American-Eurasian Journal of Scientific Research 10 (3): 154-159, 2015
ISSN 1818-6785

DOI: 10.5829/idosi.aejsr.2015.10.3.22277

Design and Implementation of Motion Artifact Reduction Asic for Wearable Ecg Recording

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Abstract: The challenge in measuring the heart rate of a patient in motion is to remove artifacts present along with ECG signal and it is more important in clinical diagnosis of heart diseases for a cardiologist. The continuous recording of ECG for accurate diagnosis requires more power. The existing method describes about a mixed signal SOC for ECG monitoring applications and reduces the motion artifacts using Adaptive filters. The goal of the proposed method is to monitor and process the ECG signal with less power and to provide long term ECG recording. The proposed system uses Adaptive filter with LMS algorithm to reduce motion artifacts. Also MAC unit in the LMS core is replaced by a configurable LUT. This LUT is optimized by using APC-OMS technique. The optimized LMS algorithm consumes less power and area than the existing LMS algorithm. A novel VLSI architecture is developed and implemented for LMS algorithm for wearable ECG ASIC with less power and area.

Key words: Adaptive filters · Anti-Symmetric Product Coding-Odd Multiple Storage (APC-OMS) · Least Mean Square (LMS) · Look up Table (LUT) · Motion Artifacts and System on Chip (SOC)

INTRODUCTION

Measurement and monitoring of ECG signal is a vital diagnostic instrument for countless Heart diseases. Monitoring of ECG and blood flow, measurement of stroke volume and Cardiac Output (CO) plays a vital act in the diagnosis of extensive illnesses such as hypertension and heart failure. The most common methods for computing Cardiac Output are Invasive intra-cardiac catheterization and non-invasive Doppler ultrasound anatomy [1]. In early days for continuous measurement and monitoring of Heart Rate the patient must be hospitalized. Also the heart rate of a person under rest varies from the heart rate of the same person under his daily activities. Hence necessary of ambulatory monitoring of ECG signal come in existence. The main advantage of ambulatory monitoring is to prevent the deadly cardiac diseases in future. This leads to the invention of wearable ECG monitoring device [2]. The use of wearable ECG becomes mandatory to record ECG signals in real time.

The main difficulty in computing the heart rate of a patient in motion is the presence of Motion Artifacts along with the ECG signal. The motion artifacts are unwanted signal Present along with the ECG signal which reduces the signal quality and leads to defective diagnosis of heart illness for a cardiologist. Many motion artifact reduction techniques [3] are Available. The block diagram for ECG measurement and processing of ECG signal is shown in Fig. 1. ECG is measured using Lead I, II, III through ECG electrode from the patient and is fed as input to an instrumentation amplifier having high CMRR [4] to remove fluctuations in the ECG signal. A programmable low power ASIC [5] developed for ECG applications in which ADC is provided to convert analog ECG signal into digital output. Since the proposed method mainly focuses on Least Mean Square adaptive filtering algorithm to reduce the motion artifacts with low power, ECG database is collected from Physio-Net and simulated using MATLAB and converted into text file in binary format. The binary file is given as input to the VLSI architecture for LMS algorithm.

Motion Artifact Reduction Using Adaptive Filters: Artifacts transpire due to movement of electrode that is allocated alongside patient skin. These artifacts encompass of larger amplitude and are comparable to ECG signals. The Artifacts have comparable frequency spectrum to the target bio potential signals.

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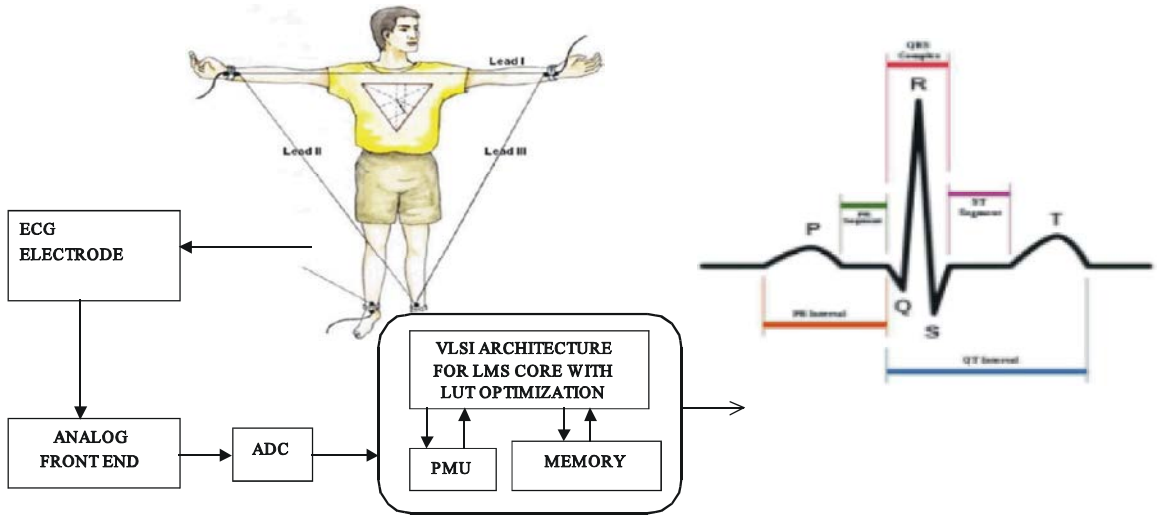


