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ELECTROCARDIOGRAM (ECG) SIGNAL PROCESSING ON FPGA FOR EMERGING HEALTHCARE APPLICATIONS

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ELECTROCARDIOGRAM (ECG) SIGNAL PROCESSING ON FPGA FOR EMERGING HEALTHCARE APPLICATIONS

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Abstract - In this project an ECG signal processing module will be implemented in VHDL on FPGA platform. The digital filtering will be carried out with low pass FIR architecture. Filters shall filter the 50 Hz coupled noise and other high frequency noises. The filtered signal is subjected to Short Time Fourier transform by which lot of inferences can be made by medical experts. A recorded ECG signal will be used as test input to test the modules implemented on FPGA. The Modelsim Xilinx Edition and Xilinx Integrated Software Environment will be used simulation and synthesis respectively. The Xilinx Chipscope tool will be used to test the results, while the logic running on FPGA. The Xilinx Spartan 3 Family FPGA development board will be used this project.

Keywords- *FPGA; FIR; STFT; VHDL*

1. INTRODUCTION

At present, cardiovascular disease has become a threat to human life and health of the major diseases, and morbidity increases year by year. The prevalence rate of cardiovascular disease, morbidity and mortality also showed an upward trend continued, the death toll of about 40% of the number of deaths, therefore, focused on the prediction of cardiovascular disease diagnosis and prevention is an important significance. With the development of digital signal processing technology, FIR filters are realized by single-chip, DSP, programmable logic devices. Compared to the FPGA, single-chip is not flexible enough, and the DSP can be flexible, although more slowly, so using FPGA realizing FIR digital filter has the characteristic of the real-time, high flexibility, faster processing speed and small volume production of low cost. Although, the digital filter signal processing in dealing with ECG occupy a larger location, the use of neural networks can achieve a good filtering effect, but need for a reference input, ECG signals cannot be updated at the same time , and in the hardware it is difficult to achieve; in the MCU and DSP as the main controller, its filtering is completed in the hardware, which is a portable ECG monitoring has increased the burden of hardware circuits; the former FPGA limited by internal resources, can only be limited to filter the 50HZ frequency interference. In view of this, the portable ECG monitor both reduce the hardware circuits and get the better ECG signal, this paper proposes the use of both 50HZ in FPGA filtering and 0.05 ~ 100Hz band-pass filtering of the double filtering.

2 .ELECTROCARDIOGRAM

An electrocardiogram (ECG) is a test that checks for problems with the electrical activity of your heart. An ECG translates the heart's electrical activity into line tracings on paper. The spikes and dips in the line tracings are called waves. See a picture of the ECG components and intervals.

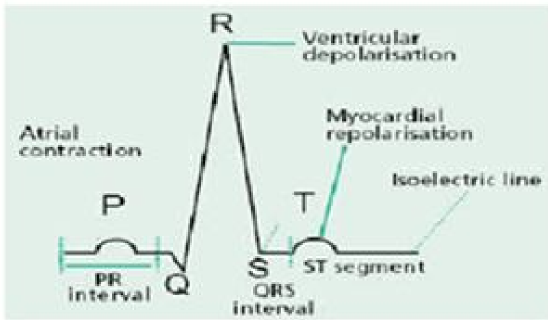

Fig.1 ECG signal characteristics

The heart is a muscular pump made up of four chambers. The two upper chambers are called atria, and the two lower chambers are called ventricles. A natural electrical system causes the heart muscle to contract and pump blood through the heart to the lungs and the rest of the body.

3. PROJECT GOALS

(i) Analysis of collected ECG signals which include narrow band and wideband noise interference to enhance the filtering effect.
(ii) ECG Signal Processing based on FPGA to improve ECG monitoring system performance, and to contribute to the judgment of the ECG's diagnostic accuracy.

4. EXISTING METHOD

The earlier method of ECG signal analysis was based on time domain method. But this is not always sufficient to study all the features of ECG signals. So, the frequency representation of a signal is required.

To accomplish this, FFT (Fast Fourier Transform) technique is applied. But the unavoidable limitation of this FFT is that the technique failed to provide the information regarding the exact location of frequency components in time. As the frequency content of the ECG Signal Analysis Using Wavelet Transforms ECG varies in time, the need for an accurate description of the ECG frequency contents according to their location in time is essential. This justifies the use of time frequency representation in quantitative electro cardiology.

