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Performance Analysis of Notch Filter in ECG Signal Noise Reduction

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Abstract

An electrocardiogram (ECG) is a medical test that records the normal and abnormal condition of the heart. It is an essential tool for identifying various cardiac related issues. However, ECG wave are often distorted by diverse noise sources, such as movement artifacts or electrical interference. To remove these artifacts and enhance the quality of the ECG signal, various filters are commonly used. The choice of filter type depends on the definite necessities of the application. FIR filters are used in the area that needs linear time response and accurate amplitude response. They have a stable and predictable response and are more robust to coefficient quantization errors. However, they require a larger number of coefficients to achieve the desired frequency response, which can lead to increased computational complexity. The use of digital filters, specifically notch filters, for denoising ECG signals is an effective technique. Adders are essential components in the design of notch filters, and researchers have been exploring different types of adders to improve the parameters of these filters. In this paper, the Ripple carry adder, Carry select Adder, and adder using Carry skip are compared in terms of their performance parameters, including area, delay, and power consumption. The RCA is a basic adder, while the C-Skip and C-Select adder are designed to reduce the delay of the addition operation. The results of the study showed that the C-Skip and C-Select adder outperformed the R-Carry adder in terms of delay and power consumption. The C-select adder had the lowest delay, while the C-Skip adder had the lowest power consumption. However, the area of the C-select Adder was larger compared to the other adders. Overall, the selection of adder depends on the particular need of the application. Notch filter used for ECG noise removal designed using these adders and its performance is analyzed.

1. Introduction

Heart disease is among the common problem in humans worldwide. Therefore, understanding the physiology and reality of the heart requires an effective tool and technique to effectively predict heart disease. An electrocardiogram is a widely used method to analyze the working of the heart. Today, automated electrocardiographic assessment is considered a key and steadfast method for the prediction of heart disease. ECG data obtained by placing electrodes on the person's chest and extremities are tainted with specific types of artifacts, including power line intrusion, noise of electrode contact, baseline shift, motion artifact, the instrument noise caused by electronic equipment, as well as the distinctive sound. The noise of the power supply is the prime factor of signal variation during the whole process of identifying the ECG (Khandpur) (Stephen and Chapman) (Malindi) (Widrow and Hoff). The single sound has a single frequency; low frequency noise can cause problems with the ECG signal, while high frequency sound can also interfere with the EKG i.e. cellular smartphone for some time Manual or automated study of ECG recordings is difficult due to ground wire interference.

Figure 1 shows the different positions of an ECG signal. One identifies the position and the other identifies the interval between various points(P-QRS_T). ECG signals have a different series of applications in the bio-medical area, such as seizures monitoring, real-time heart rhythm analysis and analysis heart rate variability using smart ECG patches (Jiashu and Heng-Ming) (Jigram, Shah, and Joshi).

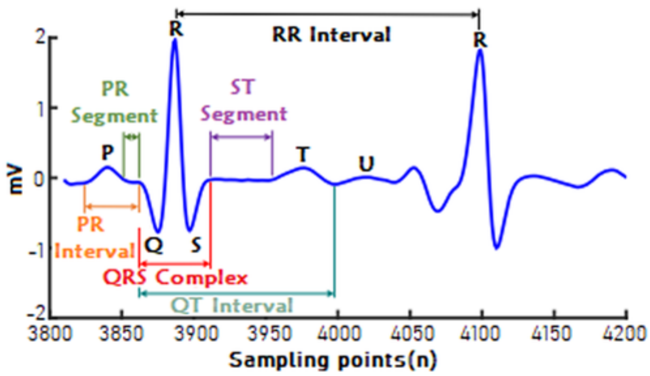

FIGURE 1. **ECG signal from MIT-BIH Arrhythmia database**

These applications needs a exact identification of the various points and interval difference for identifying dominant noise such as baseline drift, muscle noise which is recorded by electromyography (EMG), power line distortion, random noise due to motion and instrument noise, etc. ., making detection of disease-specific morphological abnormalities very difficult (Islam et al.) (Buckley) (Nishikawa and Kiya) (Sayed).

