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Design and implementation of ECG Signal Detector Using Fractional Operator For Cardiac Pacemaker

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Abstract

This paper presents low cost QRS Complex ECG Signal detector which acquires smaller area and decreased power consumption. In this paper an area and power efficient ECG detector with Fractional operator is proposed for cardiac pacemaker. The conventional methodology uses LPF & HPF to denoise the signal which shows increased power . The power and area of the conventional methodology of using band-pass filters for denoising is high as compared to the proposed methodology because of reduction in multipliers. The power of any device depends on multipliers too as the contribution of power by multiplier is very high. The proposed approach is the design of Lattice Wave Digital Filter that comprises of Fractional Differentiator and integrator based on Gruenwald-Letnikov approach and Cuckoo-search Algorithm. The use of LWDF decreases the multiplier count for structural realization. Thus the hardware required and power consumption is reduced further. The total power, individual power of adders and multipliers are observed using Xilinx Vivado 2017.4 .The tool used for the design of the ECG detector is Xilinx System Generator 2017.4 and Simulink modeling is preferred The proposed technique is implemented using Xilinx Sytem Generator. Thus a total area of 27.28% is saved using the proposed method. Considerably a low power of 320µW is also achieved which makes it useful for high performance medical applications.

Keywords— Implantable Cardiac Pacemaker (ICP), Lattice wave digital filter (LWDF), ElectroCardiogram (ECG).

I. INTRODUCTION

Medical equipment have been changing in revolutionary ways in recent years. Increasing compactness of medical devices made them light-weight and available for continuous care monitoring. One such application is the cardiac which is used to regulate the heart beat by using the electrical pulses delivered by the electrodes on contraction of the heart. The Electrocardiogram (ECG) records the electrical activity from our heart to check the heart abnormalities. Electrodes are placed over the chest to record the electrical potential that is due to heart beat. Each component of wave carries some information on the heart's activity:the P wave shows atrial depolarization; QRS-wave shows ventricular depolarization, T-wave shows ventricular repolarization , U wave shows repolarization of the purkinje fibers and baseline is the polarized state. The pacemaker once implanted into the body is expected to operate with high detection reliability over several years. It can be implanted permanently to correct a slow or irregular heartbeat or to treat heart failure. Lattice wave digital filters are cascade of first and second order all pass filters and each is made of adaptor configurations. LWDF structure realization is adopted for the implementation of cardiac pacemaker because it requires less number of multipliers compared with other existing structure realization.

Here a novel method to implement the ECG detector is proposed.

The paper is organized as follows: Section I provides an introduction to the paper. The literature survey done is described in Section II. Section III deals with information about the conventional detector design approach. The proposed ECG detector design approach is described in Section IV. The performance evaluation and the simulation results of the proposed technique are detailed in Section V. Finally, Section VI concludes the paper.

II. LITERATURE REVIEW

In [1] J.Pan and W.J. the methodology for identification of the QRS complexes of Electrocardiogram signals is presented. False detection is reduced by the bandpass filter, this false detection is caused by the types of inference present in Electrocardiogram signal. This filtering allows to increase sensitivity with use of less thresholds. The methodology itself alters parameters and thresholds occasionally to apt to Electrocardiogram changes as QRS structure and heart rate. In [2] X.Yang and Suash Deb proposes the design of Cuckoo-Search algorithm. The host bird can either abandon the nest or throw the egg away, and build a new nest. This last assumption can be approximated by replace the fraction pa of the n nests with new nests. They have to validate the algorithm using test functions with analytical or known solutions. In this work the proposed algorithm has been validated and compared with genetic algorithms and particle swarm optimization. The wavelet-based R-wave detector proposed [3] is implemented. In this work, they have depicted wavelet-based ECG detector. And it has wavelet decomposer with filter banks and a noise detector with zero-crossing points [4] .For high detection precision, soft-threshold algorithm and many-scaled algorithm are efficaciously proposed in this Electrocardiogram detector. In [4] Gupta Varshney P, Visweswaran new discretized models for fractional-order differentiator (FOD) (sr) and integrator (FOI) (s−r) using first-order and higher order operators are proposed. The expansions for FOIs of the first-order s-to-z transform proposed by Hsue et al. In this work Hsue operator based on third-order and fourth-order models of FOI, fourth-order Schneider operator as well as Al-Alaoui–SKG rule based on third-order, fifth-order and sixth-order models of FOD have been suggested. The stability of the models has been investigated and by using pole refelection method the unstable ones were stabilized The final results compared with that of recent FOD and FOI models based on the Al-Alaoui operator[5]. An approach to the design of QRS complex detector using bi-orthogonal wavelet transform[5] is proposed where the Architecture of the proposed ECG detector contains modified biorthogonal 2.2 wavelet filter bank and a modified soft threshold-based QRS complex.