5. PROPOSED METHOD

To overcome the draw backs of FFT, the immediate tool available for this purpose is the Short Term Fourier Transform (STFT). But the major draw-back of this STFT is that its time frequency precision is not optimal. Hence we opt a more suitable technique to overcome this drawback. Among the various time frequency transformations the wavelet transformation is found to be simple and more valuable. The wavelet transformation is based on a set of analyzing wavelets allowing the decomposition of ECG signal in a set of coefficients. Each analyzing wavelet has its own time duration, time location and frequency band. The wavelet coefficient resulting from the wavelet transformation corresponds to a measurement of the ECG components in this time segment and frequency band.

6. THEORY

The ECG records the electrical activity of the heart, where each heart beat is displayed as a series of electrical waves characterized by peaks and valleys. Any ECG gives two kinds of information. One, the duration of the electrical wave crossing the heart which in turn decides whether the electrical activity is normal or slow or irregular and the second is the amount of electrical activity passing through the heart muscle which enables to find whether the parts of the heart are too large or overworked. Normally, the frequency range of an ECG signal is of 0.05–100 Hz and its dynamic range of 1–10 mV. The ECG signal is characterized by five peaks and valleys labelled by the letters P, Q, R, S, T. In some cases we also use another peak called U. The performance of ECG analyzing system depends mainly on the accurate and reliable detection of the QRS complex, as well as T- and P- waves. The P-wave represents the activation of the upper chambers of the heart, the atria, while the QRS complex and T-wave represent the excitation of the ventricles or the lower chamber of the heart. The detection of the QRS complex is the most important task in automatic ECG signal analysis. Once the QRS complex has been identified a more detailed examination of ECG signal including the heart rate, the ST segment *etc.* can be performed. In the normal sinus rhythm (normal state of the heart) the P-R interval is in the range of 0.12 to 0.2 seconds. The QRS interval is from 0.04 to 0.12 seconds. The Q-T interval is less than 0.42 seconds and the normal rate of the heart is from 60 to 100 beats per minute. So, from the recorded shape of the ECG, we can say whether the heart activity is normal or abnormal. The electrocardiogram is a graphic recording or display of the time variant voltages produced by the myocardium during the cardiac cycle. The P-, QRS- and T-waves reflect the rhythmic electrical depolarization and repolarisation of the myocardium associated with the contractions of the atria and ventricles. This ECG is used clinically in diagnosing various abnormalities and conditions associated with the heart. The normal value of heart beat lies in the range of 60 to 100 beats/minute. A slower rate than this is called bradycardia (Slow heart) and a higher rate is called tachycardia (Fast heart). If the cycles are not evenly spaced, an arrhythmia may be indicated. If the P-R interval is greater than 0.2 seconds, it may suggest blockage of the AV node.

7. PITFALLS

• Certain disorders, involving heart valves cannot be diagnosed from ECG. Other diagnostic techniques such as angiography and echocardiography can provide information not available in ECG.

• Each action potential in the heart originates near the top of the right atrium at a point called the pacemaker or sinoatrial (SA) node.

• The wave generated by action potential, terminates at a point near the center of the heart, called the atrioventricular (AV) node.

The horizontal segment of this waveform preceding the P-wave is designated as the baseline or the isopotential line. The P-wave represents depolarization of the atrial musculature. The QRS complex is the combined result of the repolarization of the atria and depolarization of the ventricles, which occur almost simultaneously. The T-wave is the wave of ventricular repolarization, where as the U-wave, if present is generally believed to be the result of after potentials in the ventricular muscle. So, the duration amplitude and morphology of the QRS complex is useful in diagnosing cardiac arrhythmias, conduction abnormalities, ventricular hypertrophy, myocardial infection and other disease states.

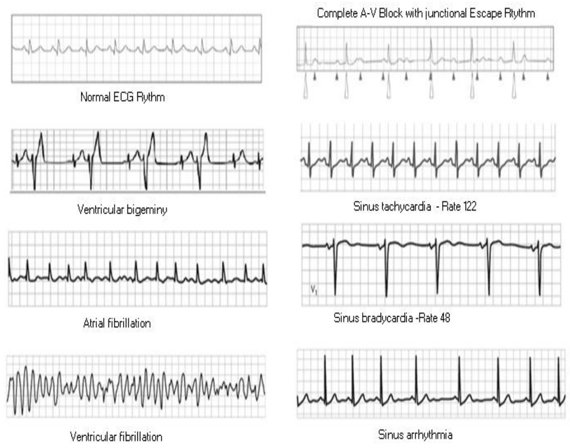

Fig.2 Cardiovascular diseases diagnostic graphs

Table . Various abnormalities and their characteristic features

S. No.	Name of abnormality	Characteristic features
1	Dextrocardia	Inverted P-wave
2	Tachycardia	R-R interval < 0.6 s
3	Bradycardia	R-R interval > 1 s
4	Hyperkalemia	Tall T-wave and absence of P-wave
5	Myocardial ischaemia	Inverted T-wave
6	Hypercalcaemia	QRS interval < 0.1 s
7	Sinoatrial block	Complete drop out of a cardiac cycle
8	Sudden cardiac death	Irregular ECG

