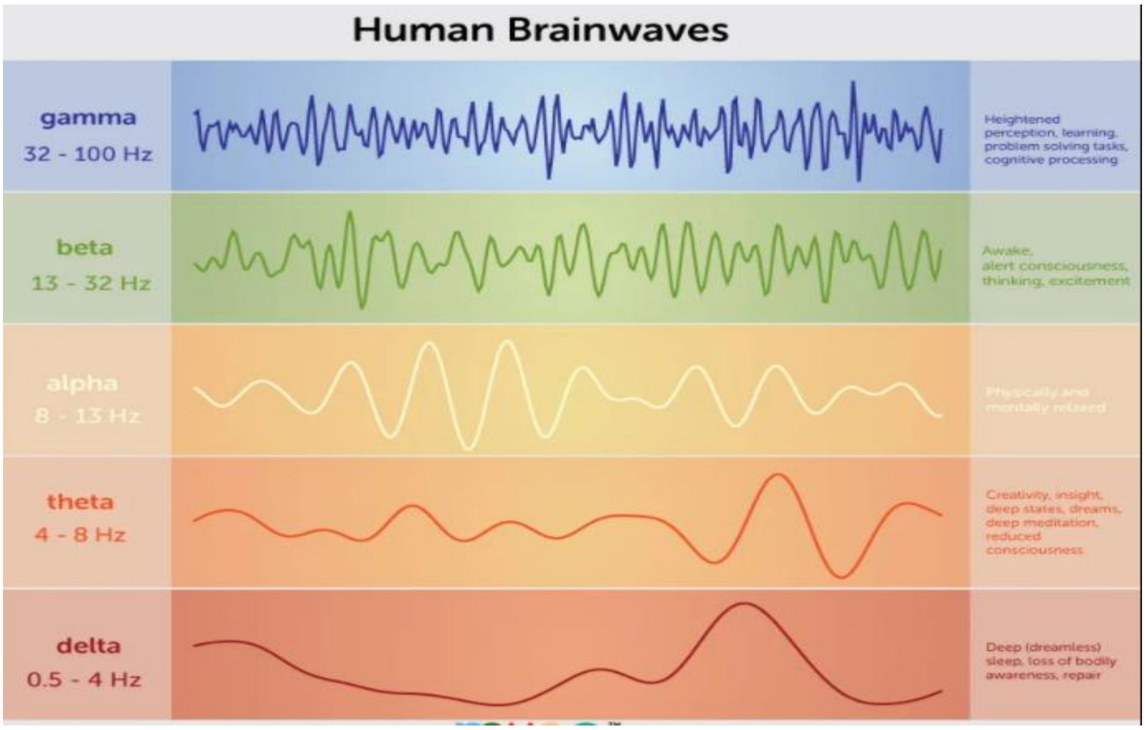

Figure 4. Human Brainwaves (Courtesy: Internet)

5. GUI Outputs

Below Figure 5 shows the channel drop down designed in Graphical User Interface to capture signals for different channels.

