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FPGA Based ECG Signal Noise Suppression

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ABSTRACT:This paper shows FPGA implementation for noise suppression of electrocardiograph signals (ECG). The recorded ECG signal is taken from MIT-BIH Database with sampling frequency 360 samples/sec. This work has used two modified median filters with size of 91 sample points and 7 sample points respectively. Then median filtered signal is subtracted from original ECG Signal. For FPGA implementation Verilog HDL is used. This implementation good enhancement of QRS complex, P wave and T wave compared to traditional median filter technique. Also it removes baseline wondering.

KEYWORDS:FPGA, Verilog HDL, QRS complex, MIT-BIH

I.INTRODUCTION

An ECG signal has very much significance in biomedical field to reflect the health status of cardiovascular system [1]. Electrocardiography is a transthoracic interpretation of the electrical activity of the heart over a period of time, as detected by electrodes attached to the outer surface of the skin and recorded by a device external to the body [2].Most of the diseases are caused by improper functioning of heart, e.g. Arrhythmia. The extraction of QRS complex without noise is important task. Before analyzing any ECG signal it must be filtered. For filtration of ECG signal the information of exact frequency band of QRS complex is must but various people have taken various bands for detecting QRS complex [3]. Use of bandpass filter gives good result for large band only but it is not deserved because large bands have many unwanted frequency component. For small band the shape of QRS is changed by bandpass filter.

This work gives technique which is not based on frequency band. This is using the technique of spike removal technique used in audio signal processing. The largest spike in ECG signal is QRS. The window of median filter is set in such way that QRS complex will be totally removed. Then this median filtered signal is subtracted from original ECG signal. It restores original QRS complex and enhances QRS complex also it removes baseline wondering. Previously same work is done in MATLAB tool but this work has observed better results in Verilog implementation with modification in the style of median filter [1]. It reduces window size of median filter. Hence the memory requirement is reduced. Median filter is very much efficient in impulse removing [4] these impulses are nothing but high frequency noise for which second median filter is used.

Now a days VLSI technology is being prominent over analog based technologies due to their small size. VLSI technology can be applied by two types of design methods. Which are frontend design and backend design method. In front end design digital circuits are implemented using hardware description languages (HDL). Backend design is done by schematic, layout design. In this work frontend method is used because it is very flexible due to programmability in FPGA. That means once used FPGA for one application can be reused by burning another code in it. Also these designs are implemented in very short span of time. This is the beauty of this method. But in other hand there is backend design which takes lot off investment of money, investment of time, inspections, clean room etc. This work has implemented on Xilinx's Spartan 3E FPGA Board.

II.THEORETICAL FRAMEWORK

This design consists of four blocks as shown in Fig. 1.

A. 1st stage Median Filter
B. Subtraction Block
C. 2nd stage Median Filter
D. Averaging Filters

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The block diagram for this work is

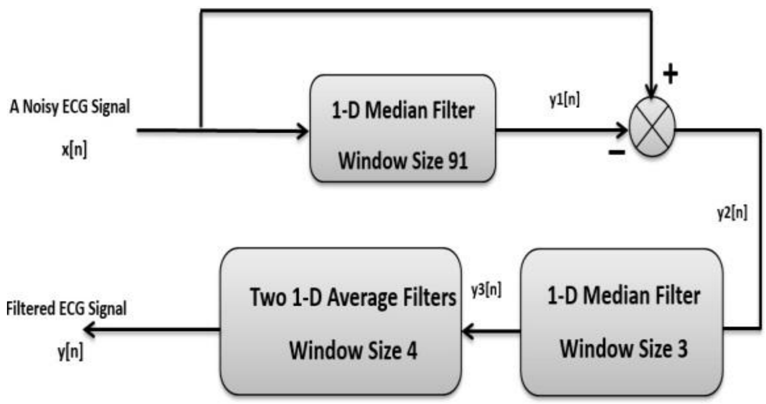

Fig. 1 Block Diagram for ECG filtering

A. 1st stage 1-D Median Filter (Window Size 91)

This work has used input ECG signal from MIT-BIH Database. This is signals are sampled at 360 samples/sec. As mentioned earlier, this work is using the spike removal technique used in audio signal processing. In audio signal processing unwanted spikes are removed by using median filter. The window of median filter is decided as per the width of spike.

The largest spike in ECG signal is QRS complex. The width of median filter is decided according to the width of QRS complex as well as width of P and T waves, so that it will be removed after 1st stage of median filter.

