FPGA Based Design and Implementation of ECG Feature Extraction

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ABSTRACT

FPGAs (Field Programmable Gate Arrays) are finding wide acceptance in medical systems for their ability for rapid prototyping of a concept that requires hardware/software co-design, for performing custom processing in parallel at high data rates and be programmed in the field after manufacturing. The main tasks in ECG signal analysis are the detection of how fast heart is beating, whether the rhythm of heartbeat is steady or irregular and the strength and timing of electrical signals as they pass through each part of the heart. This project attempts at implementing ECG heart-rate computation in MATLAB and FPGA both. ECG feature extraction system is based on Pan Tompkins’s algorithm for preprocessing of signal and QRS detection. The performance of algorithm will test against MATLAB routine and validated results based on the MITBIH arrhythmia database (which has been annotated by cardiologists) and ECG database created by using ECG machine HIC 2000, Bioimpedance Ltd. Design and implementation of ECG feature extraction using VHDL for FPGA based system.

Index Terms: ECG signal, FPGA, MITBIH, Pan Tompkins’s algorithm, VHDL

I. INTRODUCTION

An electrocardiogram is a graphical representation of the small electric waves being generated during heart activity. [1]. It provides information about the heart rate, rhythm, and morphology. Fig.1 shows the basic shape of a healthy ECG heartbeat signal with P, Q, R, S, T and U characteristics and the standard ECG intervals QT interval, ST interval and PR interval [1] [3].

The ECG is distinguished by a recurrent wave sequence of P, QRS, T and U wave associated with each beat. The QRS complex is the most extreme waveform, caused by ventricular depolarization of the human
heart. A typical ECG wave of a normal heartbeat consists of a P wave, R peak (i.e. QRS complex), and a T wave [4].

In fact, R peak (heart beat detection) is necessary to determine the heart rate, and several related arrhythmias such as Tachycardia, Bradycardia and Heart Rate Variation; it is also necessary for further processing of the signal in order to detect abnormal beats [4] [7]. The QT interval represents electrical depolarization and repolarization of the ventricles. A lengthened QT interval is a marker for the potential of ventricular tachyarrhythmias like torsades de pointes and a risk factor for sudden death.

ECG signal analysis was previously based on only time domain method. But this is not sufficient way to study all the features of ECG signal. To overcome this, FFT (Fast Fourier Transform) technique was applied. But the FFT is failed to provide the information regarding the exact location of frequency components in time. While the STFT (Short Time Fourier Transform) compromise between time and frequency information, the drawback is that it use in particular window that window frequency is same for all time. Several algorithms suggested in literature [1] [5] [6].

II. ECG SIGNAL DATABASE

ECG signals required for analysis are collected from ECG machine no. HIC 2000, Bioimpedance. Ltd. ECG was extracted from impedance signal recorded using two electrodes. One electrode placed on neck suprasternal notch and second electrode placed at the level of xiphoidal on the left side of the thorax. Output of the ECG machine is in analog format so we converted analog into digital using DAQ card. Then saved this signal into .mat file.

III. METHODOLOGY

The raw ECG signal may contain different type of noises, so ECG signal should be processed. There are mainly two parts for ECG signal Feature extraction. First is preprocessing and second one is feature extraction[1][7]. Detail structure of ECG Signal Processing shown in Fig 2.

Preprocessing

ECG signal contains noises due to baseline drift, frequency interference, polarization noise, electrode contact first page footnote as an example. Muscle noise, internal amplifier noise. In most of The ECG recordings the respiration, electrode impedance change and increase body movements creates baseline drift. The common problem in ECG signal processing is base line drift removal and noise suppression [1] [4] [7] [9].
Figure 2: Structure of ECG Signal Processing [7].

The simple waveform without preprocessing shown in Figure 3.

Figure 3: 1) Sample ECG4.dat signal from MITBIH database (2) ECG4.dat signal for 1-3 seconds.

A. Removal Of The Baseline Drift

Baseline wandering is the noise artifacts that affect ECG signals. Removal of baseline drift is therefore required in the analysis of the ECG signal to minimize the changes in beat morphology with no physiological counterpart. Respiration and electrode impedance changes due to perspiration are important sources of baseline wander in most types of ECG recordings. The frequency content of the baseline wander is usually in a range well below 0.5Hz. This baseline drift can be eliminated without changing or disturbing the characteristics of the waveform. For the elimination base line drift we are used normalization of sample value from -1 to 1 value [1] [7].

