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Review of Digital Filter Techniques for Biomedical Applications

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ABSTRACT: Over the course of the last several years, a significant amount of work has been put in by scientists to create automated systems for detecting seizures in patients. Our aim is to present a review on Digital Filter Design for use in the processing and analysing of biomedical signals. The digital filter is used to filter discrete time signals. Here we have reviewed different Signal Types used for filtering the digital Signal using different filter techniques. At low coverage, the IIR filters remove noise better than any other filters. IIR filters are commonly designed by calculating the poles and zeros for a particular filter, and accepting those which lie within the unit circle of the z-plane. Using IIR Filter we reviewed that it is used to filter the ECG Signal. The Finite Impulse Response (FIR) filter offers numerous benefits on signal processing, such as having a simple construction, stationary response, and adaptability with embedded microprocessors. One of these advantages is found that it has a shorter latency than other filters. In order to facilitate structural characteristics and design qualities, the FIR filter has been recommended as a candidate for filtering EEG/ECG signal. Photoplethysmography (PPG) is a non-invasive technique that measures relative blood volume changes in the blood vessels close to the skin. A comparative review has been carried out on different biomedical signals like EEG, ECG, and PPG etc.

KEYWORDS –ECG, EEG, PPG, IIR Filter, FIR Filter etc.

I. INTRODUCTION

The use of DSP technology to design filters offers a number of benefits in comparison to more conventional analogue approaches. Most importantly, they have a natural flexibility about them due to the fact that changing the characteristics of the filter requires nothing more than changing the programme code or the filter coefficients. In contrast, changing the characteristics of an analogue filter requires physical reconstruction.

Applications of digital filters may be found in fields such as biological signal analysis, image analysis, and image coding and decoding methods. The process of filtering typically begins with the analogue waveform being digitised by an analogue to digital converter (ADC), and then the binary values are sent to a digital signal processor (DSP) device. The DSP device then executes a real-time convolution operation in discrete space using either a finite impulse response (FIR) or an infinite impulse response (IIR) algorithm. After the data have been processed, they are transmitted to a digital-to-analog converter, or DAC, which produces a filtered analogue signal. In order to fulfil the requirements of the Sampling Theorem with regard to the waveform that is being sampled and to get rid of quantization noise in the signal that is being processed, an anti-aliasing filter is placed before the (analogue to digital converter) ADC. Likewise, a reconstruction filter is positioned after the digital to analogue converter (DAC).

II. DIGITAL FILTER APPROACH IN SIGNAL PROCESSING:

1.1. Signal Processing in EEG Signals:

In addition to their use in communication systems and image processing, digital filters also find a place in the field of biomedical signal processing. A digital filter is an important digital system in digital signal processing, and it is used for certain desired purposes, such as to eliminate various types of noise and to amplify or attenuate a range of signal frequency components. These are just some examples of the kinds of purposes that can be served by a digital filter. The finite impulse response (FIR) digital filter and the infinite impulse response (IIR) digital filter are the two varieties of digital filter. Due to the absence of feedback and the linear phase response, the FIR digital filter maintains its stability at all times. The FIR filter is frequently used in Digital Signal Processing due to the fact that it has a number of desirable characteristics, including stability, linear phase, only zeros, and design freedom (DSP). There has been a significant amount of effort put into the construction of a FIR filter that makes use of constant coefficients. However, this kind of filter can only gain fixed frequency-domain features at one time.

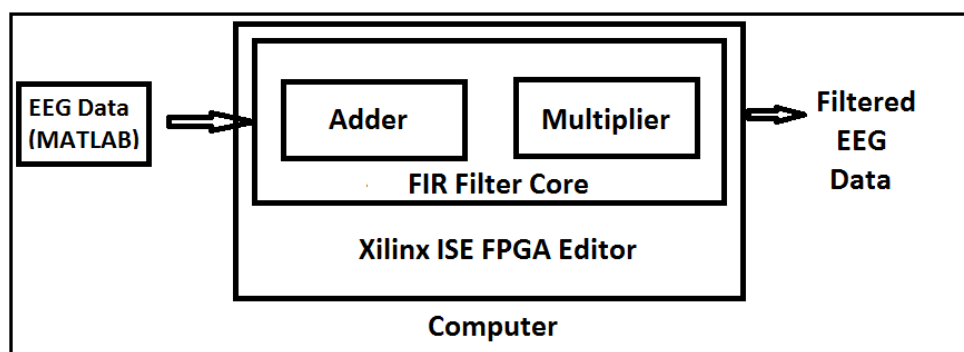


Fig 1: A scheme of FPGA-based FIR Filter Core Design

Source: *FPGA-Based Digital Filter Design for Biomedical Signal.” Perspective Technologies and Methods in MEMS Design, MEMSTECH 2016 - Proceedings of 12th International Conference (October 2018)*