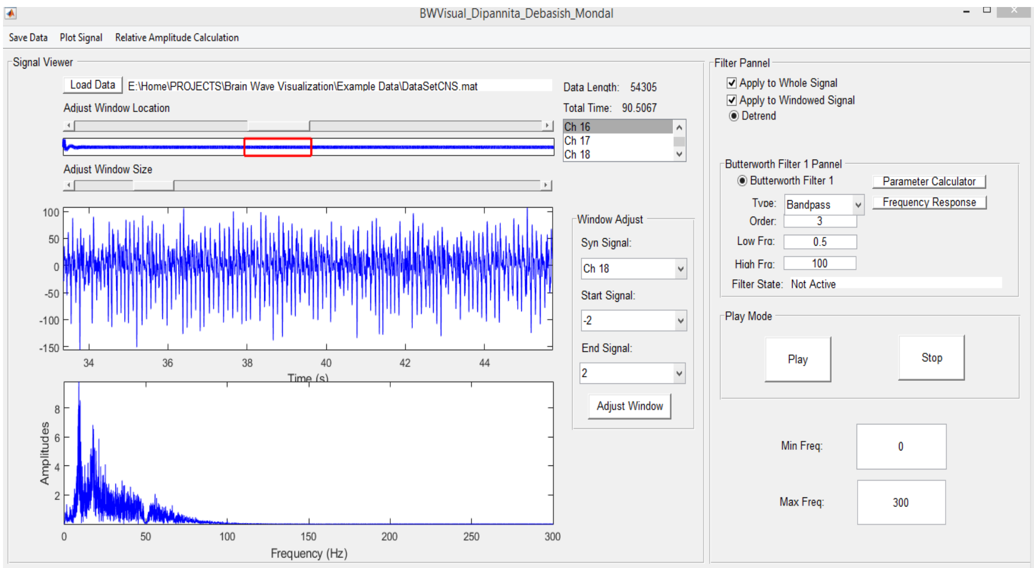

Figure 5. GUI Channel Drop Down

Below Figure 6 shows the filter drop down designed in Graphical User Interface to remove the noise received from different channels. The type of filter tabs inserted into the GUI are bandpass, lowpass, high pass and band stop.

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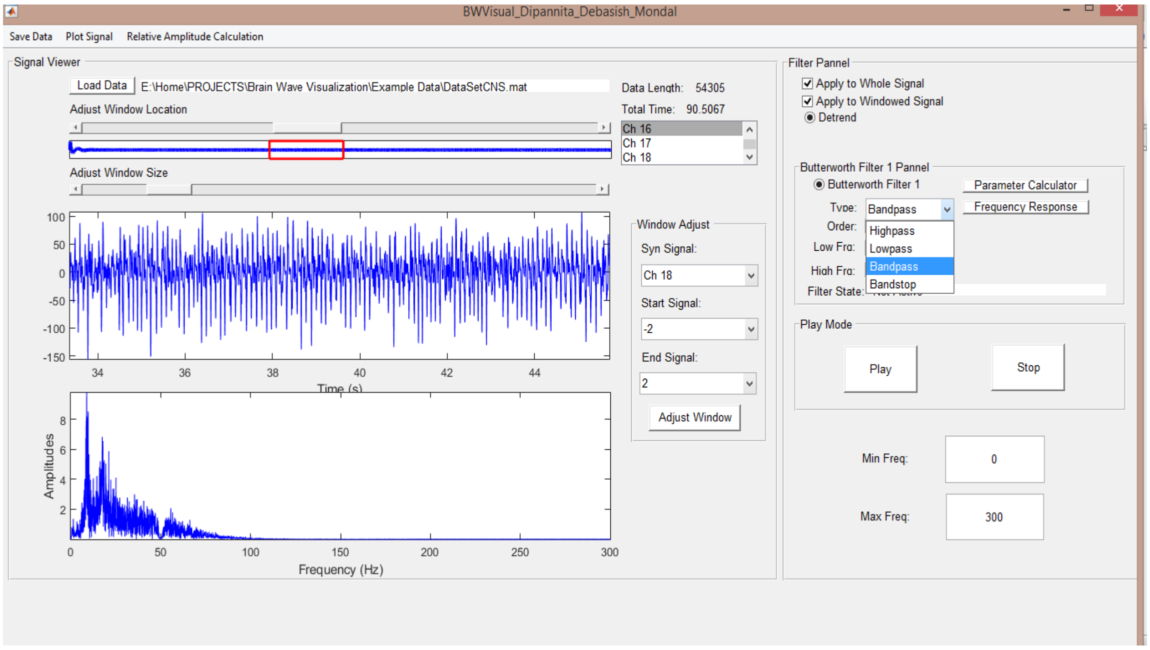

Figure 6. GUI Filter Drop Down

Below Figure 7 shows the filter parameters designed in Graphical User Interface to calculate the different parameters so as to comment on the efficiency and the accuracy.

