ECG Signal Denoising Using FIR Filter With Vedic Mathematics

Palle Shivam Goud[1*], Meghna Goud Vaskar[1], Bathini Vishal[1], P. Durga Devi[2]

[1] UG Student, Department of ECE, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India.

[2] Assistant Professor, Department of ECE, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India.

pshivam_ece210445@mgit.ac.in, mgoud_ece210440@mgit.ac.in, bvishal_ece210413@mgit.ac.in, pdurgadevi_ece@mgit.ac.in.

Abstract - FIR (Finite Impulse Response) filters are essential in Digital Signal Processing (DSP) for performing noise suppression in Electro Cardio Graphs (ECGs), imaging devices, and analog signals. Thus, evaluation of filters is performed to minimize noise. The filter retains the desired frequency and the signal being measured to minimize distortion. For operations, an FIR filter is made up of adders, multipliers and a delay element. Two categories of digital filters are available - FIR, and IIR, with IIR being dependent on the input, complexity, and size specifications. In the case of FIR filters, output performance is heavily influenced by the adders and multipliers incorporated. This work focuses on developing and optimizing the multipliers and adders of an FIR filter to achieve greater performance. Vedic Mathematics is a term for methods that contain 16 Sutras which assist in performing fast mental calculations. In this research work we apply the Kogge Stone fast adder in the direct form FIR filter designed using MATLAB, along with the modified Anurupye Vedic multiplier techniques.

Key Words: FIR, Anurupue Vedic Multiplier, Kogge Stone adder.

1.INTRODUCTION

Heart diseases, commonly referred to as Cardiovascular Diseases (CVDs), are the foremost cause of death globally, responsible for about 32% of all fatalities. Of these, nearly 85% result from heart attacks and strokes. The heart itself is a cone-shaped muscular organ that rhythmically contracts to circulate blood throughout the body [1] [2] [3] [4] .

Electrocardiogram (ECG) signals are essential indicators of heart health and are extensively used in medical diagnostics to identify and monitor conditions such as arrhythmia, myocardial infarction, and other cardiac abnormalities. However, the accuracy of ECG signals is often compromised due to the presence of various types of noise during acquisition and transmission. Common sources of interference include power-line noise at 50/60 Hz, baseline drift caused by respiration or body movement, and high-frequency muscle artifacts. These noise components can significantly distort the ECG waveform, potentially leading to incorrect diagnoses. Hence, effective noise reduction is a crucial step in ECG signal processing to ensure reliable and precise interpretation [5].

The present work focuses on designing and implementing a high-performance FIR filter to clean ECG signals. The design follows a dual-approach methodology. Initially, a conventional FIR filter is built using standard digital arithmetic components. Following that, an optimized FIR filter is developed using principles from Vedic mathematics to improve speed and efficiency. The optimized design incorporates an Anurupye-based Vedic multiplier, known for its simplicity and fast computation, alongside a Kogge-Stone adder, a high-speed parallel prefix adder used for efficient binary addition. These components are combined to create a filter architecture that is not only faster but also consumes fewer hardware resources, making it well-suited for FPGA-based implementation.

To assess the performance of both filter designs, simulations are carried out in MATLAB using real ECG signal datasets. The evaluation is based on parameters such as latency, settling time, cut-off frequency, Mean Squared Error (MSE), effective number of bits (ENOB), and signal-to-noise ratio (SNR). The results demonstrate that the Vedic FIR filter significantly outperforms the conventional FIR filter, offering better denoising capabilities, faster response times, and more efficient hardware utilization. This makes the Vedic FIR filter a promising and practical solution for real-time biomedical signal processing, particularly in portable and embedded healthcare monitoring systems.

2.LITERATURE REVIEW

ECG signals play a vital role in diagnosing heart-related conditions like arrhythmia and myocardial infarction. However, these signals often suffer from noise such as power-line interference, baseline wander, and muscle artifacts. The challenge lies in removing this noise without losing crucial clinical information. Traditional techniques like high pass and notch filters are commonly used. There is need for precise denoising to enhance diagnostic accuracy. Techniques such as wavelet transforms, adaptive filters, and FIR filters have proven effective. [6] [7].