III. CONVENTIONAL ECG DETECTOR

The band pass filtering based ECG detection technique is the most efficient technique which contains six stages. Noises present in raw ECG is supressed using the digital band pass filter. The noises include electrode noise, motion artifacts, muscle contraction, respiration and additive white noise.

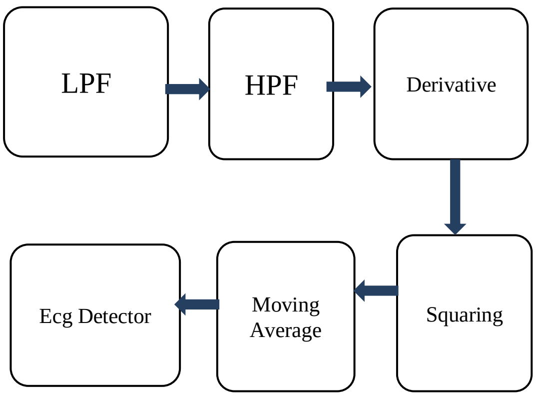

Fig.1. Block Diagram of the ECG Detector

A. *Band pass filter*

Firstly, various noises present in raw ECG signal are suppressed using a digital band-pass filter. When the ECG signal is measured, many noises get added from multiple sources. These noises mainly include electrode contact noise, motion artifacts, muscle contractions, respiration, and additive white Gaussian noise. Each type of noises affects an ECG signal in many ways, either by adding an extra frequency component or shifting baseline of the signal[13] The equation for LPF with respect to Time domain is given in equation(1) and the equation for HPF with respect to Time domain is given in equation(2)

complexes as outstanding positive peaks in the signal regardless of their polarity in the original ECG recording. Then, the output of the derivative is squared point by point. Squaring of the derivative of frequency response curve restricts false positives generated by T wave with higher spectral energy than usual. The equation for squaring is given in equation (4)

$$p(jT) = [r(jT)]^2 \quad (4)$$

D.Moving Window Average

The moving average is a simple method to smooth measured data by replacing a data point with the average (or a weighted form of it) of its neighbours. The averaging window is moved over the data, shifting it by one-time step after each calculation ("moving average"). The moving average can be denoted in a more general form by the following equation that is given as

$$y(t) = \sum_{i=-k}^{+k} w_i x(t+i) \quad (5)$$

IV. PROPOSED ECG DETECTOR

$$p(jT) = \left(\frac{1}{8}\right)[2p(jT-T) - p(jT-2T) + r(jT) - 2r(jT-6T) + r(jT-12T) \quad (1)$$

$$p(jT) = 32r(jT-16T) - [p(jT-T) + r(jT) - r(jT-32T) \quad (2)$$

B. Derivative

Band-pass filtering removes the different noises from the raw ECG signal, but the slope information is not enough for the proper ECG detection. Next, the output of band-pass filter is differentiated to get exact slope information. Besides that, many abnormal QRS complexes in the ECG signal have larger amplitude and long duration. For the better performance of the algorithm, some parameters (amplitude, energy, and width of the QRS peak) in the signal must be extracted. The equation after passing through derivative is given in equation(3)

$$p(jT) = \left(\frac{1}{8}\right)[-r(jT-2T) - 2r(jT-T) + 2r(jT+T) + r(jT+2T)] \quad (3)$$

A. Fractional Operator detector

The fractional operator structure ECG detector circuit consists of the Gruenwald- Letnikov based fractional operator. Instead of a conventional low-pass filter, high-pass filter, and derivative during the preprocessing stage, a fractional differentiator and integrator are adopted to denoise the noise-corrupted ECG signal[13]