Output after the removal of baseline drift is shown in Figure 4.
B. Removal Of Noise

After removal of baseline drift the ECG signal is stationary and contains some noise. To reduce the noise number of techniques digital filters, adaptive filtering methods. We use Band pass filter to noise rejection. For our chosen sample rate we could not use band pass filter directly, for the desired pass band 5-15 Hz using the specialized designed technique. Therefore we cascade the low pass and high pass filter to achieve 3 dB pass band from about 5-12 Hz [1]. We use second order low pass filter and the design of high pass filter is based on subtracting the output of first order low pass filter from an all pass filter.

\[
H(z) = \frac{1 - z^{-2}}{(1 - z^{-1} + z^{-2})^2}
\]

Output after LPF and HPF shown in Figure 5 and Figure 6 respectively.

Feature Extraction of ECG signals using MATLAB

The purpose feature extraction process is to retain information from original ECG signal. Figure 4 shows the general block diagram for ECG feature extraction.

First we detect the R peak i.e. QRS complex which is the highest amplitude in the ECG signal. Then Q and S waves are detected. Then detected two zero crossing of the signal before the Q and after the S waves are selected. And at last P and T waves are detected.

QRS detection [1]
After the band pass filter the output is given to differentiator.

After the signal has been filtered; it is then differentiated to provide information about the slope of the QRS complex. A five-point derivative has the transfer function

$$H(z) = 0.1 \left( 2 + z^{-1} - z^{-3} - 2z^{-4} \right)$$

This derivative is implemented with the difference equation

$$y(nT) = 2x(nT) + x(nT - T) - x(nT - 3T) - 2x(nT - 4T) / 8$$

Squaring Operation: The squaring function that the signal now passes through is a nonlinear operation. The equation that implements this operation is

$$y(nT) = [x(nT)]^2$$

This operation makes all data points in the processed signal positive, and it amplifies the output of the derivative process nonlinearly. It emphasizes the higher frequencies in the signal, which are mainly due to the QRS complex [9].

$$y(nT) = 1/N \left[ x(nT - (N - 1)T) + x(nT - (N - 2)T) + \ldots + x(nT) \right]$$

Where $N$ is the number of samples in the width of the moving window.

The only peak of the R wave is not a good way to detect a QRS event. Many abnormal QRS intervals also having large amplitudes and long durations might not be detected using information about peak of the R wave only. So, we need to extract more information from the signal to detect a QRS complex. Moving window integration extracts features in addition to the peak of the R wave [9].

Signal peaks are defined as those of the QRS complex, while noise peaks are those of the T waves, muscle noise, etc. After the ECG signal has passed through the band pass filter stages, its signal-to-noise ratio increases. This permits the use of thresholds that are just above the noise peak levels. Thus, the overall sensitivity of the detector improves [9].

Then we use Search back technique. To implement the search back technique, this algorithm maintains two RR-interval averages.

**Feature Extraction of ECG signals Using FPGA**
Details of methodology

- MATLAB will send the data serially to the FPGA. The serial data is the database data in binary format.
- Serial protocol is been implemented on FPGA. we used Serial communication techniques
- The serially received data will be stored in RAM.
- Feature extractions from the database i.e. RAM.
- Feature will be stored in new RAM
- The data i.e. send by MATLAB is again been transmitted back by FPGA.
- After the successful transmission, the peak values calculated in new RAM.
- Then after detecting the peaks of waveforms it will send the heart rate value in PC.

IV. RESULTS

MATLAB and its wavelet toolbox is used for ECG signal processing and analysis. ECG signal of one of volunteer age 30.
From the detection of RR interval or QRS complex we make calculation of heart rate. Like for 3 seconds 4 RR interval then for 60 seconds it is how much is the Heart Rate using MATLAB itself. From that data we conclude patient is normal or not.

Table -1: Comparison of final outputs

<table>
<thead>
<tr>
<th>Volunteer No.</th>
<th>Heart beat manually</th>
<th>Heart beat MATLAB</th>
<th>FPGA</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECG.1</td>
<td>73</td>
<td>72</td>
<td>72</td>
</tr>
<tr>
<td>ECG.2</td>
<td>94</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td>ECG 3</td>
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<td>135</td>
<td>135</td>
</tr>
<tr>
<td>ECG 4</td>
<td>54</td>
<td>54</td>
<td>54</td>
</tr>
</tbody>
</table>
V. CONCLUSIONS

An algorithm for R Peak and QRS complex detection using Pan Tompkins technique has been developed. The information about the R Peak and QRS complex obtained is very useful for ECG Classification, Analysis, Diagnosis Authentication and Identification performance. The QRS complex is also used for beat detection and the determination of heart rate through R-R interval estimation. The main advantage of this kind of detection is less time consuming for long time ECG signal. Comparing MATLAB output to FPGA output all values of heart rate is same. To implement the QRS detection algorithm by using FPGA so is occupies less area and low power.

VI. REFERENCES