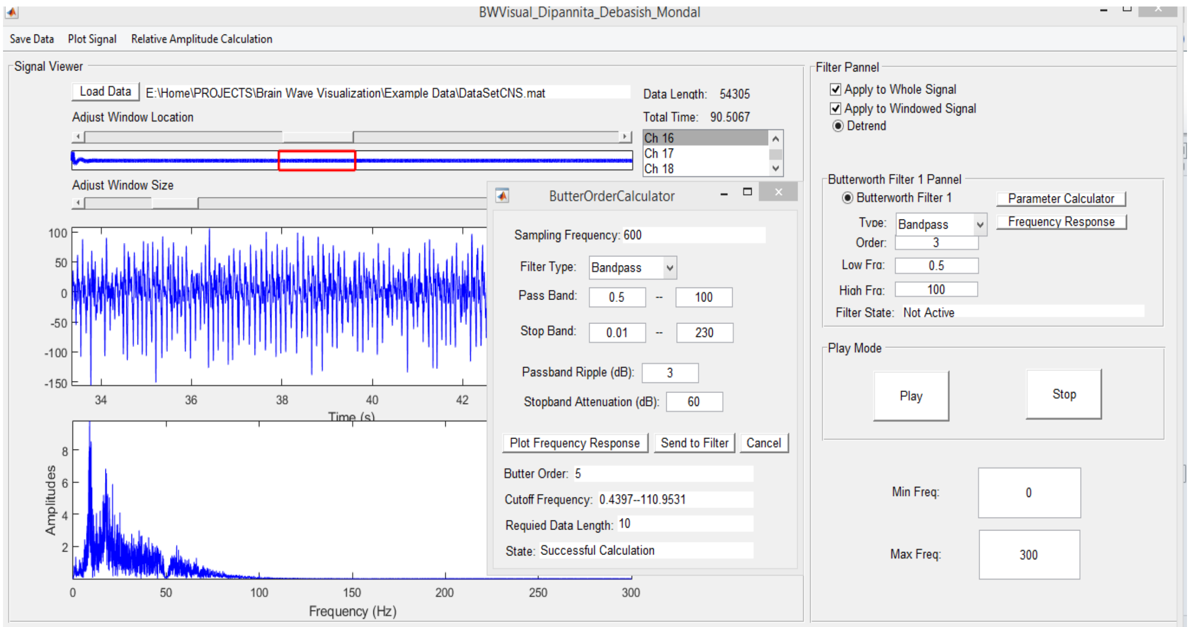

Figure 7. GUI Filter Parameters

Below Figure 8 shows the frequency response designed in Graphical User Interface to calculate the frequency response of the signal.