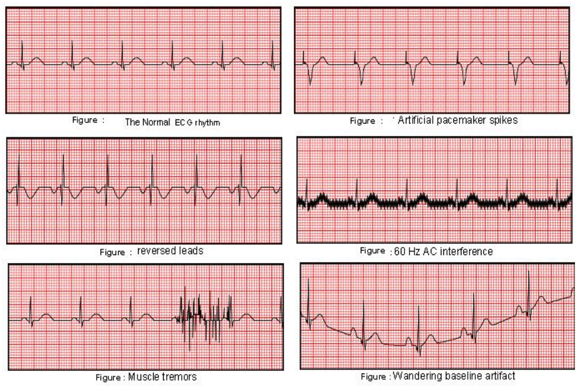

Fig.3 Interference of various noises on ECG signal

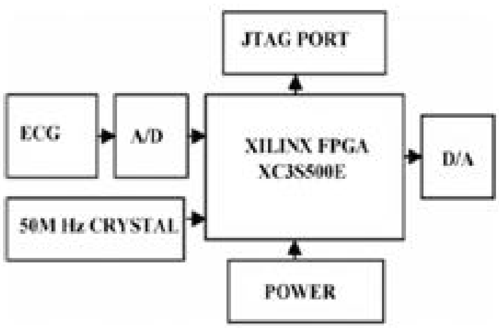

Fig.4 FPGA system overall schematic

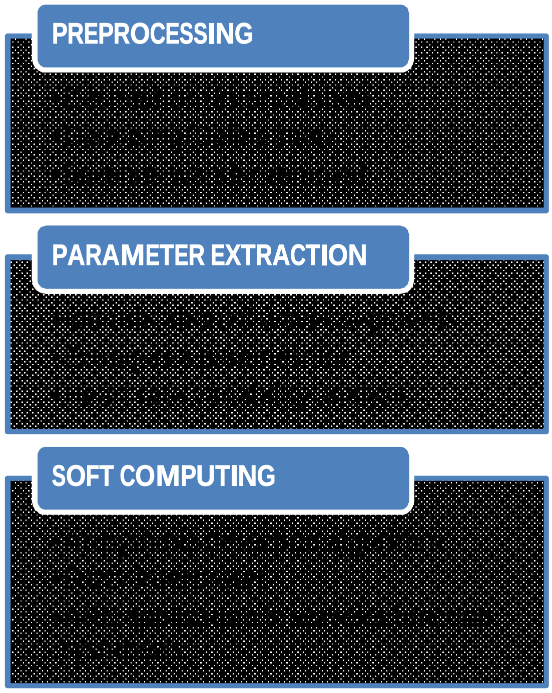

Fig.5 Computational Methods Involved

8. ECG SIGNAL GENERATION

Using Matlab heartbeat is generated that will be forced on to sound card of the system; heart beat signal will be given to the ADC to convert analog signal to 12 bit digital signal. Interfacing code will convert serial 12 bit data to parallel 12 bit that is feed to notch filter.ECG signal coefficients that are stored in the ROM are designed with help of Matlab. To select which input signal has to be accessed, can be selected by a sliding switch present on the FPGA board. Resultant signal is feed to Notch Filter. Notch filter is designed to operate at a frequency of 50 Hz (attenuation), in order to remove power supply interference noise. Data thus obtained from the Notch filter is sent to high frequency noise removal filter. This filter is designed to attenuate signals which are not in the range of 0.05 to 100Hz (allows these frequencies only). The output from high frequency noise removal filter is given to block ram which store the data in it and forwards data to STFT (Short Time Fourier Transform) block to process FFT on the signal. STFT is developed by Xilinx IP core. So Block ram is also embedded in the core which is utilized in the project. So external block ram is not required as shown in block diagram, STFT is used to analyze frequency response of the heart beat. Magnitude and phase comparator module will carry out time domain analysis i.e. magnitude and time period of each wave (P, Q, R, S & T).