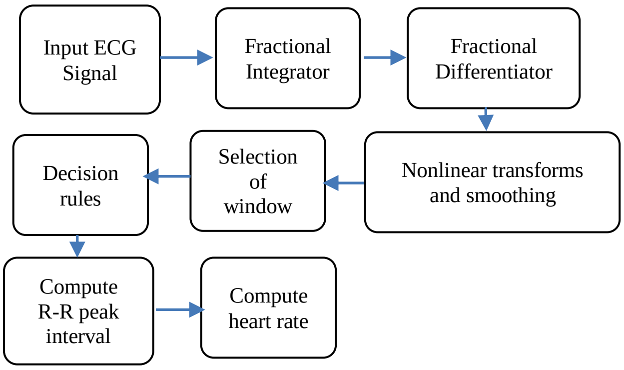

Fig.2. Block Diagram of the Proposed ECG Detector

B.Preprocessing

Initially, the input ECG signal is taken from different online databases taken from physionet, namely QT Database, Apnea Database, Fantasia Database and MIT-HIB Arrhythmia Database. The MITBBIHADB contains ECG signal ranging from 10 seconds to 30 minutes of duration, a gain of 200 adu/mV, baseline at 1024 mV, and sampling frequency of 360 Hz, respectively. Whereas the QTDB contains ECG signal ranging from 10 seconds to 15 minutes of duration, with a gain of 200 adu/mV, the baseline at 1024 mV, and sampling frequency of 250 Hz, respectively. The major concern for ECG detection algorithm is the noise present in ECG signals. Fractional order filters and fractional order derivative are used as they provide more precise control of the attenuation gradient compared with integer order filters. The FD & FI follows the adaptor configurations as given in Fig3.

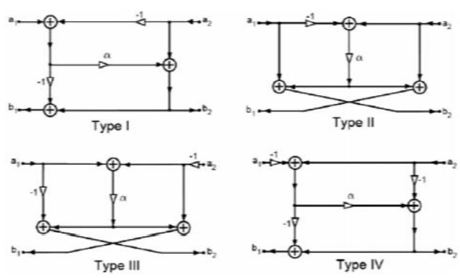

Fig3. Four adaptor configurations

The adaptor types are based on the values of ɣ and α and they are all equivalent. The value coefficients ɣ lies in the range [-1,1], but the actual multiplier coefficient α to be implemented 0< α<0.5. A two-port adapter requires one multiplier and three adder circuits. The need of minimal number of a multiplier circuit in LWDF structure realization makes it the most useful for efficient implementation of IIR system of predefined order

C. Cuckoo Search Algorithm

Cuckoo Search Algorithm (CSA) is based on unique brood parasitism of cuckoo species with Levy flights approach . Like other nature inspired algorithms, CSA is also used to find the optimal solution of the problem under consideration from the search pace. Yang and Deb introduced three basic rules to apply CSA:

(a) Each cuckoo bird lays one egg at a time and hide it randomly selected nest.

(b) The nest with the best quality of eggs will carry forward to the next generation.

(c) The number of host nests is constant, and the probability that the laid egg is identified is given as $Pa \in [0,1]$.

Each egg in the host nest represents a solution, and the cuckoo egg represents the new solution. The objective is to use better solution and replace the solutions in the host next with better solutions. The search space is iteratively updated using Levy flight approach given as follows:

$$X_i^{k+1} = X_i^k + \alpha \oplus \text{Levy}(\lambda) \quad \textbf{(6)}$$

where α is the step size related to problem under consideration and *Levy* (λ) is Levy flight distribution

D.Fractional Integrator

The fractional equation for Fractional integrator is given in equation (7)

$$H_1(z) = \frac{0.8576-0.032z^{-1}+0.8629z^{-2}-0.0811z^{-3}}{1-1.2096z^{-1}+0.2644z^{-2}+0.0144z^{-3}} \quad (7)$$

The LWDF realization provides a minimum multiplier fractional integrator where only three multipliers are required The LWDF realization provides a minimum multiplier fractional integrator where only three multipliers are required .