FIR filters are preferred for ECG applications due to their stability and linear phase, which preserve the signal's shape. They work without feedback, making them inherently stable. A popular approach for FIR filter design is the windowing technique, where different window functions like Hamming, Hanning, Blackman, and Kaiser help shape the filter's frequency response [8].Various windowing methods are used for ECG applications, in noise suppression and frequency handling. Kaiser windows for low-pass filtering, noting how adjustable parameters can fine-tune performance [9].

Vedic mathematics offers efficient arithmetic algorithms. The Anurupye-based Vedic multiplier, in particular, enables faster parallel multiplication and has shown promise in DSP implementations. Paired with Vedic multipliers, the Kogge-Stone adder boosts speed in FIR filters with its parallel, low-latency design, it outperforms traditional adders, making it ideal for rapid ECG processing. [10] [11].

2.1 MATLAB for FIR filter design

The design and implementation of FIR digital filters using MATLAB, highlights the importance in modern signal processing. FIR filters are valued for their stability, linear phase, and precision, making them essential in applications such as audio processing, communications, image enhancement, and biomedical signal analysis.

The fundamentals of FIR filters, including their non-recursive nature and FIR, which offer advantages over IIR filters, especially in high-fidelity systems. The design approach discussed focuses on the window function method, where an ideal impulse response is shaped using window functions to meet specific filter requirements.

Using MATLAB's Signal Processing Toolbox and FDATool, the paper demonstrates the design of a band-pass FIR filter with Kaiser windowing [12] The filter is fine-tuned using parameters like order, cutoff frequencies, and window beta value. MATLAB provides an efficient and user-friendly platform for FIR filter design, allowing quick iterations and accurate implementation of complex filtering tasks.

2.2 Vedic mathematics in Signal Processing

Vedic mathematics, an ancient Indian mathematical system, provides highly efficient algorithms for arithmetic operations. In recent years, the application of Vedic multipliers in DSP has gained attention due to their ability to reduce the computational complexity and increase processing speed. The Anurupye Sutra-based multiplier, derived from Vedic mathematics, is particularly useful for parallel multiplication and offers faster computation than traditional binary multipliers. This Vedic multiplier has been used in hardware design (such as FPGA and ASIC) and signal processing applications, providing an efficient method for fast arithmetic operations in FIR filters. There are studies that show the Vedic multiplier reduces the overall delay and hardware complexity, making it suitable for real-time applications like ECG monitoring [13] [14]

3. DATA AND METHODS

3.1 Data collection

The MIT-BIH Arrhythmia Database, available through the PhysioNet.com platform, is one of the most widely used and trusted ECG datasets in the field of biomedical signal processing. It was created specifically to support the development and testing of algorithms for detecting and classifying heart-related issues using ECG signals. PhysioNet, a well-known resource for physiological data, offers open access to a variety of carefully documented medical signal databases, and the MIT-BIH dataset stands out as a key reference point.

Developed by the Massachusetts Institute of Technology in collaboration with Beth Israel Hospital, this dataset includes real ECG recordings collected from patients with different types of heart conditions. Because it features actual clinical data, it provides a realistic and reliable foundation for researchers and developers working on improving ECG analysis and diagnosis technologies.

The MIT-BIH Arrhythmia Database is a well-established and clinically annotated ECG dataset that plays a key role in biomedical research. It's widely used as a benchmark for developing and testing signal processing techniques and diagnostic algorithms. What makes this dataset especially valuable is its diverse range of patient conditions, detailed annotations, and well-structured records. These qualities make it particularly suitable for our project, where we apply FIR filter-based techniques to effectively denoise ECG signals and enhance their clarity for more accurate analysis.

Table -1: Different formats of ECG data

File extension	Description	Content
.dat	Signal file (binary)	Raw ECG waveform data
.hea	Header file	Contains metadata such as signal name, sampling frequency, duration
.atr	Annotation file	Time-stamped beat and rhythm annotations by cardiologists
.mat	MATLAB data file (if converted)	Contains digitized ECG Signal arrays and may include sampling rate

Each ECG recording in the dataset is composed of several synchronized files that collectively describe the raw signal, patient metadata, and expert annotations. These files are typically stored in formats given in the table 1.