In 1929, Hans Berger was the first person to perform an electroencephalogram (EEG) measurement on a human. Recordings of the electrical potentials generated by the brain are called electroencephalograms, or EEGs for short. In the field of brain research, the electroencephalogram (EEG) is now the most widely used and productive of all physiological signals.

The electroencephalogram (EEG), a signal that is very complicated, is one of the most popular sources of information that is used to research brain function and neurological illnesses. The EEG monitoring devices create a vast quantity of data, and it is not normally feasible to provide a thorough visual examination of this data. The electroencephalogram (EEG) is made up of electrical rhythms and transient discharges that may be differentiated according to their location, frequency, amplitude, shape, periodicity, and functional features.

1.2. Signal Processing in ECG Signals:

The first step in the processing of the ECG signal using a digital filter is the sampling of the signal from the electrodes that are placed on the surface of the body. The next step is for the digital ECG to eliminate or suppress low-frequency noise caused by baseline wander, movement, and respiration, as well as higher-frequency noise caused by muscle artefact and power-line or radiated electromagnetic interference. Low-frequency noise can be caused by any of these factors. Because of this, the electrocardiograph has to filter and then amplify the ECG signal that is received at the surface of the body”. There is a broad range of AI-based biomedical applications, such as intelligent ECG monitoring, EMG monitoring, blood pressure monitoring, and hearing aids, in which AI-based classification algorithms are utilised for automated diagnosis and categorization. Some examples of these applications include: AI-Based algorithms, as opposed to traditional signal processing algorithms, help physicians improve the intelligence and accuracy of the diagnosis or classification. This is because AI-Based algorithms can automatically extract and analyse the signal features while being less affected by subjective factors. In the past, numerous AI-based classification algorithms, such as the support vector machine (SVM), the back propagation neural network (BPNN), the convolutional neural networks (CNN), the probabilistic neural networks (PNN), the recurrent neural networks (RNN), the Long Short-term Memory Network (LSTM), the fuzzy neural network, and many others, have been proposed. Various applications are best suited for particular algorithmic configurations. For the processing of ECG signals, for instance, SVM and CNN are rather common, while fuzzy classifiers are quite common in their application for blood pressure monitoring. For the purpose of hardware design, specialised biomedical processors have been suggested as a means of accelerating AI-based biomedical processing algorithms while simultaneously achieving minimal levels of power consumption. Microcontrollers, field-programmable gate arrays (FPGAs), and application-specific integrated circuits (ASICs) are only some of the hardware platforms that have been used throughout the development of biomedical processors. Microcontrollers may be used to construct relatively simple machine learning algorithms like SVM and KNN, which results in reduced design time and costs. In comparison to the microcontroller, the field-programmable gate array (FPGA) offers superior performance and is well suited for the acceleration of algorithms with greater complexity, such as the computing of neural networks. The usage of ASIC has allowed for considerably greater calculation speeds and very reduced power consumptions, both of which are impossible to accomplish with FPGA. ECG signal classification, epileptic seizure detection, and EMG signal classification are the primary areas of concentration for the majority of AI-based biomedical processors. A stress detection processor for health monitoring and an AI-based acoustic processor for hearing aids are two examples of other uses of artificial intelligence.