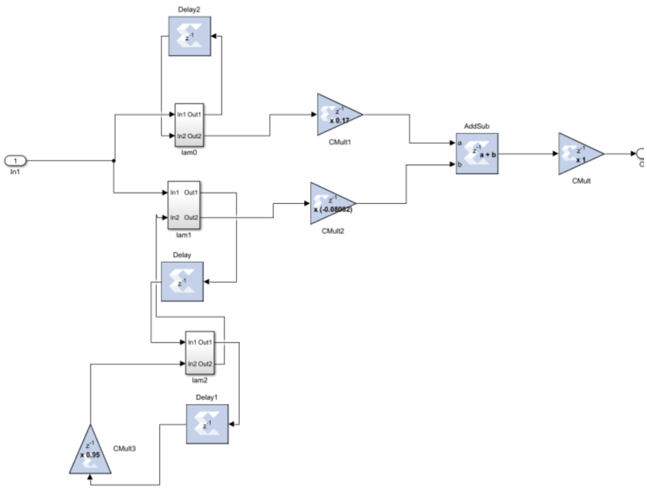

Fig 4. Fractional Integrator

The CSA-based fractional integrator provides better performance when compared with the prevailing techniques with less computation time. the proposed fractional differentiator and integrator realized using LWDF only require 20 adders, eight multipliers, and six delay elements[5].

E. Fractional Differentiator

The projected fractional differentiator realized using LWDF solely need twenty adders, eight multipliers, and six delay components .

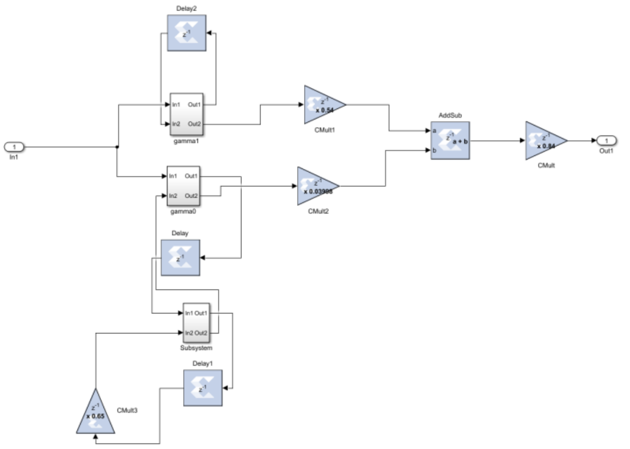

Fig 5. Fractional Differentiator

The fractional equation for Fractional Differentiator is given in equation (8). The QRS complicated looks abnormal with big amplitudes and prolonged durations. Signal parameters like amplitude, width, and QRS energy are important to comprehend consistent performance, thereby creating it imperative to square the signals purpose by purpose following the differentiation stage.

$$H_1(z) = \frac{-0.5034+1.9441z^{-1}-1.9441z^{-2}+0.5034z^{-3}}{1-1.1737z^{-1}+0.2982z^{-2}+0.0245z^{-3}} \quad (8)$$

This method strengthens the slope of the frequency response curve of the derivative.

V. Simlulation Results and Discussions

A. Lattice wave digital Filter Design

LDWF consists of two all-pass filters, which are mainly implemented with the help of delay elements and two port adapters[15].Lattice Wave Digital Filters (LWDFs) are famed to be insensitive to finite accurate arithmetic effects and might be designed for standard filtering applications employing a set of explicit formulas.The implemented Fractional operator based ECG detector is shown in Fig5.1. The block implies the connections between the elements such as integrator, differentiator, math function, moving average and the scope window[8].

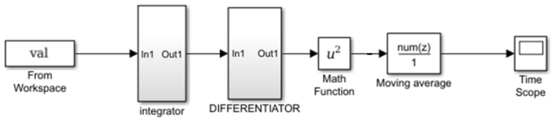

Fig.6. Lattice wave digital filter

LWDFs are most commonly used for the realization of IIR systems due to its valuable properties such as decrease sensitive to coefficient variation, needed less word-length, free from overflow and round-off conditions, highly modular, guarantee stability for implementation, and less hardware necessity. LDWF consists of two all-pass filters, which are mainly implemented with the help of delay elements and two port adapters.[8]. A two-port adapter requires one multiplier and three adder circuits. The requirement of less number of a multiplier circuit in LWDF structure realization makes it the most useful for efficient implementation of IIR system of predefined order

B. Implementation of ECG Detector

The output waveforms for nearly 10 samples of ECG signal taken from the MIT-BIH Arrhythmia database were obtained. The input given is from the QT Database for 10ns and the next waveform is obtained from derivative filter where the amplitude is reduces in order to reduce the noise too. Third waveform is obtained from squaring the signal for which only peaks are squared so that it is easy to locate the peaks[17].