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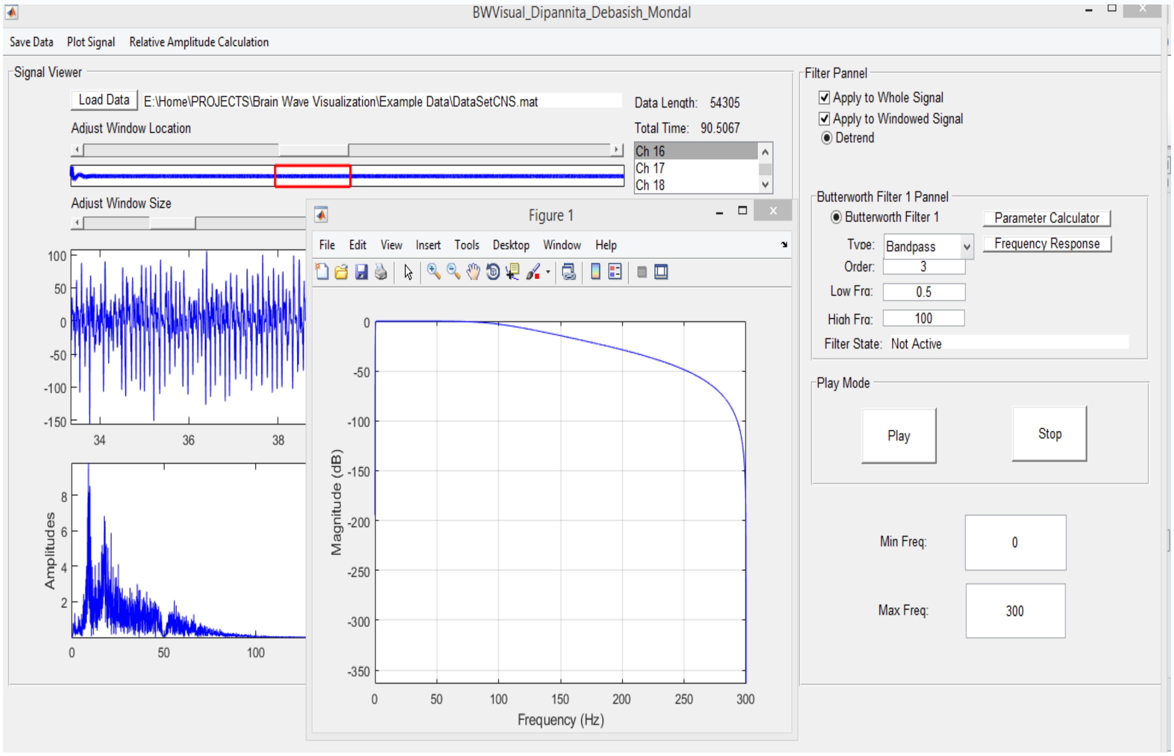

Figure 8. GUI frequency response

6. Design Status/ Research And Key Findings/Next Steps

The below sub points would indicate the status at which the design is being worked upon and also the research findings based on the survey that is carried out by studying different research papers thereby indicating the key findings of this paper. The last point would describe the next steps to comment on the direction the research is moving forward to.

A. Design Status

The dataset for the proposed design has been recovered 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 mathematical complexity needs to be worked upon so that the delay and area required to derive the noise free EEG signal is less. Butterworth filter as IIR filter and hamming window filter as FIR filter are selected in this paper that are used in the preprocessing process of EEG signals. The outcome of the design is proposed to be the choice of best filter for EEG noise removal. However, study shows that some more research related studies should be undertaken to get to the choice of the digital filter.

B. Research and Key Findings

This paper has a detailed study of 15 research papers on the different filters that are used to remove the unwanted artifacts of noise from the EEG signal. Based on the study, IIR and FIR filters were selected as Butterworth filter and Hamming window filter respectively. In most of the research papers, the key research findings are that the FIR filters are more preferred than the IIR filters. This is mainly because of the computational complexity as IIR filters need more multiplier that adds to the overall hardware complexity of the system.

C. Next Steps

The next steps are to enable tabs for Hamming window filter and create appropriate panel for the same. Also, to start simulating the dataset of CNS and get validated results for different parameters of the filter with appropriate filter frequency response.

Conclusion

In conclusion, our study has provided a broad overview of different types of Infinite Impulse Response (IIR) and Finite Impulse Response (FIR) filters, focusing on their speculative foundations, design methodologies, and practical applications through literature survey of EEG signal processing. Through this study, we have gained a deeper understanding of the fortes and flaws of various filter types, including Butterworth, Chebyshev, and Elliptic filters, empowering us to take better decisions when selecting filters for our EEG analysis.

Furthermore, the design of a Graphical User Interface (GUI) for the simulation of EEG signals and real-time application of IIR-FIR filters represents a substantial contribution to the research field in undergoing the gap analysis. Its capabilities to generate synthetic EEG signals using online database of datasets with adjustable parameters, apply filters in actual, and picturize filtered outputs enable not only research activities but also clinical diagnostics and educational purposes. As we look to the future, the understandings gained from this study can suggestively impact the improvement of neuroscience research and clinical practices. The obtainability of a readily accessible GUI for EEG signal analysis opens doors for wider association and innovation in the research field.

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We are deeply grateful to all of those who helped in our journey to make this paper a reality, and we hope that our findings will make a meaningful contribution to the field.

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