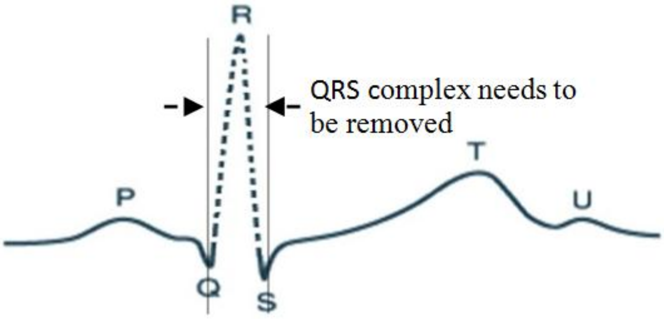

Fig.2 QRS complex needs to be removed

The output of 1st stage median filter is calculated as follows

- Design memory unit with size N.
- Store all previous input samples in memory unit.
- Arrange all memory elements in ascending or descending order.

$$y1[n] = median\{x[n], x[n-1], \dots\dots\dots, x[n-N]\}$$

Where N is the width of median filter. Here N is 91.

- Then mid value is assigned to output.
  If N is odd then

$$y1[n] = x\left[n - \frac{N-1}{2}\right]$$

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If N is even then

$$y1[n] = \frac{1}{2}\left(x\left[n - \frac{N}{2}\right] + x\left[(n+1) - \frac{N}{2}\right]\right)$$

Fig. 2 Shows the QRS complex need to be removed using median filter.

Fig. 3After applying median filter.

Fig. 3 shows result of median filter, which shows it has removed the portion of QRS complex, P wave and T wave. It is nothing but detection of baseline of ECG signal. If this is subtracted from original signal then baseline wondering will be removed.

B. Subtraction

Here the median filtered signal is subtracted from original signal [1]. This is done for retrieval of QRS complex, P and T waves. This will reduce noise associated with signal and will remove baseline wondering [1]. Therefore there is no need of separate baseline wondering removal. In first stage QRS complex is clipped as shown in Fig. 3.Therefore after subtraction there will not be distortion of QRS Complex, it will remain as it is.
Actual substraction method

$$y2[n] = x\left[n - \frac{N}{2}\right] - y1[n]$$

This work subtraction method

$$y2[n] = x[n] - y1[n]$$

This is the modification of this method. In traditional median filtering technique to find mid value previous and next sampling points are considered. Therefore it gives delay of half of window size of sampling points in output. It is not real time system. For large window size like 500 sampling points there will be delay of 250 sampling points, which is quite large. But this work does not have to wait for next sampling points it considers all previous sampling points for window of median filter then subtract present sampling point from mid value of median filtered signal. This give good result for reduced window size. Also it enhances P and T waves which have very large width size. To have good result using actual method there is need of large width of median filter. Then also it does not enhances QRS complex, P, and T waves as compared to this work.

C. 2^{nd} stage Median Filter (Window Size 3)

The second median filter is used to reduce the high frequency noise associated with ECG signal. This work has used window size 3, so that it will reduce small spikes associated signal whose width is 1 sample. This can also reduce spikes of width more than 1 sample and less than width of QRS complex by increasing size of 2^{nd} median filter.
The output of 2^{rd} stage median filter is calculated as follows

- Design memory unit with size 3.
- Store all previous input samples in memory unit.
- Arrange all memory elements in ascending or descending order.

$$y3[n] = median\{y2[n], y2[n-1], y2[n-2]\}$$

- Then mid value is assigned to output.

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$$\text{Hence,} y3[n] = y2[n-1]$$

D. Averaging Filters (Window Size 4)

This block is optional, but this work has added it to have smoothened result. The size of this filter can be varied, as per our need. This is simple FIR filter. This work has used two averaging filters with window size 4. Hence the total window size is 8. But it is observed by practical experience if two 4 point averaging filters are used instead of direct 8 point single averaging filter, it gives good result.
The output of average filter is as follows

$$y[n] = \frac{1}{M}(y3[n], y3[n-1], y3[n-2], \ldots \ldots \ldots \ldots, y3[n-M])$$

Where M is width of averaging filter.
Here M is 4.

