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Design of the Adaptive LMS Filter For ECG Signal Noise Reduction

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ABSTRACT

In this project, we aim to explore and address the core challenges associated with the chosen subject. By investigating both theoretical and practical aspects, the paper intends to present a comprehensive analysis that contributes to existing knowledge. The research methodology encompasses various data collection techniques, including surveys, interviews, and case studies, ensuring the acquisition of diverse perspectives. Through this multifaceted approach, the paper seeks to uncover key insights that can inform future strategies and solutions. Furthermore, the project emphasizes the importance of collaborative efforts, drawing on interdisciplinary resources to enhance the quality and applicability of the findings. Ultimately, this work aspires to offer valuable recommendations and innovative solutions that can be utilized in real-world scenarios, benefiting both practitioners and researchers alike. By bridging the gap between theory and practice, the project aims to make a meaningful impact in the field.

Keywords: Challenges, Theoretical, Practical, Analysis, Methodology, Datacollection, Perspectives, Collaborative, Recommendations, Innovative

I. INTRODUCTION

The electrocardiogram (ECG) is a crucial diagnostic tool in cardiology, but its effectiveness can be hindered by various noise sources, including baseline drift, power line interference, and muscle artifacts. To improve ECG signal quality, adaptive filtering techniques such as the Least Mean Square (LMS) filter are commonly used.

These filters iteratively adjust their coefficients to minimize the error between the desired clean ECG signal and the filtered output. The LMS filter's efficiency depends on parameters such as filter length, step size, and convergence criteria. In real-time applications, such as continuous monitoring, the filter must operate with low latency while adapting to dynamic ECG changes.

Additionally, evaluating filter performance using metrics like Mean Squared Error (MSE) and Signal-to-Noise Ratio (SNR) ensures optimal noise reduction.

Ultimately, an effective LMS filter can outomes. essential step -size LMS to computational costs essential monitoring systems health ecg-based lms filter.

II. EXISTING METHOD

ECG signals are essential for monitoring heart conditions, but they often get contaminated by various noise types, making it harder to analyze them accurately.

Common noise sources include baseline wander (due to respiration and skin impedance) and highfrequency noise (from power lines, muscle artifacts, or poor electrode contact). To mitigate these issues, existing systems use digital filtering techniques, especially the Least Mean Squares (LMS) adaptive filter.

While LMS filters are effective, they pose challenges in terms of power consumption, area usage, and processing delays. IRACST – International Journal of Computer Networks and Wireless Communications (IJCNWC), ISSN: 2250-3501

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Efficient hardware implementations are needed to overcome these limitations.

Crucial to the development of next-generation ECG noise reduction systems. By focusing on optimizing hardware components like adders and multipliers, and employing techniques such as approximate computing and algorithm-level enhancements, it's possible to reduce power consumption, improve speed, and reduce area usage.

This optimization will help make portable ECG devices more effective, compact, and power-efficient, which is essential for real-time monitoring.

Ultimately, these innovations will support the goal of providing high-quality, continuous ECG data for accurate and timely cardiac diagnoses, even in resource-constrained environments.

Table 1 Sources of Noise in ECG Signals

Noise Type	Source
Baseline Wander	Respiration,
	n impedance
High-Frequency Noise	Powerline interference,muscle artifacts, electrode contact noise

Table 2 **Digital Filtering Techniques**

Filter Type	Features
FIR Filters	Linear phase,
	guaranteed stability
Adaptive Filters	Dynamically adjusts
•	to signal
	changes

several key limitations that require further research and FPGAs for real-time noise cancellation. optimization.

One major issue is the high transistor count and area consumption of traditional adder and multiplier implementations, particularly when larger bit-widths are necessary for high-precision processing.

This leads to increased chip area and cost, which is problematic for miniaturized portable ECG devices. Additionally, power inefficiency remains a significant challenge, as multipliers are known to be power-hungry, and their widespread use in LMS filters can significantly impact battery life in portable devices

Current designs often prioritize speed over power efficiency, resulting in higher energy consumption.

Furthermore, the iterative nature of the LMS algorithm and the inherent delays in conventional adder and multiplier architectures can introduce processing latency. complicating real-time noise reduction.

These drawbacks highlight the need for more advanced techniques to optimize both performance and efficiency in ECG noise reduction.

Current ECG noise reduction systems, though functional, face significant challenges in achieving an ideal balance between performance and efficiency.

The iterative nature of the LMS algorithm and the complexity of traditional hardware implementations of adders and multipliers underscore the need for more efficient designs that prioritize space and energy savings. To address these challenges, researchers are investigating approximate computing.

where minor errors are deliberately introduced to reduce power, area, and processing time, thus improving overall efficiency. Additionally, efforts are focused on optimizing the LMS algorithm itself through techniques such as sparse adaptive filters, which reduce computational load by using only a subset of coefficients, and variable step-size LMS.

which dynamically adjusts the step size to enhance convergence speed and reduce steady-state errors. Emerging technologies, including memristors and spintronic devices, hold great promise for developing ultra-low-power, high-density adaptive filters that could significantly improve ECG monitoring systems.