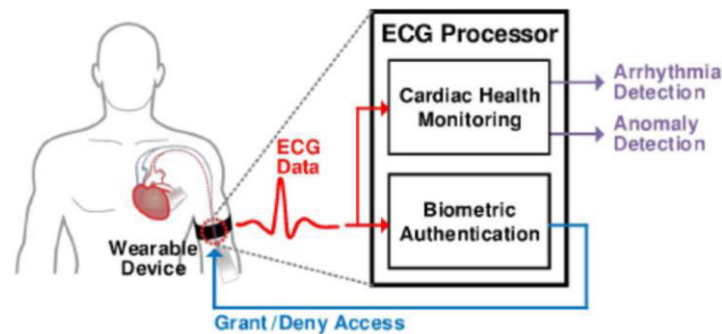


Fig 2: Integrated ECG processor for both cardiac monitoring and biometric authentication

Source : *Survey of Filter Bank Algorithms for Biomedical Applications.* " 2014 International Conference on Computer Communication and Informatics: Ushering in Technologies of Tomorrow, Today, ICCCI 2014 (January 2014).

Although the applications are different, the system architectures of these processors are very similar. The pre-processing module is responsible for filtering/denoising and segmentation, the feature extraction module is responsible for feature extraction and dimension reduction, and the classification module is responsible for diagnosis and classification. Because many of these processors are used in wearable and portable devices, one of the primary focuses of the design process for AI-based biomedical processors is to optimise the power and area consumption while simultaneously achieving high classification accuracy. "This is the case because of the nature of these processors. In the first step, algorithm-level exploration and optimization are used in order to lessen the amount of computing effort required for classification while keeping the same degree of precision. This includes the usage of sparse neural networks and spiking neural networks. Second, in order to decrease the amount of power that is required, certain architectural-level design strategies are used. These strategies include sparse matrix computing architecture, weak-strong hybrid classification architecture, and serial processing architecture. Thirdly, in order to further limit the amount of power that is being used, circuit-level design approaches are implemented. These techniques include analogue computing circuit design, switchable clocking circuit design, and near-threshold circuit design.

1.3. Signal Processing in PPG Signals:

This method for determining heart rate is comprised of two primary components: the part that collects data and the part that processes information in real time. During the data-gathering stage, the pre-processing and filtering stages comprise deriving PPG signals from the pulse sensor. These stages are included in both processing stages. During the real-time processing, it is filtered out of the PPG signal. During the stage of data collection, initially the PPG signal is obtained from the pulse sensor, and then it is preprocessed to remove noise and increase the signal quality in order to collect the PPI index. After this, the PPG signal is used to determine the PPI index. After the signal has been preprocessed, the PPI index is extracted from the signal. This signal, together with its properties, is then collected as a data point to provide Raspberry Pi with an input signal for drawing the heart rate plot. In this particular application of the system, the pulse sensor is what is utilised to get information about the heartbeat from the blood stream. This fingertip-sized pulse sensor fits over the top of the digit and measures the amount of infrared light that is reflected by the blood that is flowing in the capillaries. The aforementioned sensor is made up of an infrared emitter as well as a detector that are both installed side by side and are brought very near to the surface of the skin. The sensor has two sides; on the front side, an LED is positioned lengthwise with an ambient light sensor, and on the back side, some electronics has been attached. The sensor can detect light in a variety of environments. This circuitry is in charge of the job of amplifying the signals and cancelling out any noise that the amplified signals produce. The light-emitting diode of the sensor is positioned directly above a vein on a human body. This may be a fingertip or the tip of an ear, but it should be positioned exactly on top of a vein. Either option is OK. When the heart contracts, there is a sudden increase in blood pressure, and at the same time, there is an increase in the quantity of infrared light that is reflected in the detector from the emitter. When there is more light hitting the detector, the current it outputs increases, which results in a decrease in the voltage that is received by the amplifier circuits. The light that is emitted from the LED, which is directed straight down onto the vein. Only when the heart is actively beating will the veins have a steady flow of blood moving through them; thus, monitoring both the blood flow and the heartbeats is necessary for accurate results. If blood flow is detected, the ambient light sensor will take up lighter because they will be reflected by the blood; this minute variation in the amount of light received is studied over time to calculate the frequency of heartbeats.