III.SNR CALCULATION

The SNR (signal to noise ratio) is defined as the ratio of signal power to noise power. For any other signals SNR should be positive but in case of ECG, SNR should be negative. The more negative SNR the more noise free ECG signal.
The SNR (Signal to Noise ratio) is calculated as follows [1].

$$SNR = \frac{\sum_{n=0}^{N-1}[y[n]]^2}{\sum_{n=0}^{N-1}[x[n]-y[n]]^2}$$

Where $\sum_{n=0}^{N-1}[y[n]]^2$ and $\sum_{n=0}^{N-1}[x[n]-y[n]]^2$ power of signal and power of noise respectively.
Where N is number of sampling points in ECG signal.
Large SNR means high capability of rejection of noise.

IV.RESULTS AND COMPARISON

Section II gives all theoretical understanding of this work. Fig. 4 and and Fig. 5 are the results of actual work.

Fig. 4: Waveform for this work (analog mode).

Fig. 4 is nothing but the result of this work mentioned in section II. This figure shows three ECG signals. The first signal ‘x’ shows the input ECG signal. This input ECG is 123.dat file from MIT-BIH database. Input signal shows P wave, T wave and QRS complex. The second ECG signal ‘y’ in Fig. 4 is output after 2nd stage median filter. Finally third ECG signal ‘yaveraged’ shows the final output after averaging filters.

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Fig. 5: Waveform for traditional median filter based system (analog mode)

Fig. 5 also have three ECG signals as similar as Fig. 4. Fig. 5 does not represent this work but it represents the waveform of noise removal system using traditional median filter method which is also mentioned in section II and in reference [1]. Both are implemented in Questasim (Verilog Implementation). The previous works are done using MATLAB with traditional method of median filter but this work has implemented by using Verilog language in FPGA using proposed method in section II.

Table 1: Comparison with previous work

	Sampling Rate (Samples/Sec)	1st stage Median Filter width	2nd stage Median Filter width
Previous Work [1]	1000	501	21
This Work	360	91	7

If the block diagram mentioned in fig.1 is implemented with the help of traditional median filtering technique, explained in section II, then for good results there is need of large window size of 1st stage median filter. This work has reduced this window size by considering all previous sampling points for median instead of previous and next sampling points which are used in traditional method. Due to the consideration of next sampling points traditional method gives delay of half of the width of 1st stage median filter. This can be say this is not real time system. This work gives real time filtering technique and reduced window size, as shown in table 1. Table 1 shows previous work used 1000 samples/ sec sampling rate and this work has used 360 samples/ sec sampling rate. The sampling rate of previous work is 2.777 times greater than this work. Therefore expected window width for traditional method in this work is 2.777 times smaller than previous, which is 180 sampling points. This can be say that the window size used for this work is half of actual width. It shows reduction in memory required to store previous sampling points.

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Table 2: PQRST amplitude comparisons between traditional method and this work

QRS Complex	Waves	Original Signal Amplitudes (mv)	Traditional Median Filtering Technique Amplitudes (mv)	This Work Filtering Technique Amplitudes (mv)
1st	P wave	-0.775	0.205	0.225
	Q wave	-1.00	0.030	0.00
	R wave	1.125	1.915	1.95
	S Wave	-1.800	-0.580	-0.775
	T Wave	-0.575	0.280	0.400
2nd	P wave	-0.725	0.215	0.225
	Q wave	-0.925	0.000	0.050
	R wave	1.325	2.075	2.15
	S Wave	-1.700	-0.415	-0.700
	T Wave	-0.425	0.315	0.475
3rd	P wave	-0.675	0.215	0.225
	Q wave	-0.875	0.001	0.000
	R wave	1.325	1.930	2.075
	S Wave	-1.650	-0.465	-0.700
	T Wave	-0.425	0.305	0.450

Table 2 shows the comparison of amplitudes of PQRST points between traditional method and this work method. This can be say that there are improvements in the amplitudes of PQRST points by this work compared to previous work.

Table 3: SNR comparison between traditional method and this work

Work	SNR
Traditional Method	-9.7469 dB
This Work	-10.330 dB

Table 3 shows SNR results obtained for traditional method and this work. The calculation of SNR is discussed in section III. This table shows good SNR is obtained by this work compared to traditional method.
Also this work has used extra averaging filter which gives smoothening effect for ECG signal.

VI.CONCLUSION

Thus the results and comparison indicates the method used to remove ECG noise is more efficient than the traditional median filter method. Also, the implantation of this work on FPGA is easier. The based on FPGA's are more flexible than ASIC due their reprogramability i.e. in future also the design can be modified with very short span of time as compared to ASIC based design.

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