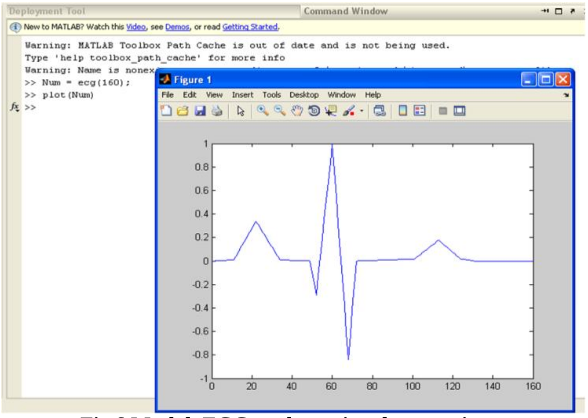

Fig.6 Matlab ECG package signal generation

9.1 The Wavelet Transform

The wavelet transform is a convolution of the wavelet function **ψ(t)** with the signal **x(t)**. Orthonormal dyadic discrete wavelets are associated with scaling functions **φ(t).** The scaling function can be convolved with the signal to produce approximation co-efficients S. The discrete wavelet transform (DWT) can be written as

$$T_{m,n} = \int_{-\infty}^{\infty} x(t)\psi_{m,n}(t)dt$$

By choosing an orthonormal wavelet basis $\psi_{m,n}(t)$ we can reconstruct the original. The approximation coefficient of the signal at the scale **m** and **n** location can be written as

$$S_{m,n} = \int_{-\infty}^{\infty} x(t)\phi_{m,n}(t)dt$$

But the discrete input signal is of finite length N. So the range of scales that can be investigated is $0 < m < M$. Hence a discrete approximation of the signal can be written as

$$x_0(t) = x_M(t) + \sum_{m=1}^{M} d_m(t)$$

where the mean signal approximation at scale M is $x_M(t) = S_{M,n}\,\varphi_{M,n}(t)$ and detail signal approximation corresponding to scale m, for finite length signal is given by

$$d_m(t) = \sum_{n=0}^{M-m} T_{m,n}\psi_{m,n}(t).$$

The signal approximation at a specific scale is a combination of the approximation and detail at the next lower scale is given by

$x_m(t) = x_{m-1}(t) - d_m(t)$

In the present work Daubechies wavelet is chosen although the Daubechies algorithm is conceptually more complex and

has a slightly complicated computations yet this algorithm picks up minute detail that is missed by other wavelet algorithms, like Haar wavelet algorithm. Even if a signal is

not represented well by one member of the Daubechies family, it may still be efficiently represented by another.

9.2 Wavelet Analysis

The wavelet analysis of ECG signal is performed using MATLAB software. MATLAB is a high performance; interactive system which allows to solve many technical computing problems. The MATLAB software package is provided with wavelet tool box. It is a collection of functions built on the MATLAB technical computing environment. It provides tools for the analysis and synthesis of signals and images using wavelets and wavelet packets within the MATLAB domain.

10. ADC MODULE

FPGAs are well suited for serial Analog to Digital (A/D) converters. This is mainly because serial interface consumes less communication lines while the FPGA is fast enough to accommodate the high speed serial data. The ADCS7476MSPS is a high speed, low power, 12-bit A/D converter. A/D converter is a high speed serial interface that interfaces easily to FPGAs. The A/D interface adapter (AD1_PMOD) is implemented within the FPGA. Inside the FPGA, this adapter facilitates parallel data acquisition. Sampling is initiated at the rising edge of a clock applied at the line sample. The timing diagram of the communication protocol obtained with Modelsim is illustrated.

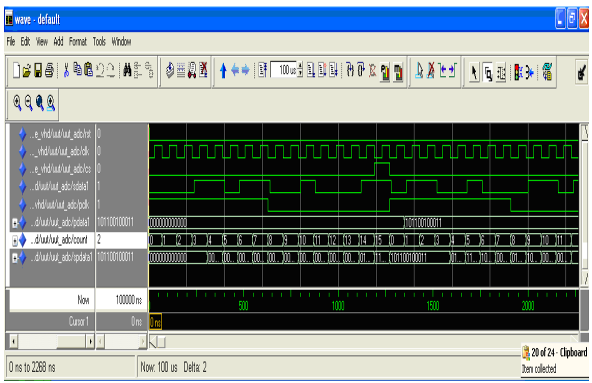

Fig.7 Simulation of ADC interface

11. DESIGN OF FIR FILTERS

Digital filter includes infinite impulse response (IIR) filters and finite impulse response (FIR) filter. IIR filter design, although simple, but there are limitations of non-linear, while the ECG signals processing requirements of a linear phase system, so using FIR filter for design. FIRS filter transfer function as follows:

$$H(z) = \sum_{k=0}^{N-1} h(k) z^{-k}$$

FIR filters should be designed to meet the following requirements: filter type confirmation, expectations response and phase response; satisfy filter coefficient to determine and quantify; choose a suitable filter structure; for software and hardware testing. The main part: ECG storage unit ROM, the first 50Hz frequency interference FIR filter, the second FIR high-frequency interference level filter, scaling unit. In the block the ROM storages ECG signals with 150Hz sinusoidal & 50Hz sinusoidal interference. The first 50Hz frequency interference FIR filter design: 45~55Hz the band-stop filter, the sampling frequency of 300Hz, FIR distributed algorithms, Hamming window. The second high-frequency interference for FIR filter design: 0.05~100Hz band-pass filter, the sampling frequency of 300Hz, FIR distributed algorithms, Hamming window. The first 50Hz frequency interference FIR filter can decrease power frequency noise 40db; the second high-frequency interference FIR filter can decrease high-frequency 60dB.

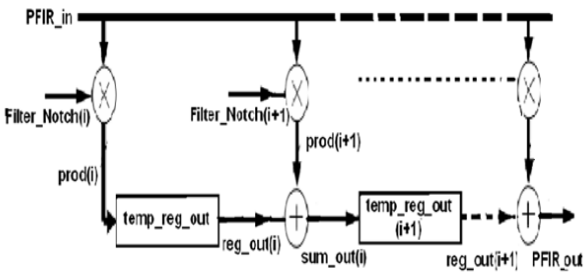

Fig.8 PFIR Filter Design Perspective

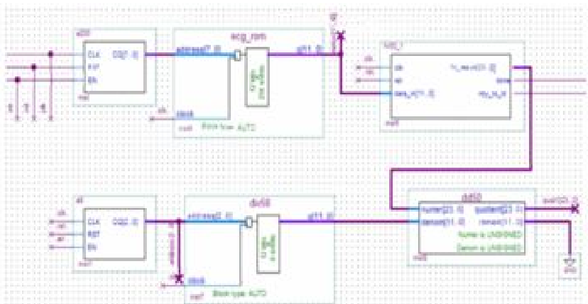

Fig.9 The first 50 Hz power frequency interference filter schematic

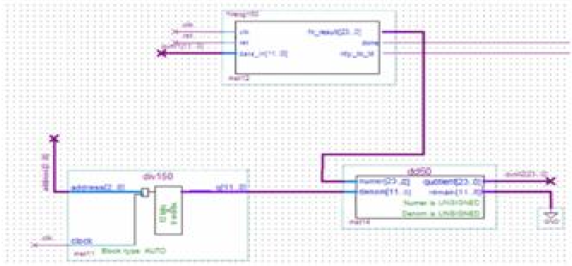

Fig.10 The second 150Hz high frequency interference filter schematic

Fig.11 Overall Project Simulated Window (Modelsim)

The real effect of the filter by the logic analyzer, from the figure can be seen, the filters for the high-frequency interference and power frequency noise have a strong ability to filter. **Noecg** means the ECG signal with interference, **out1** means the ECG signal after filtering 50Hz frequency interference, **out2** means the purity ECG signal after filtering 150Hz high-frequency interference.

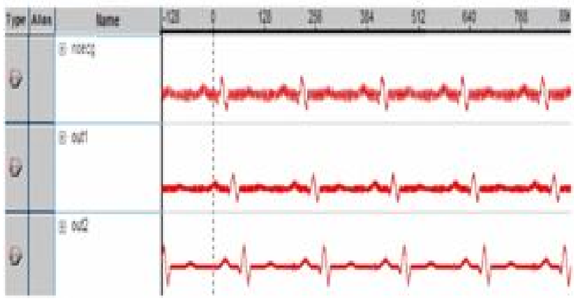

Fig.12 Before and after filtering ECG signal

Fig.13 Synthesised Window viewed on Xilinx Chipscope

CONCLUSIONS

This paper introduces the ECG FIR filter design method based on FPGA, the results of high-frequency and 50Hz power-frequency interference dual filters can be seen, the filters can be used directly in FPGA embedded ECG monitor design, ECG monitor system to collect, store, playback, wireless transmission can be integrated into a FPGA chip, so that greatly reducing the development of analog circuits, reducing development costs and research and design cycle, the filters have a good application value.

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