The analogue heart-beat information signal is converted into digital form by the pulse sensor, which is directly linked to the analogue section of the Arduino Uno. Raspberry Pi was the primary controller for the work being done in this

research project. The signal containing the digitalized information about the heart rate is sent to the Raspberry Pi so that the digital filtering procedure may be carried out. In Raspberry Pi, the information about the digitalized heart rate is stored in a comma-separated value, or csv, format. In order to apply the FIR filter to the signal, the Raspberry Pi reads the csv file and processes it. The Butterworth FIR filtering method is devised using the computer language MATLAB, and it is implemented on Raspberry Pi using the programming language Python.

In order to properly analyse a PPG signal, it must first be segmented into smaller time intervals of 30 to 60 seconds each, and then STFT must be used to perform the necessary pre-processing processes. The STFT is used in the process of isolating high-frequency components and low-frequency components from the cardiopulmonary data. Converting a signal from the time domain to the frequency domain is another use of the STFT. As a result, the signal representing the heartbeat is transformed into the frequency domain. After that, the frequency that is directly proportional to the rate of the heartbeats is determined by selecting the heartbeat with the highest amplitude between 0.8 Hz and 3 Hz. Because the heartbeat fluctuates over time, the Fast Fourier Transform (FFT) does not work very well; as a result, it is not possible to extract the heart rate variability (HRV). It is suggested that the STFT be used to monitor the change in heart rate (HR) over time. This method is based on the concept of applying the Fourier transform across portions of the signal, more specifically windows, rather than applying the Fourier transform over the whole signal. This is done in order to get better results.

III. LITERATURE REVIEW

(Jagtap and Uplane 2013) studied “Digital Filter Approach for ECG in Signal Processing The use of digital filters may be used in areas such as biological signal analysis, image analysis, and image coding and decoding methods. The process of filtering typically begins with the analogue waveform being digitised by an analogue to digital converter (ADC). Next, the binary values are sent to a digital signal processor (DSP) device, which then executes a real-time convolution operation in discrete space using either a finite impulse response (FIR) or an infinite impulse response (IIR) algorithm. After the data have been processed, they are sent to a digital-to-analog converter (DAC), which generates a filtered analogue signal. In order to fulfil the requirements of the Sampling Theorem with regard to the waveform that is being sampled and to get rid of quantization noise in the signal that is being processed, an anti-aliasing filter is placed before the (analogue to digital converter) ADC, and in a similar fashion, a reconstruction filter is placed after the digital to analogue converter (DAC). Many benefits come along with the use of digital signal processing (DSP) technology in the construction of filters rather from the more conventional analogue approaches. Most importantly, they have a natural flexibility about them due to the fact that altering the characteristics of the filter requires nothing more than changing the programme code or the filter coefficients. In contrast, altering the characteristics of an analogue filter necessitates physical reconstruction.

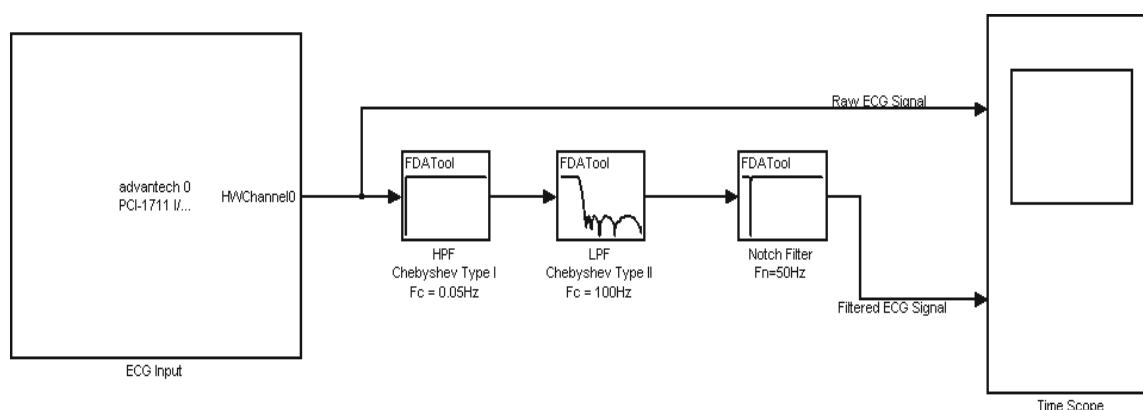
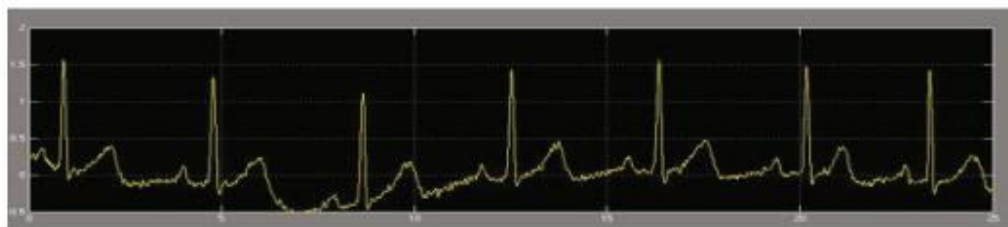
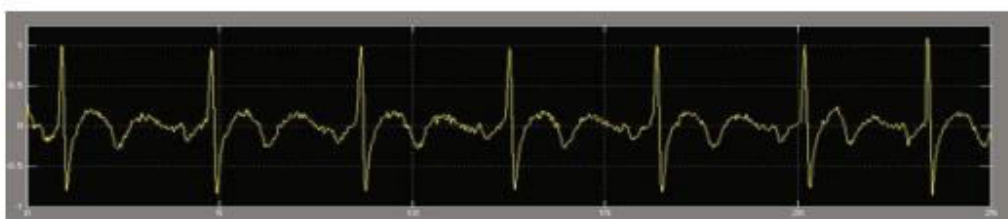