2. Related Work

Chhavi Saxena, Avinash Sharma, Rahul Srivastav and Hemant Kumar Gupta (2018) in the paper

"Denoising of Ecg Signals Using Fir & Iir Filter: a Performance Analysis" provides to a distint estimation problem with a least-squares method. Some methods, such as the LMS-adaptive matching algorithm, have the characteristics of slow convergence speed, cannot operate on fastchanging signals, and are not suitable for observing the precise value. This method is mainly used in noise control and real-time systems due to its fast convergence and large size compared to other algorithms.

Shubhojeet Chatterjee, Rini Smita Thakur, Ram Narayan Yadav, Lalita Gupta and Deepak Kumar

Raghuvanshi (2020) in the article "Review of noise removal techniques in ECG signals"

analyzes the procedure and design ethics for classifying the noise. It is also compared with various existing method. Data taken from MIT-BIH are used for analyzes and mean square error, signal to noise ratio, error rate are calculated.

Ms.Chhavi Saxena, P.D Murarka, Hemant Gupta and Avinash Sharma (2017) in the paper

"Denoising of ECG Signals Using Adaptive Filters". This article focuses on using methods for gaining acceptance as signal conditioning techniques which involve adaptive filters. Interference cancellation is widely used in many applications such as audio and voice data processing, data transmission, biological indication, etc. The disadvantage of techniques which is linear is that they are naturally not time changing to identify certain noise. Adaptive methods overcome the listed problems.

Dipali Bansal(2013) in the paper "Design of 50 Hz notch filter circuits for better detection of online ECG". This work analyzes the notch type of filter designed at 50 Hz for ECG filtering. The development of technology has enabled automated ECG analysis, which is balancing to physicians in terms of effective diagnosis. However, the steadfast acquirement and drawing out features of ECG signals using computerized systems is very susceptible to interference from power lines.

Jasbir Kaur and L. Sood(2015) in the paper "Comparison Between Various Types of Adder Topologies" in the compared various adder topologies used in signal processing applications. Adder is need for application in a wide range, so its effective utilization based on the area is a concern. This paper analyzed various adders for different measurements such as area, delay and power values. Comparison shows different adders which improves any one of these parameters and results in degradation in other parameter. Based on trade-off it can be selected by considering the application and the area it is used.

3. ECG Denoising using Notch Filter

There are various noise associated with ECG signal. Some power related disturbance includes electromagnetic disturbance, power variation and poor grounding of electrodes. EMG noise occurs due to the muscle movements of the patient. Some noise occurs due to low and high frequency components which is due to breathing and body movements. Electrode contact and poor channel condition also results in noise which affects the original ECG signal. Figure 2 shows the different types of noise associated with ECG signals.

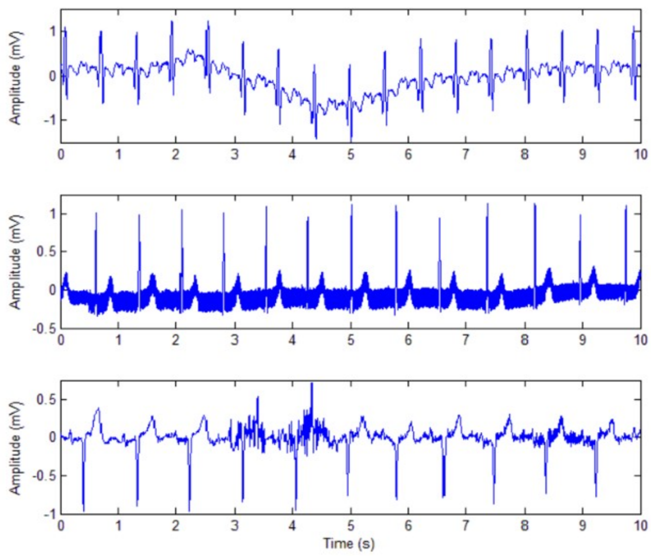

FIGURE 2. Common types of noise in ECG recordings. (a) Baseline wander, (b) 50 Hz power line interference, and (c) Electromyographic noise.