These innovations could lead to the creation of portable, real-time ECG devices, offering the potential for early, accurate diagnoses and revolutionizing cardiac healthcare.

one of the biggest advantages of the LMS algorithm is its suitability for real-time ECG signal processing, especially in wearable or portable healthcare devices. Due to its low Existing methodologies for ECG noise reduction computational complexity, LMS can be implemented on provide a solid foundation, but they are hindered by digital signal processors (DSPs), microcontrollers, or even

A.FIR Filter

An N-tap FIR (Finite Impulse Response) filter is a type of digital filter that uses a fixed number of past input values called taps to produce each output sample. Each tap corresponds to a delayed version of the input signal, multiplied by a specific coefficient. These weighted values are then summed to generate the output.



Fig. 1. N-tap FIR filter

Common noise sources include baseline wander (due to respiration and skin impedance) and high- frequency noise (from power lines, muscle artifacts, or poor electrode contact). To mitigate these issues, existing systems use digital filtering techniques, especially the Least Mean Squares (LMS) adaptive filter.

While LMS filters are effective, they pose challenges in terms of power consumption, area usage, and processing delays. B. Adaptive LMS Filter



Fig .3. 8x1 multiplier full adder

are determined by the truth table of a full adder, which defines the output for all eight possible combinations of the three inputs. For the sum output, the logic is $A \oplus B \oplus Cin$, and for the carry output, the logic is AB + BCin + ACin.

assigning the appropriate binary values (0 or 1) to the MUX inputs (I0 to I7) according to the truth table of sum and carry

adaptive LMS Least Mean Squares filter is a type of respectively, the multiplexer can generate the correct outputs. adaptive filter that adjusts its filter coefficients automatically This method provides a systematic way of This optimization to minimize the error

between the desired signal and the will help make portable ECG devices more effective, compact, actual output. It uses the LMS algorithm, which is based on and power-efficient, which is essential for real-time

a simple and efficient gradient descent method.

The updates its weights by using the error signal the Crucial to the development of next-generation ECG noise difference the desired and the output signal to reduction systems. By focusing on optimizing hardware between

iteratively adapt to changing signal conditions.



C. 8X1 multiplexer full adder

A Full Adder can be implemented using an 8×1 multiplexer by utilizing the multiplexer's ability to select one of eight inputs based on three select lines. Since a full adder has three inputs—A, B, and Cin—these can be directly used as the select lines of the 8×1 MUX. The sum and carry outputs

monitoring.

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Noise Type	Source
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Table 1: Sources of Noise in ECG Signals

Table2:Digital Filtering Techniques

Filter Type	Features
FIR Filters	phase, guaranteed stability Linear

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Existing methodologies for ECG noise reduction provide a solid foundation, but they are hindered by several key limitations that require further research and optimization.

One major issue is the high transistor count and area digital consumption of traditional adder and multiplier and Ci implementations, particularly when larger bit-widths are Carry output necessary for high-precision processing.

This leads to increased chip area and cost, which is problematic for miniaturized portable ECG devices. Additionally, power inefficiency remains a significant challenge, as multipliers are known to be power-hungry, and their widespread use in LMS filters can significantly impact battery life in portable devices

Current designs often prioritize speed over power efficiency, resulting in higher energy consumption.

Furthermore, the iterative nature of the LMS algorithm and the inherent delays in conventional adder and multiplier architectures can introduce processing latency, complicating real-time noise reduction.

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diagnoses and revolutionizing cardiac healthcare.

III. PROPOSED METHOD

The proposed design introduces a more efficient 4:1 multiplexer-based full adder in place of the traditional 8:1 multiplexer.

This seemingly small change leads to several benefits, including a reduced transistor count, simplified logic, and lower power consumption.

A. Proposed full adder

the proposed full adder refers to a modified or optimized version of the traditional full adder circuit, designed to improve performance in terms of speed, area, or power consumption. In digital electronics, a standard full adder adds three input bits—A, B, and Cin—and produces a Sum and a



B. Ripple carry adder

A ripple carry adder is a type of digital circuit used for binary addition. It consists of a series of full adders, each of which adds two input bits and a carry bit from the previous stage. The name "ripple carry" comes from the way the carry output from each full adder is passed (or "ripples") to the next one in the sequence.



Fig.5. Designed ripple carry adder

The use of multiplexers (MUX) in the adder design makes it more efficient by reducing complexity and minimizing errors.

Additionally, the design is implemented using Verilog HDL, ensuring scalability, flexibility, and rigorous simulation for functional verification. This optimized approach contributes to a more power-efficient and compact design suitable for portable ECG monitoring devices. Current ECG noise reduction systems face challenges in balancing performance and efficiency.