Fig 3: filtering of ECG signal



Raw ECG Signal Before Filtration



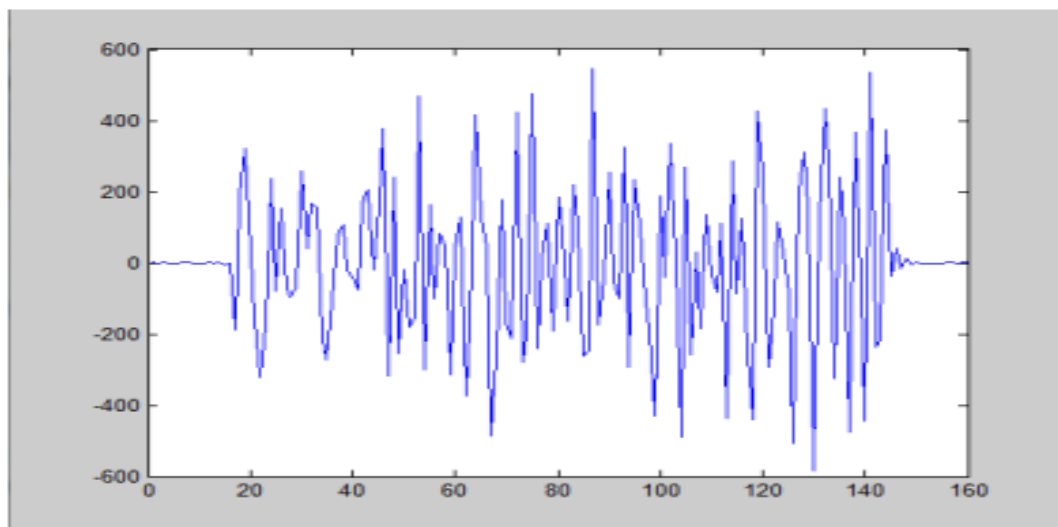
ECG Signal After Filtration

Fig 4

(Ozpolat et al. 2016) studied FPGA-based digital Filter Design for Biomedical Signal discovered this and Over the course of the last several years, a significant amount of work has been put in by scientists to create automated systems for detecting seizures in patients. In this work, a Field Programmable Gate Array (FPGA)-based Fir Filter Design for Biomedical signal processing is going to be presented. Electroencephalography, often known as EEG, has proven to be the most reliable instrument used in the field of biomedical signal processing. It is possible to change the frequency response of the digital filter at any time, which allows it to be used in a wide variety of applications, including data compression, biomedical signal processing, communication receivers, and many more. The digital filter is used to filter discrete time signals. The Finite Impulse Response (FIR) filter offers numerous benefits on signal processing, such as having a simple construction, stationary response, and adaptability with embedded microprocessors. One of these advantages is that it has a shorter latency than other filters. In order to facilitate structural characteristics and design qualities, the FIR filter has been recommended as a candidate for filtering EEG signal. The Xilinx FPGA ISE editor may be used to simulate the design and can be accessed on the computer that is included in the system. The primary purpose of this research is to calculate FIR filter coefficients using the MATLAB Filter Design Toolbox and then implement those coefficients into an integrated design using the FPGA so that the EEG signal may be filtered.