Notch filters and anti-notch filters are basically notch/bandpass filters with a very narrow stop-band/stopband and two passbands/stopbands respectively, used to block or pass specific notches of any signal wave or peak frequency. Notch filters are used to remove various types of noise such as power variation, poor grounding electrode noise, noise due to the muscle movements and other noise associated with electrodes.

Various architectures for high-speed filters realizable by FPGA are discussed in the literature. This paper presents an FPGA implementing a tunable

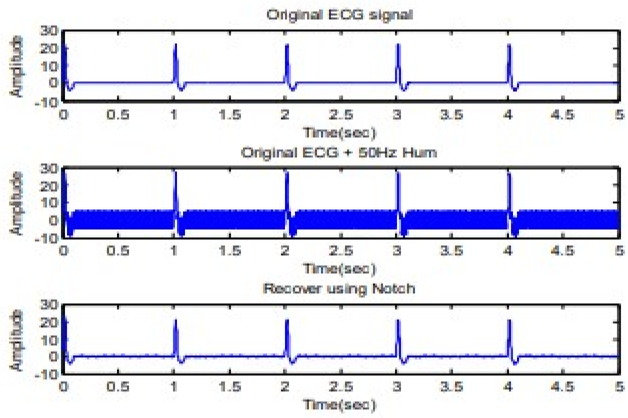

FIGURE 3. Noise removal of notchfilter at 50 Hz

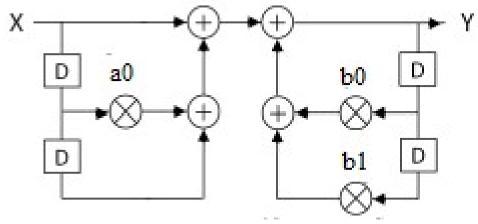

FIGURE 4. Basic 2nd Order IIR Notch Filter Structure

notch filter with such high throughput using various adder topologies. X is the input ECG sample and Y is the filtered output with a0, b0 and b1 is the filter co-efficients. For effective removal of noise a feedback mechanism is used for next level processing. Here in this paper, we propose an FPGA-feasible ultra-fast notch filter structure, applying standard pipeline techniques for power-of-2 decomposition, recalculation, and expansion of the basic filter structure as shown in Figure 4. Table I gives the various parameters of notch filter used in ECG denoising.

TABLE 1. Summary Notch Filter

Sl.no	Description	Parameter
1	Notch Frequency	50 Hz
2	3 dB Bandwidth	10 Hz
3	Attenuation at Notch Frequency	3dB
4	Sampling Frequency	600 Hz
5	R	0.947
6	b_o	0.9463

4. Parametric Analysis with Different Adder Topologies

Ripple carry adder(RCA)

The binary ripple carry adder uses a group of full adder connected forming an n-bit adder. It is the basic form of adder in which carry moves from one full adder to another. This propagation results in increase in the critical path value when the number of input bit increases. It can be used in application where delay is not a concern with power and area is considered as the important factor.

Basic architecture of ripple carry adder is shown in Figure 5.

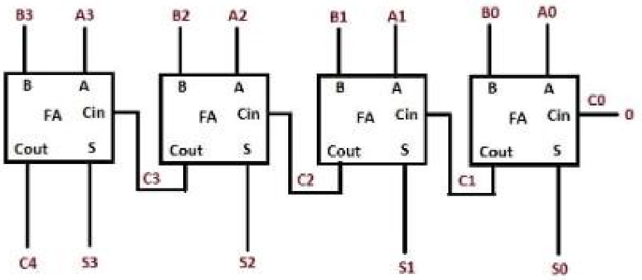

FIGURE 5. **Ripple Carry Adder**

Carry select adder(CSLA)

In alternative to ripple carry adder, carry select adder results in lower delay but has more area and power consumption. It uses a two identical network of ripple carry adders with carry input given alternatively. There also various research works done on carry select adder to minimize the area overhead. But still its mainly deals with application were the performance is the important factor.

