WAVELET TRANSFORM BASED ECG SIGNAL FILTERING IMPLEMENTED ON FPGA

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ABSTRACT

Filtering electrocardiographic (ECG) signals is always a challenge because the accuracy of their interpretation depends strongly on filtering results. The Discrete Wavelet Transform (DWT) is an efficient, new and useful tool for signal processing applications and it's adopted in many domains as biomedical signal filtering. This transform came about from different fields, including mathematics, physics and signal processing, it has a growing applicability due to its so-called multiresolution analyzing capabilities. FPGAs are reconfigurable logic devices made up of arrays of logic cells and routing channels having some specific characteristics which allow to use them in signal processing applications. This paper presents a DWT based ECG signal denoising method implemented on FPGA, using Matlab specific Xilinx tool, as System Generator, the procedure is simulated and evaluated through filtering specific parameters.

Keywords: Discrete Wavelet Transform, Nonlinear filtering, FPGA

1. Introduction

Electrocardiogram (ECG) obtained by noninvasive technique is a quick and safe method of cardiovascular diagnosis. The accuracy of extracted information needs specific evaluation of waveform morphologies, therefore good noise elimination is required. The purpose of ECG signal denoising is to separate the valid signal components from the undesired artifacts, so as to present an ECG signal that facilitates accurate interpretation. There are numerous advanced signal processing methods applied on the study of ECG noise reduction, such as wavelet [4, 5], adaptive filter [3], and independent component analysis , however, it is still an interesting and attractive approach to investigate ECG filtering characteristics.

The wavelet transform provides a time-frequency representation of the signal, and thus permits the inspection of characteristic waves of the ECG signal at different scales with different resolutions. The discrete wavelet transform (DWT) provides a dyadic division of the bandwidth allowing the application of subband filtering techniques which permit independent processing in these subbands (scales) [1].

This work tries to find solutions to implement the discrete wavelet transform based filtering methods in a reconfigurable hardware structure, using specific engineering tools as Matlab/Simulink and System Generator.

2. The discrete wavelet transform

The discrete wavelet transform uses translated and scaled mother wavelets as a set of basis functions to represent a signal. The translation factor shifts the original signal in the time domain and the scale factor determines the frequency band. A wavelet decomposition (or transform) simply re-expresses a function (a data signal) in terms of the wavelet basis, and, as a result, gives time-frequency joint representations of the original signal:

$$x(t)=\sum_{k=-\infty}^{\infty}c_k\varphi(t-k)+\sum_{k=-\infty}^{\infty}d_k\psi\left(2^{j/2}t-k\right) \quad (1)$$

where $\varphi(t)$ is called the scaling function and c_k and d_k are the coarse and detail level expansion coefficients. The following equation show how wavelets are generated from the basic function, called the mother wavelet:

$$\psi_{j,k}(t)=2^{j/2}\psi\left(2^{j/2}t-k\right) \quad (2)$$

The discrete wavelet transform represents a one-dimensional signal $f(t)$ in terms of shifted versions of a low-pass scaling function of multi resolution analysis (MRA), $\varphi(t)$, and shifted and dilated versions of a prototype band-pass wavelet function of MRA, $\psi(t)$. From a signal processing point of view the discrete wavelet transform is a

mathematical function that involves multiplication and addition operations to convolve the signal of interest with a predefined wavelet. In the field of signal processing, the implementation of the wavelet transform is performed using filter banks. In applications one never has to deal directly with the scaling functions or wavelets, only with the coefficients of the associated filters in the filter banks. In a wavelet transform system, the signal is convolved with a pair of maximally decimated quadrature mirror filters (QMF). These filters are related to wavelet and scaling functions as expressed in (1), the structure is presented on fig. 1:

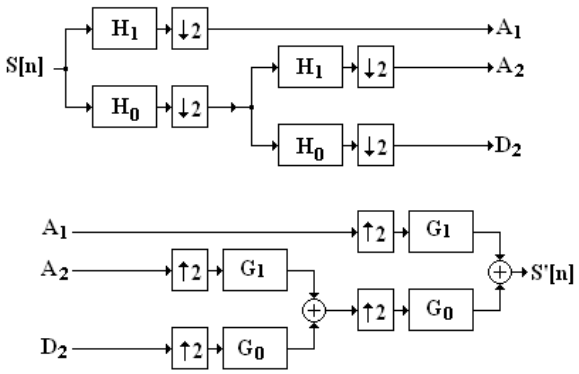

Fig. 1 – 2nd order DWT decomposition and reconstruction structure

The coefficients are ordered using two dominant patterns, one that works as a smoothing filter (like a moving average), and one pattern that works to bring out the "detail" information of the data. These are performed by a quadrature mirror filter pair which split in half the frequency band after every decomposition, as can be seen in fig. 2. To eliminate the redundance from the signal, after every filtering a downsampler is applied to reduce to half the number of coefficients.

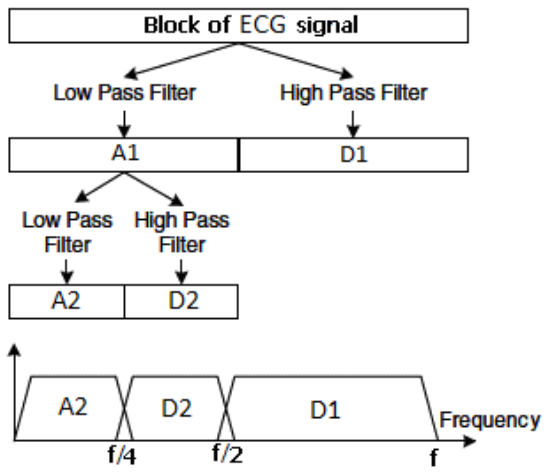

Fig. 2 – The obtained frequency subbands after decomposition

3. The filtering procedure

The wavelet based signal denoising is performed using a technique called wavelet shrinkage and thresholding. This means non-linear thresholding of coefficients in wavelet transform domain. After applying the DWT, some of the resulting wavelet coefficients correspond to details in the data set, others to the approximations. If the details are small, they might be omitted without substantially affecting the main features of the data set. The idea of thresholding, then, is to set to zero all coefficients that are less than a particular threshold. The thresholding procedure is applied only to detail coefficients because it is assumed that the major part of the noise is contained in these components. There are two ways to perform the thresholding, the hard and the soft procedure. Hard thresholding can be described as the usual process of setting to zero the elements whose absolute values are lower than the threshold, soft thresholding is an extension of hard thresholding, first setting to zero the elements whose absolute values are lower than the threshold, and then shrinking the nonzero coefficients towards zero, as shown in fig. 3.

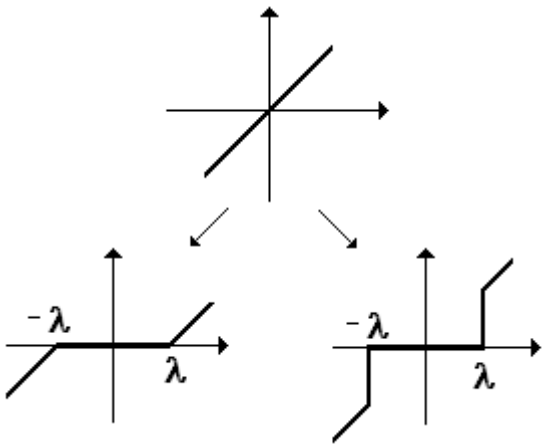

Fig. 3 – Soft and hard thresholding

These thresholded coefficients are used in an inverse wavelet transformation to reconstruct the data set as presented in fig. 4.

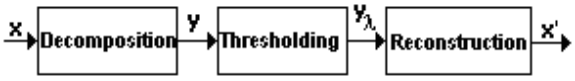

Fig. 4 – The nonlinear filtering procedure

The choice of the threshold is a very delicate and important statistical problem, in literature there are many values used, the most important are the universal threshold (developed by Donoho and Jonstone [4], [1]), the minimax and the Stein's unbiased risk estimator based threshold [3]. The proposed filtering procedure implemented with Xilinx System Generator is presented in fig. 5.