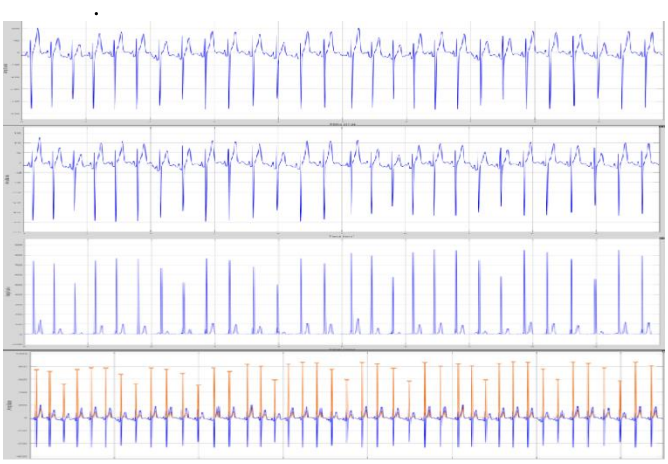

Fig7.QRS Peak detector waveforms A.Input waveform from QT database B. Output of Derivative C. Output of squaring D. Peak detector output

The wave thus obtained detects the R peak which is very important in detection of proper functioning of heart. Once the ECG detector is designed for pacemaker it is classified based on the peaks and intervals and then followed to the telemetry circuit and V&I Reference generator. Similar to the above Fig 7, can also give n number of samples.

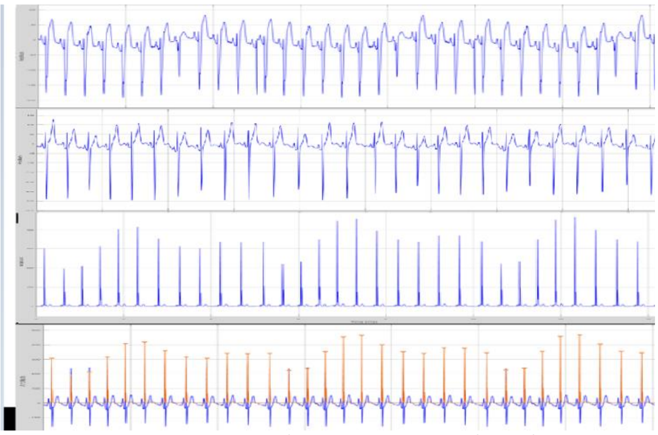

Fig8.QRS Peak detector waveforms A.Input waveform from Apnea database B. Output of Derivative C. Output of squaring D. Peak detector output

From the above Fig.8 the input wave is taken from the Apnea Database. Apnea database comprises of expert-labelled apnea annotations and machine-generated QRS annotations. After passing through the derivative filter the noises are suppressed and it is passed to the squaring. The peak finder finds and located the peaks[17]. Similarly, Different databases haven been considered and corresponding waves were obtained by getting through the blocks.

C. *Performance Parameters*

The performance parameters for the ECG detector such as sensitivity (Se), predictivity (P+) and Detection Error Rate (DER) for different samples of ECG signal are calculated and tabulated [12].

Sensitivity (Se) is given as follows

$$Se = \frac{TP}{TP + FN} \% \quad (9)$$

Where TP is the true positive which represents the number of correctly detected QRS complexes and FN is the false negative which denotes the number of missed detections.

Positive predictivity (P+) is given as follows

$$P+ = \frac{TP}{TP + FP} \% \quad (10)$$

Where FP is the false positive which denotes the detection of false QRS complexes.

Detection Error Rate (DER) is calculated using

$$DER = \frac{FP+FN}{\text{Total Number of QRS Complexes}} \% \quad (11)$$

TABLE I. PERFORMANCE PARAMETER OF THE PIPELINED FILTER BASED ECG DETECTOR FOR DIFFERENT SAMPLES OF ECG SIGNAL USING 10 SECOND MIT-BIH DATABASE

ECG Signal	Total (beats)	TP (beats)	FN (beats)	FP (beats)	Se (%)	P+ (%)	DER (%)
100	13	0	0	0	100	100	0
101	13	13	0	1	100	92.85	0.07
102	12	11	1	0	91.66	100	0.08
103	14	13	1	1	92.85	92.85	0.24
104	13	13	0	0	100	100	0
105	11	11	0	1	100	94.85	0.07
106	13	12	1	0	92.30	100	0.07
107	12	11	1	0	91.76	100	0.08
108	11	11	0	0	100	100	0
109	14	14	0	1	100	92.65	0.06
Total	126	122	5	5	96.84	97.14	0.07