Methodology

This work focuses on the denoising of ECG signals using two different FIR filter designs—one conventional and one optimized using Vedic mathematics. The ECG dataset used for this study is sourced from the Arrhythmia Database available on PhysioNet (https://physionet.org/about/database/), in. mat format. These real-world signals often contain various types of noise such as baseline wander, muscle artifacts, and power-line interference, which can compromise diagnostic accuracy.

The first phase involves designing conventional FIR filters using popular windowing techniques such as Hamming, Hanning, and Kaiser windows. These filters serve as the baseline for comparison and are implemented in MATLAB using standard arithmetic units.

The second phase introduces an optimized FIR filter design based on Vedic mathematics. Specifically, the Anurupye Sutra is used to construct a high-speed Vedic multiplier, which is paired with a Kogge-Stone adder—a fast, parallel prefix adder known for low latency and high efficiency. This architecture is implemented to enhance computational performance, reduce delay, and minimize hardware complexity.

4.RESULTS & DISCUSSION

The conventional and vedic filters are simulated in MATLAB using the same ECG dataset. To evaluate their effectiveness, several performance parameters are analysed, including transition bandwidth, passband and stopband ripple, stopband attenuation, main lobe width, sidelobe level, SNR, MSE, ENOB, and FIR filter coefficients.

The results demonstrate that the Vedic FIR filter offers superior performance across most metrics, making it highly suitable for real-time biomedical signal processing applications.