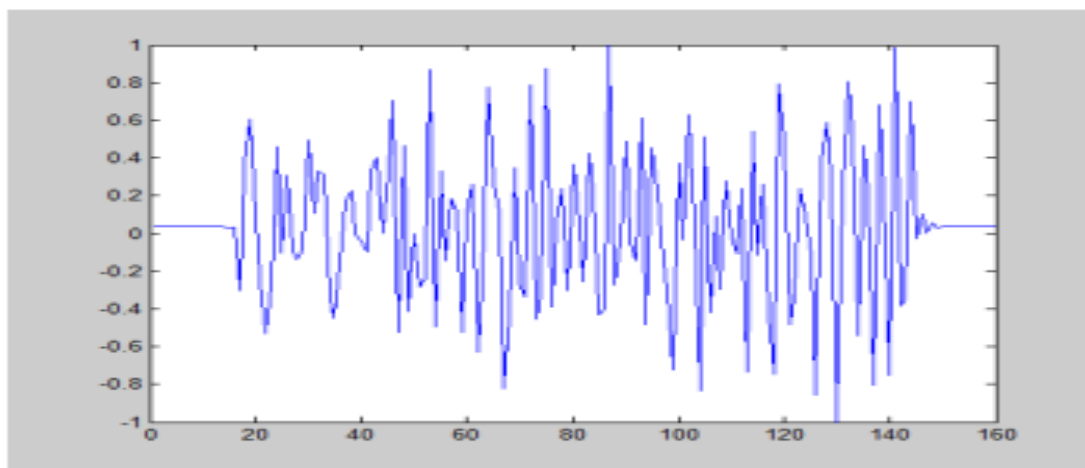


Fig 5



Untreated EEG signal

Fig 6



Normalized -1 to 1 by normalization method EEG signal.

Fig 7

(Wei et al. 2020) studied A Review of Algorithm & Hardware Design for AI-Based Biomedical Applications discovered this and Review and discussion have been conducted on the algorithmic and hardware underpinnings of a variety of biological applications, including ECG, EEG, and hearing aids. Several widely used biomedical signal classification algorithms, such as support vector machine (SVM), back propagation neural network (BPNN), convolutional neural networks (CNN), probabilistic neural networks (PNN), recurrent neural networks (RNN), Short-term Memory Network (LSTM), fuzzy neural network, and others, have been discussed as part of the algorithm design process. In the context of various application situations, an examination and comparison of the benefits and drawbacks of various categorization algorithms has been carried out. Also covered in this article are recent developments in the investigation of AI-based biomedical processing algorithms and applications. In the area of hardware design, a number of AI-based biomedical processors, such as ECG classification processors, EEG classification processors, EMG classification processors, and hearing aid processors, have been examined and debated. Analyses and comparisons have been performed on a wide variety of techniques, both on the architectural and circuit levels. In addition to this, the research tendencies of the AI-based biomedical processor have been highlighted.

(Tun 2021) studied Photoplethysmography (PPG) Scheming System Based on Finite Impulse Response (FIR) Filter Design in Biomedical Applications Hl discovered this and Photoplethysmography, often known as PPG, is a method that does not need any invasive procedures and is used to monitor relative changes in blood volume in blood arteries

that are near to the skin. The ultimate goal of this line of inquiry is to develop a filtering system that operates in real time. This method of determining heart rate is comprised of two primary components: the data collection section and the processing that occurs in real time. During the data-gathering step, PPG signals are derived from the pulse sensor, and both the preprocessing and filtering stages of processing use these signals. In real-time processing, it filters the signal coming from the PPG. During the stage of data collection, the PPG signal is first obtained from the pulse sensor, and then it is preprocessed to get rid of noise and improve the signal quality in order to get the paired-pulse index (PPI). After the signal has been preprocessed, the PPI is extracted from the signal. This signal, together with its characteristics, is then collected as a data point to provide Raspberry Pi with an input signal for drawing the heart rate plot. In this particular application of the system, the pulse sensor is what is utilised to get information about the heart beat from the blood stream. It's possible that using this computer-aided technique may assist patients save the time they spend waiting for decisions from their physicians. When it comes to the automated diagnostic system, things like biomedical analysis, digital signal processing, image processing, and data analysis are going to become key aspects.