Thus a sensitivity of 99.83%, positive predicitivity of

IMPLEMENTATION	Slice LUTs (Out of 53200)	Slice Flip Flops (Out of 106400)	Slice DSPs (Out of 220)	Slice IOs (Out of 200)	Slice LUT RAMs (Out of 17400)	Overall percent of resource used (%)
Conventional Pipelined FIR Filter	188	147	0	33	48	22.12
Proposed Lattice wave filter	100	105	1	33	48	17.08
Total Area Saved in (%)						22.78

99.44% and Detection Error Rate (DER) of 0.16% is achieved using the pipelined filter based ECG detector circuit for 1minute MIT-BIH Database.

D.Resource Utilization of ECG Detector

The system created in system generator is converted to HDL netlist.The sum of hardware consumption using fractional operator made comparison with the conventional bandpass detector and is shown in the successive Table II

TABLE II. COMPARISON OF RESOURCE UTILIZATION OF FILTER STRUCTURE REALIZATIONS

The power consumed by the system using pipelined filter structure is shown in Fig 9.

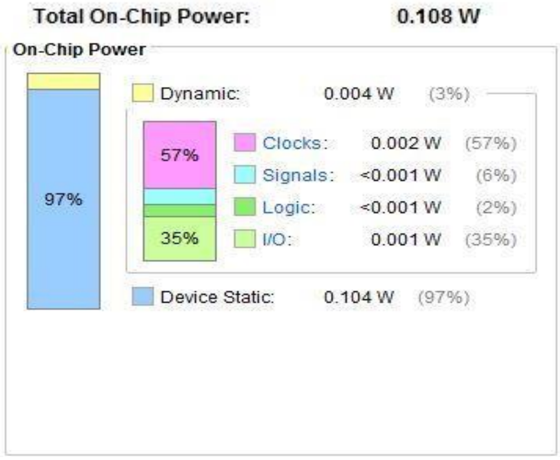

Fig.9. Power consumed by the system using pipelined filter structure

The power consumed by the system using Lattice wave filterstructure is shown in table

TABLE III. COMPARISON OF POWER UTILIZATION OF FILTER STRUCTURE REALIZATIONS

S.no T	TYPE OF REALIZATION	POWER CONSUMED BY ADDERS	POWER CONSUMED BY MULTIPLIERS
1	Lattice Wave	320 **µW**	2688 **Mw**
2	Linear Structure	190.8 **µW**	4032 **Mw**
3	Direct Form	190.8 **µW**	4704 **µW**

hus it can be seen that a total area of 22.78% is saved using the proposed technique. The total on chip power of the proposed circuit using lattice filter structure is only upto micro W.

E.Comparison of Proposed Architecture with Existing Method

The comparison of total hardwares used between the proposed method and the existing method is shown in TABLE IV.

TABLE IV. COMPARISON OF HARDWARES BETWEEN PROPOSED ARCHITECTURE AND EXISTING METHOD

HARDWARES USED	CONVENTIONAL ECG DETECTOR(Direct Form)	MODIFIED ECG DETECTOR (LATTICE WAVE DIGITAL FILTER)
Adder	12	20
Multiplier	12	8

VI. Conclusion

The area and power efficient Electrocardiogram detector are modeled and its efficiency is analyzed and compared with previous techniques. In the conventional modeled ECG detector circuits Band Pass Filters are employed. In addition, noise detectors are also used. The power and area of the conventional methodology of using band-pass filters for denoising is high as compared to the proposed methodology because of reduction in multipliers. The power of any device depends on multipliers too as the contribution of power by multiplier is very high. The proposed approach is the design of Lattice Wave Digital Filter that comprises of Fractional Differentiator and integrator based on Gruenwald-Letnikov approach and Cuckoo-search Algorithm. The use of LWDF decreases the multiplier count for structural realization. Thus, the hardware required and power consumption is reduced further. The project can be extended with many samples. Also, the area can be made minimal by applying folding architecture or any VLSI signal processing area minimalization techniques. The VLSI signal processing is the demand domain where we can innovate many things and produce efficient and new innovations furthermore. Further, the work has been extended to approximation to detect various arrhythmia and noisy input conditions. Further to compute the QRS complex, the Q and S points based on the R-peaks are detected.

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