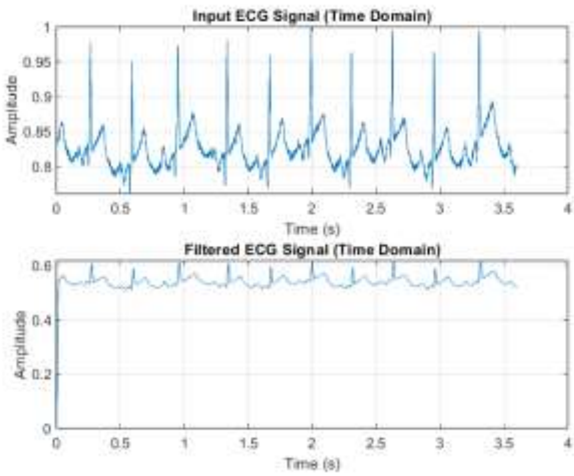

Fig-1: Time domain response for Conventional FIR filter

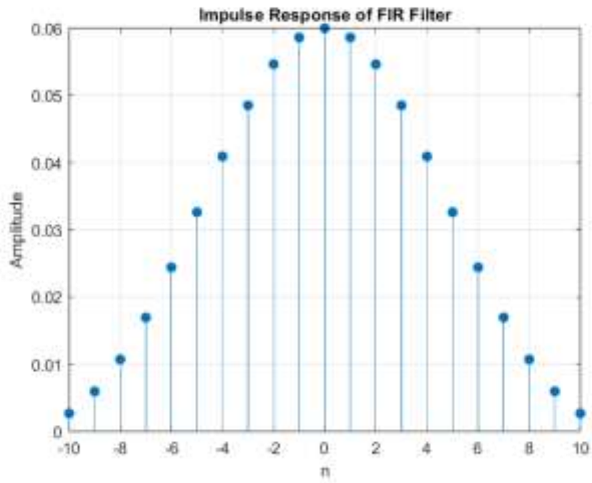

Fig-2: Impulse response for Conventional FIR filter

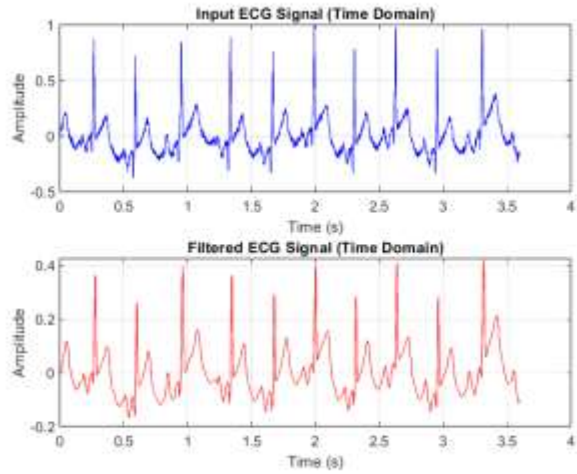

Fig-3: Time domain response for Vedic FIR filter

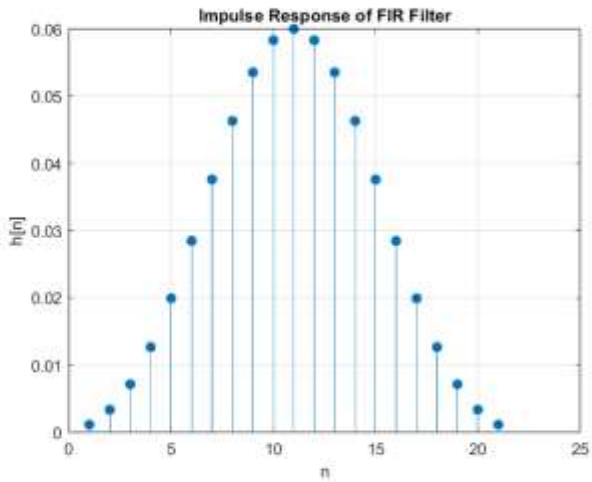

Fig-4: Impulse response for Vedic FIR filter

Performance metrics such as SNR, MSE, ENOB, sidelobe level, main lobe width, stop band attenuation, stopband ripple, passband ripple and latency. The performance comparison of both the filters is given in the table below.

Table-2: Performance comparison of both the filters

Transition Bandwidth	102.05 Hz	0.48828 Hz
Passband ripple	0.1318	0.65208
Stopband Attenuation	9.65 dB	-106.6002 dB
Main lobe width	60.00 Hz	58 Hz
Sidelobe level	-6.72 dB	4.6773e-06
SNR (dB)	6.37 dB	9.0729 dB
MSE	0.006857	0.08471
ENOB	0.77 bits	0.29579 bits

The table shows that Vedic FIR filter outperforms the conventional FIR filter in terms of signal clarity and noise reduction since the former sustains a markedly higher SNR of 9.07 dB compared to 6.37 dB, and stopband attenuation superiority at -106.6 dB versus 9.65 dB, respectively. It is especially helpful for ECG signal denoising due to having smoother frequency response with lower sidelobe levels. In contrast, the conventional FIR filter is superior in precision signal reconstruction accuracy, as indicated by the lower MSE of 0.006857 compared to 0.08471, higher ENOB of 0.77 opposed to 0.29579, simpler design, and lower latency. These results suggest that the Vedic filter is more applicable for real-time biomedical procedures where high noise rejection is essential.

5.CONCLUSION & PERSPECTIVES

The present work was focused on designing an efficient ECG signal denoising system using a FIR filter enhanced by Vedic mathematics. The goal was to improve the clarity and accuracy of ECG signals, which are often affected by noise, especially in wearable health devices.

Simulation results showed that the Vedic FIR filter delivered significantly better results. It achieved a higher SNR of 9.07 dB versus 6.37 dB for the conventional filter, meaning the Vedic design produced a much clearer ECG signal. It also demonstrated a superior Stopband Attenuation of −106.6 dB, indicating excellent noise suppression. Additionally, the Sidelobe Level was nearly zero, reducing spectral leakage and enhancing signal clarity.

Although the conventional filter had slightly better MSE and ENOB, these minor advantages were outweighed by the Vedic filter's improvements in key areas like Transition Bandwidth, Main lobe Width, and Settling Time. Some trade-offs, such as increased latency, were noted but considered acceptable given the performance gains.