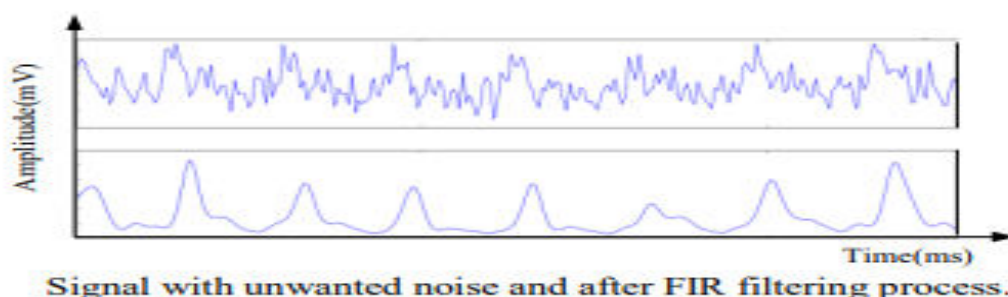


Fig 8

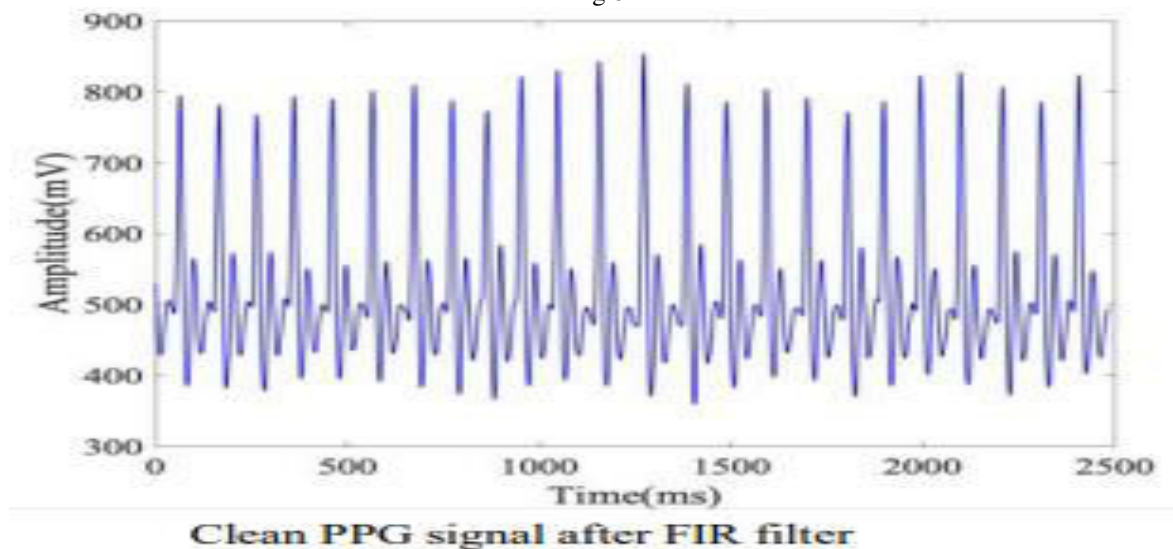


Fig 9

(Weik 2000) studied biomedical digital signal processing discovered this and The use of computers in medical care is a very vast subject. In this book, we will only be able to cover a very tiny portion of it. In the field of medical instruments, we have decided to place an emphasis on the significance of real-time signal processing. The nature of medical data, the basic features of a medical device, and the discipline of medicine itself are all topics that are covered in this chapter. Following that, we will discuss the development of the system that is based on microprocessors. This is done because of the significance of the microprocessor in the creation of contemporary medical equipment. After that, we provide a few examples of medical devices in which the microprocessor has played a significant role. In some instances, the microprocessor has even enabled us to design new instruments that were previously impossible. A study of software design and the role of the personal computer in the creation of medical devices is presented as the concluding topic of this chapter.