Figure 6 shows basic form of carry select adder.

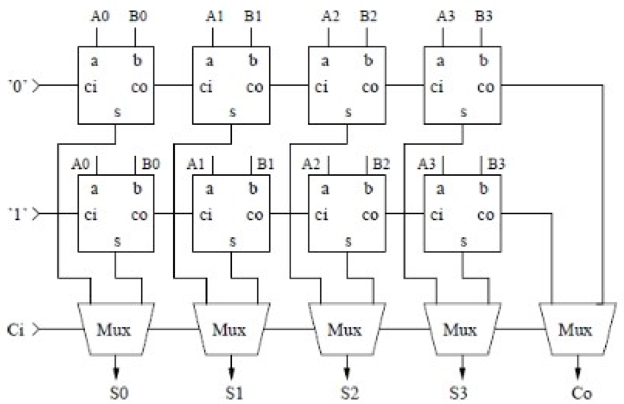

FIGURE 6. **Carry Select Adder**

Carry skip adder

Carry-skip adder results in parameters which are average of carry select and ripple carry adder. It divides the input in blocks as shown in Figure 7. The carry in each block is generated earlier than the sum output using the input operands. This helps to process the next blocks before the sum calculation is entirely completed. It is suitable in applications where the data to be processed is already known.

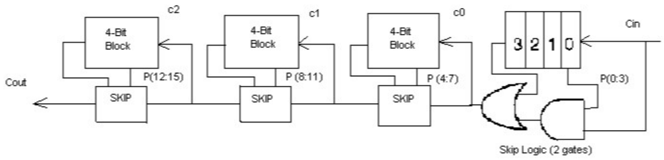

FIGURE 7. **Carry Skip Adder**

TABLE 2. **Comparative analysis of Notch filter for different adder topologies**

Adder Types	Area(Gate count)	Delay(r	Power(mW)
Ripple Carry Adder	844	23.401	133.72
Carry Skip Adder	856	21.305	132.79
Carry Select Adder	880	20.235	134.65

5. Experiment Results

The proposed VLSI architecture of notch filter is synthesized using Xilinx ISE 8.1i and targeting SPARTAN 2E FPGA family. The area utilization in terms of gate count, power and delay of notch filter with different adder topologies are summarized in Table II. This table indicates that for high speed application carry select or carry skip can be used and for applications which need optimized area ripple carry adder can be used. The Figure 8 shows result of ECG denoising using notch filter designed using Verilog and simulated in Modelsim tool. ECG samples taken from MIT-BIH physionet database and converted into binary value is given as the input to the notch filter. Signal Y is the noise minimized ECG signal obtained as the output.

6. Conclusion

The electrocardiogram is an important measurement used in the biomedical applications. For effective detection of ECG signals to identify the exact abnormality noise removal is a important pre-processing step. The proposed work dealt with notch filter for ECG noise removal which helps in denoising the

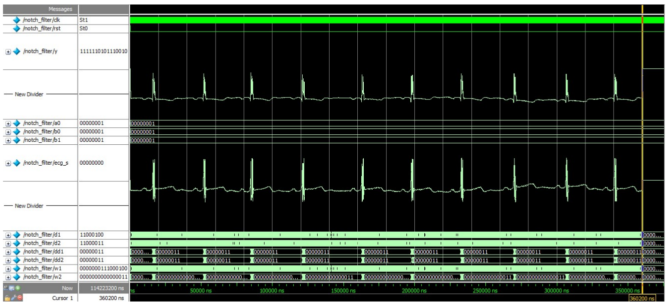

FIGURE 8. Simulation result of ECG denoising

signal for various noises listed out in this work. For efficient VLSI implementation of notch filter different adder topologies are considered. The parameters of notch filter with different adder are compared and listed. It can be used based on the application requirement for hardware design. Compared with other adaptive and non-adaptive techniques notch filter results in better removal of noise for various type of distortions.

Authors' Note

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the pa-per was free of plagiarism.

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