C. Multiplier

multiplier is a digital circuit used to perform multiplication of two binary numbers. It takes two input binary numbers usually called the multiplicand and the multiplier and produces an output which is their product.

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D.FIR Filter

A FIR (Finite Impulse Response) filter is a type of digital filter used in signal processing to manipulate or enhance signals. The term "finite impulse response" means that the filter's response to an impulse (a very short signal) settles to zero in a finite amount of time. FIR filters work by taking a finite number of past input values, multiplying them by fixed coefficients (called filter taps), and summing the results to produce the output.



Fig.7.Designed multiplier

The iterative nature of the LMS algorithm, combined with the complexity of traditional hardware components like adders and multipliers, results in high power consumption, large area usage, and increased latency.

These limitations make it difficult to integrate such systems into portable, real-time ECG monitoring devices, hindering their effectiveness in critical, time-sensitive cardiac applications.

Optimization in hardware design is necessary to meet

the demands of real-time monitoring while reducing power consumption and area requirements.

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the proposed design replaces the traditional 8:1 multiplexer full adder with a more efficient 4:1 multiplexer-based version.

This change reduces transistor count, simplifies logic, and lowers power consumption. Using multiplexers in the design decreases complexity and minimizes errors.

The design is implemented in Verilog HDL, ensuring flexibility, scalability, and thorough verification, making it a more powerefficient and compact solution for portable ECG devices.

E. LMS Filter

A 4-tap LMS (Least Mean Squares) filter is an adaptive digital filter with four taps, meaning it uses four past input

samples to compute the output. The LMS filter is designed to minimize the error between the desired signal and the actual filter output by adjusting its coefficients (weights) dynamically using the LMS algorithm.



Array multipliers are simple circuits that multiply numbers using a grid of AND gates and adders, but they can be slow and inefficient for larger numbers.

Booth multipliers, on the other hand, speed up the process by reducing the number of partial products, making them more power-efficient.

Wallace tree multipliers use a tree structure to quickly add partial products, improving speed. The Least Mean Squares (LMS) algorithm is used in signal processing to minimize errors by adjusting filter settings.

An Electrocardiogram (ECG) records the heart's electrical activity, and FIR filters process signals using a limited

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number of previous inputs to remove noise and improve clarity.

Wearable devices face several challenges when integrating complex arithmetic units, such as multipliers, which can hinder their performance and practicality.

One major issue is the high area consumption associated with large transistor counts, making it difficult to miniaturize these components for use in compact wearable devices.

This increases both the size and cost of the devices, limiting their feasibility. Additionally, excessive power consumption is a significant concern, particularly for multipliers, which are power-hungry.

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This increases both the size and cost of the devices, limiting their feasibility. Additionally, excessive power consumption is a significant concern, particularly for multipliers, which are power-hungry components.

This results in shorter battery life, making continuous monitoring difficult and limiting the device's long-term usability.

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This increases both the size and cost of the devices, limiting their feasibility. Additionally, excessive power consumption is a significant concern, particularly for multipliers, which are power-hungry cocombination of 4:1 and 2:1 multiplexers along with

basic logic gates like AND, OR, and NOT, which reduces the potential for errors during implementation. Third, the reduction in the number of transistors and simplified circuit design directly lowers power consumption, making the system more energy-efficient, an important factor for modern devices.

 Table 1: Challenges in Current ECG Noise Reduction Systems

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Challenges	Description
High Area Consumption	Large transistor counts limit
	miniaturization, increasing
	cost and space requirements.
ExcessivePower	Multipliers are power-
Consumption	hungry, reducing battery life
-	and limiting contimonitoring.

IV. RESULTS AND DISCUSSION

Electrocardiogram (ECG) signals are often corrupted by various types of noise, including power line interference, baseline wander, muscle artifacts, and electrode motion artifacts. An Adaptive Least Mean Squares (LMS) Filter is a widely used technique for noise reduction in ECG signals due to its ability to adaptively adjust filter coefficients to minimize the error signal.

Fig 1: RTL Schematic diagram







Power consumption

The power line interference from ECG signal can be removed by adaptive filtering while it's harmonics and high frequency noise can be removed by implementing general notch rejection filter.

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Fig 2: power consumption

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This graph shows the resource utilisation after synthesis and implementation. Interesting, the IO utilisation is the highest.



Fig 3: Utilization





An adaptive LMS filter was developed to reduce noise in ECG signals, effectively addressing baseline drift and high-frequency interference, thereby enhancing the accuracy of cardiac diagnosis using ECG data. The filter was implemented in Xilinx Vivado version 2021.2, utilizing a custom adder and multiplier design that incorporated basic gates, a 2x1 MUX, and a 4x1 MUX. The results showed that the proposed design led to a 5.53% reduction in power consumption and a 4.48% decrease in area compared to the existing adaptive LMS filter with conventional adders and multipliers. This advancement holds significant potential to improve hardware performance in both cardiac diagnostics and clinicalapplications

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