(Challis and Kitney 1982) studied the. Design of digital filters for biomedical signal processing discovered this and The investigation of a wide variety of biological occurrences often involves carrying out processes that are associated with

signal processing. One essential component of these analyses is digital filtering operations. This has been made possible, at least in part, by the rising prevalence of the use of computers with varying degrees of complexity in the field of biological study. In the fields of medicine and physiology, digital filters have been used throughout the course of research conducted on all of the body's main organ systems. Signals such as blood pressure and flow, electrograms from the heart, brain, and smooth and striated muscle, nerve action potentials, and pressure signals from the lumina of the gastrointestinal system, urinary tract, and uterus are all involved. Other signals include nerve action potentials. (Subbulakshmi and Manimegalai 2014) studied A Survey of Filter Bank Algorithms for Biomedical Applications discovered this and The algorithms for digital signal processing are promising strategies that are utilised to ease the filter bank design issues that are present in a variety of applications. The use of a filter bank is a method that enables a variety of capabilities, including speech coding, noise reduction, sub band coding, and auditory compensation. The design process focuses almost entirely on the most important aspect of the system, which is the kind of filter that will be used. Nevertheless, it mandates a variety of answers to a wide range of issues. The most significant problems are high processing complexity, space requirements, and power consumption. The filter bank is an important component of digital hearing aids since it enhances sound quality for those with hearing loss. The purpose of this work is to provide an overview of the filter bank algorithms under different qualities and the obstacles that they encounter, in addition to the present state-of-the-art in this field of research. to improve the practicability of the design by using the qualities of the filter banks in appropriate contexts in order to find viable applications. This study addresses a broad spectrum of concerns with the design of filter banks. The contribution of this work may be broken down into three parts. To begin, we will demonstrate the operational function of the filter bank. The second topic is the categorization of the filter bank algorithms for hearing aids. Third, a discussion is had about the advantages, disadvantages, and additional design issues posed by the filter banks.

Table 1: Comparison of digital filters technique for bio-medical signal

<u>SIGNAL'S TYPE</u>	<u>AUTHOR & YEAR ESTABLISHED</u>	<u>DIGITAL FILTER TECHNIQUE</u>	<u>OUTPUT</u>
ECG	SonalK.Jagtap and M.D. Uplane in 2013	IIR Filter	Filtering is an important step in the processing of the surface ECG signal. This study investigated some of the different factors influencing digital filtering approach in filtration of the ECG and compared the performances of all IIR filters.
EEG	ErmanOzpolat, Baris Karakaya,Turgay Kaya, ArifGulten in 2016	FIR Filter	In Conclusion of this study, it is shown that EEG signal can be processed faster on FPGA platform under favour of speed and parallel process ability of FPGA by using FIR Filter Core model.
PPG	Hla Myo Tun in 2021	FIR Filter	The Estimated Heart rate performance is compared with that of the PPG Signal where both the time domain and frequency domain parameters are extracted and evaluated.

IV. CONCLUSION

The aim of this Review paper is to extract important features of ECG using signal processing techniques. In this paper, approaches of different digital filter for ECG in signal processing are discussed. Electroencephalography, often known as EEG, has proven to be the most reliable instrument used in the field of biomedical signal processing. The digital filter is used to filter discrete time signals. It is possible to change the frequency response of the digital filter at any time, allowing it to be used in a wide variety of applications. The electroencephalogram (EEG) is one of the most popular sources of information that is used to research brain function and neurological illnesses. EEG monitoring devices create a vast quantity of data, and it is not normally feasible to provide a thorough visual examination of this data. The FIR filter performance is determined by the accuracy of the estimated instantaneous heart rate, and the appropriate value of the filter coefficient depends on the accuracy of the PPG signal. Digital filters may be found in



fields such as biological signal analysis, image analysis, and image coding and decoding. The process of filtering typically begins with the analogue waveform being digitised by an analogue to digital converter. After that, the binary values are sent to a digital signal processor (DSP) device. Thus nowadays, importance of signal processing appears to be no visible sign of saturation.

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