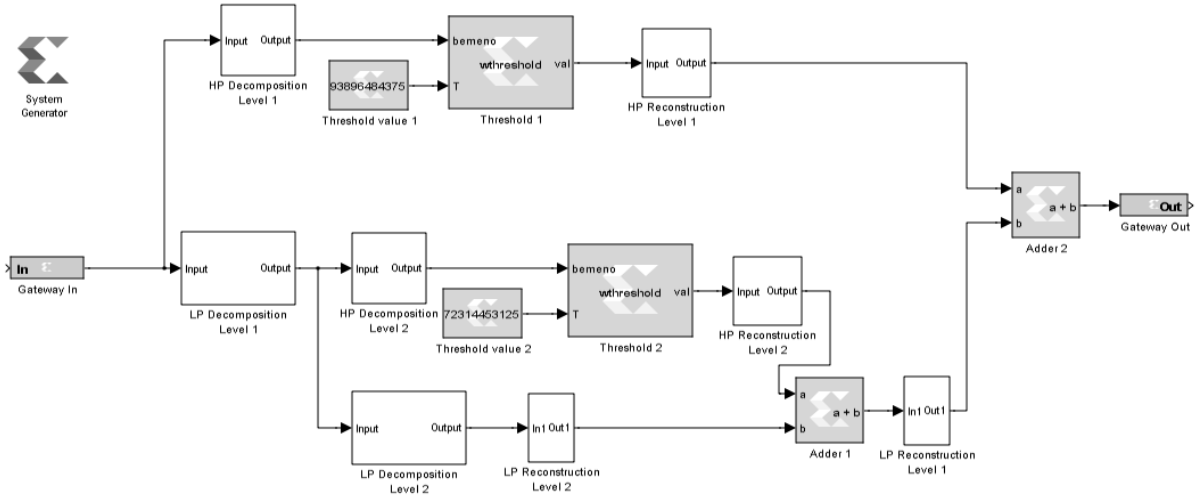

Fig. 5 – The synthesized model for wavelet based denoising

Xilinx System Generator is a design environment over Simulink for FPGAs, provided by Xilinx. The FPGA boundary in the Simulink model is defined by Gateway In and Gateway Out blocks. The Gateway In block converts the Simulink floating point input to a fixed point format, permitting for the designer to set the saturation and rounding mode. The Gateway Out block converts the FPGA fixed point format to Simulink double numerical precision floating point format. Basically, a two level DWT based decomposition, thresholding and reconstruction structure is implemented, using multiple analyzing functions (Daubechies, different orders) and the universal threshold value, defined as [1].

$$\lambda_{UNIV} = \sqrt{2\ln N} \tag{3}$$

4. Simulation results

Xilinx System Generator allows minimizing the time spent by the designer for the description and simulation of a circuit. In order to evaluate the filtering parameters, such as absolute error or signal to noise ratio, signals from MIT-BIH database were used. The model for the noisy signal is the superposition of the signal and a zero mean gaussian white noise. A second order DWT transform was implemented, the way how the component blocks are synthesized in Xilinx System Generator is presented in fig. 6

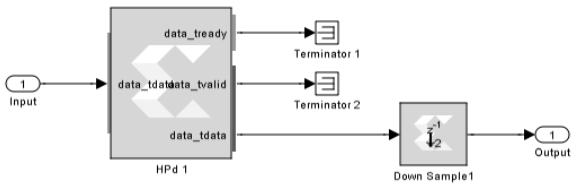

Fig. 6 – Component block for one level analysis

A block is not necessarily a hardware circuit; it exists in relation with others blocks to generate the appropriate hardware.

The experimental procedure was carried out in Simulink using Xilinx System Generator and the results were processed using a Matlab script.

The resulting absolute error was calculated in case of each filtering (using four different analyzing wavelets), with the help of equation 4:

$$\varepsilon = \frac{1}{N}\sum_{i=1}^{N}\left(s[i] - s_f[i]\right)^2 \tag{4}$$

where s and s_f are the original and the filtered signals. Fig. 7 presents the different mean squared errors for db1, db2, db3 and db4 wavelets.