Fig. 1: Block Diagram for ECG Processing

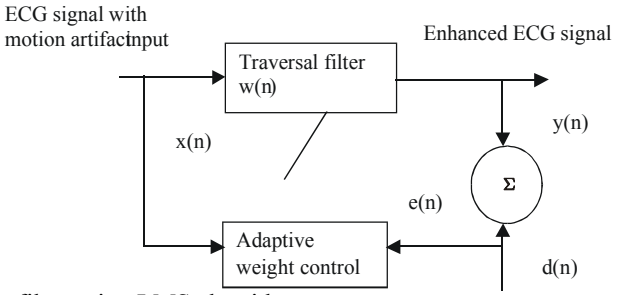


Fig. 2: Schematic of Adaptive filter using LMS algorithm

Ambulatory recording systems tolerate from motion artifacts leads to fake alarm and wrong event detection. These motion artifacts can be cancelled from ECG signals by employing adaptive filter for achieving reliable and elevated integrity recording quality under ambulatory conditions. Adaptive filter utilizes optimization algorithms to remove motion artifacts in ECG signal. Adaptive filter utilizes many Motion Artifact reduction algorithms [6] to remove motion artifacts present along with the ECG signal. These algorithms are differing from each other by its convergence factor and complexity.

Least Mean Square algorithm is one of the linear low power consuming adaptive filtering algorithms that are utilized to remove gesture artifacts present alongside the ECG signal. Fig. 2 shows the method of cancelling motion artifacts from ambulatory recorded ECG signal. The primary input to the filter is the ambulatory recorded ECG signal and the reference input is the original or motion artifact free ECG signal. The input signal $x(n)$ and output signal $y(n)$ of the adaptive filter is expressed in (1), (2) and (3).

$$X(n) = [x(n), x(n-1) \ldots x(n-L+1) \quad (1)$$

$$y(n) = \sum_{i}^{L-1} {}_{i}(n)x(n\text{-}i) \quad (2)$$

$$y(n) = w^{T}(n)x(\quad (3)$$

The variable filter updates the filter coefficients at every time instant is described in (4).

$$W(n+1) = w(n) + \mu . x(n) . e(n) \quad (4)$$

$$e(n) = d(n) - y(n) \quad (5)$$

Memory Based Multiplication: Finite Impulse Response (FIR) is a common tool used in many signal processing algorithms. Digital signal processing algorithms such as Least Mean Square requires more memory based computations to be performed rapidly and repetitively on set of data. Also the number of multiply-accumulate (MAC) operations of FIR filter increases with the filter order.

The implementation of such large order filters is extremely difficult. To reduce the computational complexity, memory based multiplications are replaced by Look up Table based multipliers. Of the two operands,

Table 1: APC Words for different input values

Input X'	Product Values	Inputx	Product Values	Address $x_3' x_2' x_1' x_0'$	APC word
00001	A	11111	31A	1111	15A
00010	2A	11110	30A	1110	14A
00011	3A	11101	29A	1101	13A
00100	4A	11100	28A	1100	12A
00101	5A	11011	27A	1011	11A
00110	6A	11010	26A	1010	10A
00111	7A	11001	25A	1001	9A
01000	8A	11000	24A	1000	8A
01001	9A	10111	23A	0111	7A
01010	10A	10110	22A	0110	6A
01011	11A	10101	21A	0101	5A
01100	12A	10100	20A	0100	4A
01101	13A	10011	19A	0011	3A
01110	14A	10010	18A	0010	2A
01111	15A	10001	17A	0001	A
10000	16A	10000	16A	0000	0

Table 2: APC words for OMS Technique

Input X' $x_3' x_2' x_1' x_0'$	Product Value	No of Shifts	Shifted Input X"	Stored APC Word	Address $d_3 d_2 d_1 d_0$
0001	A	0			
0010	2XA	1			
0100	4XA	2			
1000	8XA	3	0001	P0=A	0000
0011	3A	0			
0110	2X3A	1			
1100	4X3A	2	0011	P1=3A	0001
0101	5A	0			
1010	2X5A	1	0101	P2=5A	0010
0111	7A	0			
1110	2X7A	1	0111	P3=7A	0011
1001	9A	0	1001	P4=9A	0100
1011	11A	0	1011	P5=11A	0101
1101	13A	0	1101	P6=13A	0110
1111	15A	0	1111	P7=15A	0111

one is fixed coefficient A and the variable input word X of length L is multiplied by A. Conventional LUT size increases with the input word size.