In conclusion, the integration of Vedic multipliers and parallel prefix adders in FIR filter design proves to be highly effective for real-time ECG denoising. The Vedic FIR filter offers faster processing, better noise rejection, and cleaner signal output, making it ideal for biomedical applications.

REFERENCES

[1] S. Sahoo, M. Dash, S. Behera, and S. Sabut, "Machine Learning Approach to Detect Cardiac Arrhythmias in ECG Signals: A Survey," *Irbm*, vol. 41, no. 4, pp. 185–194, 2020, doi: 10.1016/j.irbm.2019.12.001.

[2] M. Wasimuddin, K. Elleithy, A. S. Abuzneid, M. Faezipour, and O. Abuzaghleh, "Stages-based ECG signal analysis from traditional signal processing to machine learning approaches: A survey," *IEEE Access*, vol. 8, pp. 177782–177803, 2020, doi: 10.1109/ACCESS.2020.3026968.

[3] M. E. Mangoni and J. Nargeot, "Genesis and regulation of the heart automaticity," *Physiol. Rev.*, vol. 88, no. 3, pp. 919–982, 2008, doi: 10.1152/physrev.00018.2007.

[4] J. Stern, " Clinically Oriented Anatomy by Keith L. Moore, Arthur F. Dalley, and Anne M. Agur ," *Clin. Anat.*, vol. 22, no. 5, pp. 635–635, 2009, doi: 10.1002/ca.20801.

[5] E. N. Bruce, *Biomedical signal processing and biometrics*. 2015. doi: 10.1109/cibec.2014.7020954.

[6] S. Chatterjee, R. S. Thakur, R. N. Yadav, L. Gupta, and D. K. Raghuvanshi, "Review of noise removal techniques in ECG signals," *IET Signal Process.*, vol. 14, no. 9, pp. 569–590, 2020, doi: https://doi.org/10.1049/iet-spr.2020.0104.

[7] Y. Jia *et al.*, "Preprocessing and Denoising Techniques for Electrocardiography and Magnetocardiography: A Review.," *Bioeng. (Basel, Switzerland)*, vol. 11, no. 11, pp. 1–38, 2024, doi: 10.3390/bioengineering11111109.

[8] G. Gautam, S. Shrestha, and S. Cho, "Spectral Analysis of Rectangular, Hanning, Hamming and Kaiser Window for Digital Fir Filter," *Int. J. Adv. smart Converg.*, vol. 4, no. 2, pp. 138–144, 2015, doi: 10.7236/ijasc.2015.4.2.138.

[9] K. S. Kumar, B. Yazdanpanah, and D. G. S. N. Raju, "Performance Comparison of Windowing Techniques for ECG Signal Enhancement," *Int. J. Eng. Res.*, vol. 3, no. 12, pp. 753–756, 2014, doi: 10.17950/ijer/v3s12/1210.

[10] S. Jayakumar and D. A. Sumathi, "High-Performance FIR Filter Implementation Using Anurupye Vedic Multiplier," *Circuits Syst.*, vol. 07, no. 11, pp. 3723–3733, 2016, doi: 10.4236/cs.2016.711312.

[11] G. Ananya and K. Sujatha, "Boosting FIR Filter Performance : A Novel Approach Using Approximate Kogge-Stone Adders and Vedic Multipliers," vol. 45, no. 9, pp. 310–318, 2024.

[12] C. Li, "Design and realization of FIR digital filters based on MATLAB," in *2010 International Conference on Anti-Counterfeiting, Security and Identification*, 2010, pp. 101–104. doi: 10.1109/ICASID.2010.5551524.

[13] M. Sumalatha, P. V Naganjaneyulu, and K. S. Prasad, "Low power and low area VLSI implementation of vedic design FIR filter for ECG signal de-noising," *Microprocess. Microsyst.*, vol. 71, p. 102883, 2019, doi: https://doi.org/10.1016/j.micpro.2019.102883.

[14] V. V Manusmare and D. S. Chaudhari, "Design and Implementation of Parallel FIR Filter Using High Speed Vedic Multiplier," no. July, pp. 713–717, 2017.