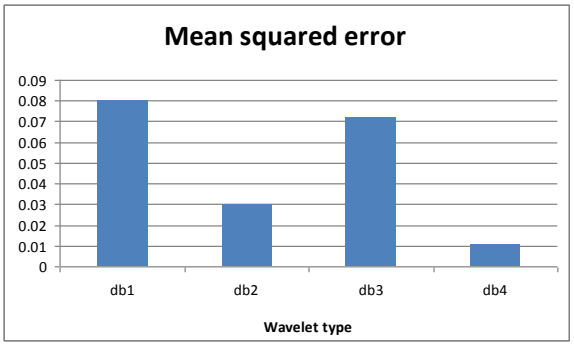

Fig. 7 – The obtained mean squared errors

Increasing the complexity of the used analyzing functions the simulation results are not necessarily closer to the desired output, which means that the analyzing function should be chosen carefully, so that it is correlated with the signal to be analyzed.

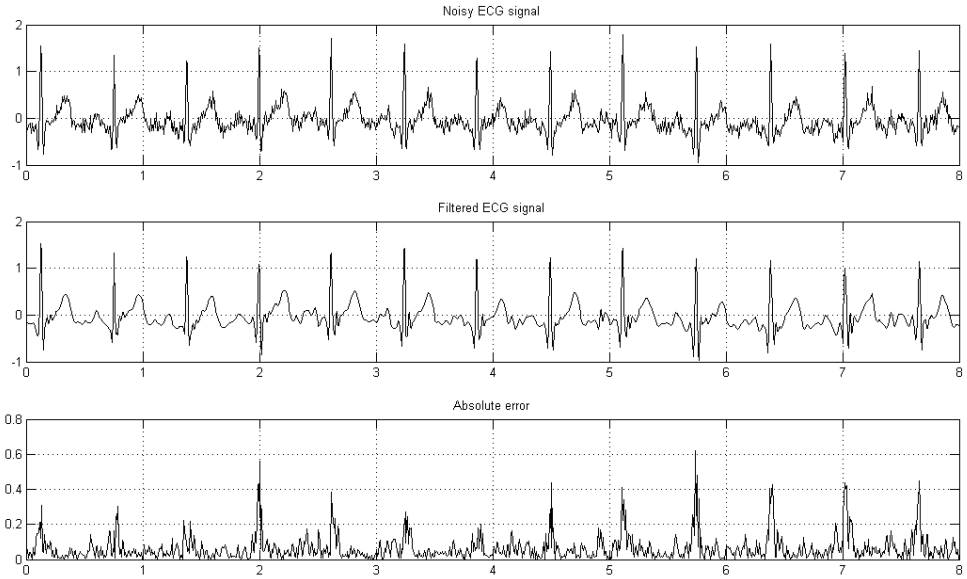

Fig. 8 – Filtering results

5. Concluding remarks

The created model works efficiently, the FPGA resources are used relatively efficiently and easy. On the other hand, the design is flexible, it is possible to change the design parameters and check quickly the effect on the performances and the architecture of the system. The Xilinx System Generator simulations are faster than traditional hardware description language simulators, and the results are easier to analyze. In Simulink each block is configured after opening its dialog window, this permits fast and flexible design. The main filtering parameters can be calculated in Matlab/Simulink environment.

Topics for future research include algorithms for selecting optimal thresholds, distributed arithmetic based filtering procedures.

References

[1] Aldroubi, A., Unser, M.. – *Wavelets in Medicine and Biology*, CRC-Press, 1996

[2] M.Nibouche, A.Bouridane, O.Nibouche, D.Crookes, *Rapid Prototyping of Orthonormal Discrete Wavelet Transforms on FPGAs* IEEE International Symposium on Circuit and Systems, Sydney, Australia, May 2001.

[3] Smith, S. W. – *Digital Signal Processing A Practical Guide for Engineers and Scientists*, Newnes, 2003

[4] Meyer – Baese, U. – *Digital Signal Processing with Field Programmable Gate Arrays (Signals and Communication Technology) 3rd Edition*, Springer, 2007.

[5] K. K. Parhi, "VLSI Digital Signal Processing System-Design and Implementation", John Wiley, USA, 1999.