The product word is stored in location X_i for $0 \le X_i \le 2^L-1$. L-bit binary value of $X_i$is used as the address for the LUT to store the product word. The LUT size is decreased by employing assorted optimization methods such as Anti-symmetric Product coding (APC), Odd Multiple Storage (OMS).

LMS Algorithm with Lut Based Multiplier Optimization Techniques

Anti-Symmetric Product Coding: In APC technique [7], LUT size is reduced half thanthe conventional LUT. This technique stores only upper half of conventional LUT words. Consider a 5 bit input word X

$$X = \{x_4, x_3, x_2 x_1 x_0\} \quad (6)$$

where $x_4, x_3, x_2 x_1$ are the four least significant bits of

$$X' = X_L', \text{ for } x_4 = 1, \quad X_L, \text{ for } x_4 = 0 \quad (7)$$

$$\text{Product value} = 16A + (\text{signed value}) * \text{APC} \quad (8)$$

where sign value = 1 for $x_4 = 1$
sign value = -1 for $x_4 = 0$

The product words for input word X of Length L = 5 is shown in Table 1.

Odd Multiple Storage: In OMS technique [8], only odd multiples are stored in LUT's and even multiples are attained by easy left shifting operation. The Select lines for shifting will be derived from barrel shifter. LUT size is reduced to half from its original. The APC words stored in LUT are shown in Table 2.

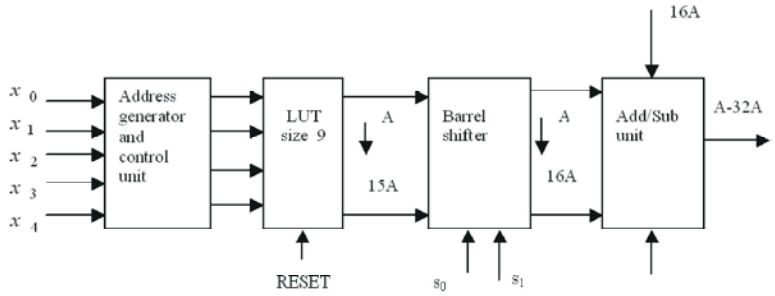


Fig. 3: Schematic of combined APC-OMS technique

Combined APC-OMS Technique: The Combination of APC and OMS technique [9] will reduce the LUT size further by 50% .Overall size reduction will be around 75 % as compared to conventional LUT. The block diagram for APC-OMS technique shown in Fig. 3 consists of a barrel shifter to store even multiple values.

X Generation Module takes a 5-bit as input. It is utilized to produce anti-symmetric of last 4-bits (X (4 to 0)) when the MSB of X i.e. X (4) = 0 and process the same input when the MSB of X= 1 hence only 16 combinations will be achieved for 5-bit of input. If (x (4) = 0‘) then X_{comps} = X (4) & 2‘scomplement of (X (3 to 0)). Else X_{comps} = X. The address generation unit generates the 4-bit address for the input given by X generation module the 4-bit address is named as d. The reset output will be set, when the input combination X =10000 to make the output of the barrel shifter to 0

$$RESET = (\overline{x_0 + x_1 + x_2 + x_3 +}), x_4 \quad (9)$$

X’’ is generated by shifting out leading out zeros in X’. The5-bitinput word *X* can be mapped into a 4-bit LUT address (*d*3*d*2*d*1*d*0), by set of mapping relations as:

$$X' = X_L', \text{ for } x_4 = 1 \quad (10)$$
$$X_L, \text{ for } x_4 = 0$$

The address for LUT is calculated as in (11). Values from LUT will be shifted based on select lines $\{s_1 s_0\}$

$$d_i = x''_{i+1} \text{ for i} = 0,1,2 \quad (11)$$

$$d_3 = \overline{x_0}''$$

The select lines for barrel shifter are estimated as in (12). The control and reset circuit can be designed as:

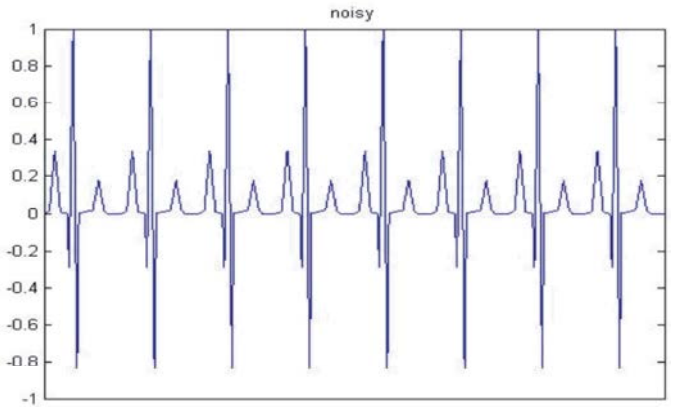
$$s_0 = (x_0+(x_1+x_2)')' \quad (12)$$
$$s_1 = (x_0+x_1)'$$

Reset = $(x_3 \text{ and } x_2)' x_1$

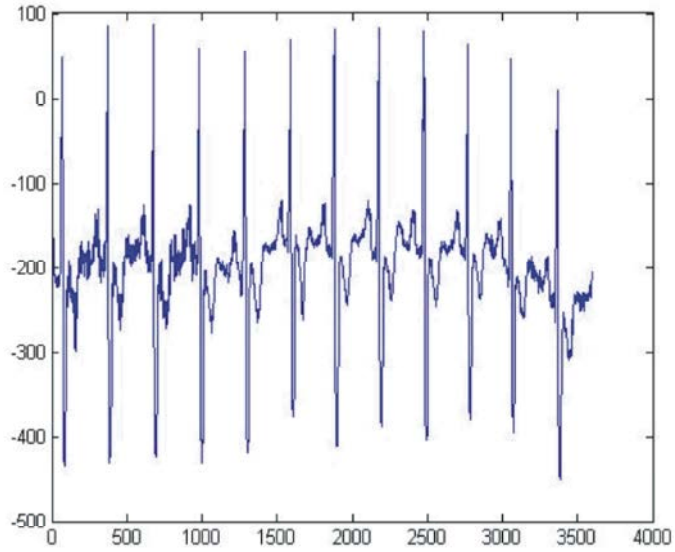
The Add/Sub Unit either add or subtract barrel shifter output to x_4. Mid value 16A is added or subtracted from 16A. Initially 8 odd values are stored in LUT and 2A is stored as a ninth value. This is shown in Table 3.

Experimental Results: ECG database is loaded and simulated in MATLAB is shown in Fig. 4. LMS algorithm with LUT based multipliers optimized using APC-OMS technique is simulated using Modelsim6.4a and Quartus II tool and the simulation results are shown in Fig. 5. The analog ECG signal with motion artifact and desired signal are given as input in the binary text file format. Motion artifact free ECG signal is viewed as analog signal by using this tool. The comparison results of LMS algorithm with LUT based multipliers and LMS algorithm with LUT based multipliers with optimized APC-OMS technique is shown in Table 4.

To notice and stop the fatal heart illnesses in upcoming there is a demand to compute and monitor ECG of a patient in his daily activities. The main setback of computing and monitoring ECG signal for long term is large requirement of power. Also when the patient is in motion, the observed ECG signal consists of motion artifacts that lead to wrong diagnosis of a cardiologist. The proposed LMS algorithm with LUT based multipliers optimized using APC-OMS technique provides motion artifact free ECG signal. Also the optimized algorithm reduces the size of LUT. Thus area and power consumed by motion artifact reduction algorithm is also reduced. The power of ordinary LMS algorithm and LUT optimized algorithm are compared. The software used for simulation is ModelSimQuartusII. Further in the subsequent step a real time ECG signal is generated from a patient using ECG electrode and processed in Analog Front End to remove fluctuations present along with ECG signal. Then a novel area efficient architecture for LMS algorithm with low power is planned to be implemented in FPGA.



(a)



(b)

Fig. 4: (a) Desired ECG signal (b) ECG signal with motion artifacts

Fig. 5: Simulation result of LMS algorithm with LUT optimized using APC-OMS technique

Table 4: Comparison Results

Methods	Power
LMS algorithm with LUT based multipliers	145.05mW
LMS algorithm with LUT optimized using APC-OMS technique	128.48mW

CONCLUSION

The continuous recording of ECG for accurate diagnosis requires more power. The existing method describes about a mixed signal SOC for ECG monitoring applications and reduces the motion artifacts using Adaptive filters. The goal of the proposed method is to monitor and process the ECG signal with less power and to provide long term ECG recording. The proposed system uses Adaptive filter with LMS algorithm to reduce motion artifacts. Also MAC unit in the LMS core is replaced by a configurable LUT. This LUT is optimized by using APC-OMS technique. The optimized LMS algorithm consumes less power and area than the existing LMS algorithm.

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