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Analyzing ElectroCardioGraphy Signals using Least-Square Linear Phase FIR Methodology

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Abstract. This paper presents a signal processing methodology to analyze Electrocardiography (ECG) signals. Discrete Wavelet Transform (DWT) is used as a feature extraction methodology to achieve efficient design. Baseline wandering noise is removed in this design using Lest-Square Linear Phase FIR methodology. ECG signals classification is done using Feed forward neural network methodology. An accuracy of 100% in identifying the normal samples, and accuracy of 95.23% for identifying abnormal ECG beats are obtained, achieving a total accuracy of 97.78% for identifying ECG signals using this presented methodology.

Keywords: Discrete Wavelet Transform, Denoising, Neural Networks,Field Programmable Gate Array, ElectroCardioGoraphy.

1. Introduction

Time domain analysis has been commonly used in previous methodologies for analyzing ECG signals. These methodologies are not always perfect to study all the properties of the ECG signals. Fast Fourier Transform (FTT) is applied to study the frequency spectrum of the ECG signal to overcome this shortage [1]. Limitation of using FFT analysis is its inability to determine the location of the frequency components with respect to time. To overcome this issue Short Term Fourier Transform (STFT) has been used [2]. The major drawback of STFT is its non-optimum time frequency precision. To solve this issue, the wavelet transform is proposed [3-4].

Wavelet transform depends the decomposition of ECG signal into a set of coefficients; approximate and detailed coefficients. The wavelet coefficients resulting from this decomposition represent the ECG signal in both time and frequency domains.

In this paper, ECG signal analysis using Least-Square Linear Phase FIR methodology is presented. In this design, the discrete wavelet transform methodology is employed to overcome the limitations encountered in the previous methodologies employing FFT and STFT. The least-square FIR filtering as a methodology is employed here to denoise ECG input signals against baseline wandering noise.

The paper is organized as follows. In section 2,The design block diagram along with the function of each block are presented. The design implementation along with the simulation results are presented in section 3. The conclusions are provided in section 4.

2. Design Blocks

Fig. 1 represents the block diagram of the design. The main blocks of the block diagram are Denoising block, Feature Extraction block and Classifier block. In the following subsections different blocks are discussed.

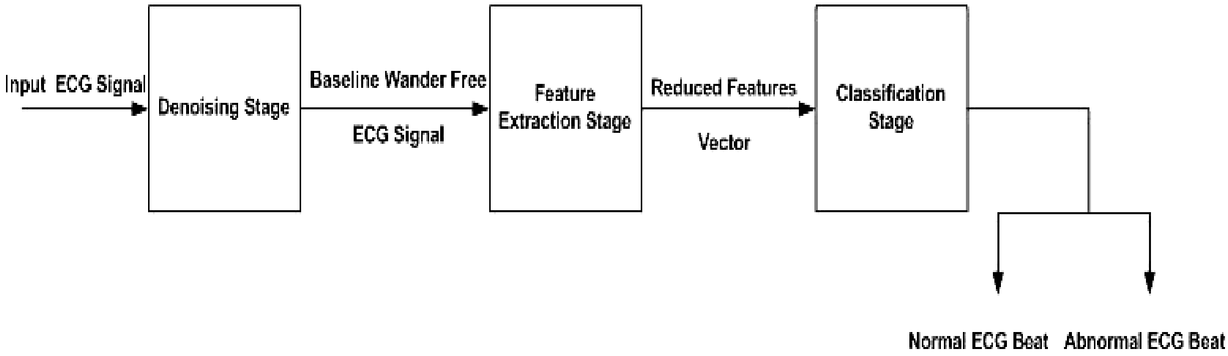

Fig. 1: Design block diagram.

2.1. Denoising block

Noise encountered in ECG signals is classified into: Low frequency noise and High frequency noise. Low frequency noise is represented in the form of baseline wander noise, caused by the cables moving during reading and patient movement [5]. Power-line interference and muscle contraction cause high frequency noise. By discarding the first detail component resulting from wavelet transform decomposition in this design, high frequency noise is removed. Least square linear phase FIR high-pass filtering methodology is used to remove baseline wandering noise in the input ECG signal [13].

2.2. Feature extraction

Fig. 2 shows the filter structure of the wavelet transform filter bank. The input signal which is entered to the filter bank is filtered by the low-pass (LP) and the high-pass (HP) filters. The outputs from the low-pass filter and the high-pass filter are called the approximation coefficients and detail coefficients respectively. A down sampling by factor of 2 is applied to the output of each filter. Decomposition is done by further filtering the output of the LP, this process goes on until enough steps of decomposition are achieved. This design uses three levels of filtering for the input denoised ECG signal, resulting in four signals (d1, d2, d3 and a3) output from the decomposition.

This design uses wavelet transform decomposition as a methodology for feature extraction. The ECG signal samples are extracted from MIT-BIH Arrhythmia Database. The continuous ECG signals are cut into individual ECG beats, each ECG beat consists of 300 samples centered around R peak determined by the annotations provided by the database. Each beat begins at R-150 position and is terminated at R+149 position, giving individual ECG beats of 300 samples each [3].

This design uses Daubechies of order 3 filter with coefficients for wavelet transform. In this methodology, the input denoised ECG signal is decomposed into 3 levels. Fig. 2 shows the decomposition steps. The input signal to the wavelet transform block with 300 samples each will be down sampled by a factor of 2 in each filtering stage, giving only 38 samples in the 3rd stage (d3, a3). The detail signal d1 is considered a noise signal and is eliminated. The detailed signals d2 and d3, represent the high frequency coefficients. (a3) is considered the approximation of the input signal, so, it contains the main features of the signal, so, (a3) is used in the subsequent stage for the classifier as the features vector.

2.3. Classification block

This design design depends on classifying normal ECG beats and abnormal ECG beats. Neural network is used as the classifier for other designs [6-7]. Feed forward neural network is used as the classifier circuit in this design. This classifier is used to determine whether the input ECG beat is classified as normal beat or abnormal beat. The design employs a neural network of one hidden layer with four hidden neurons and one output layer.

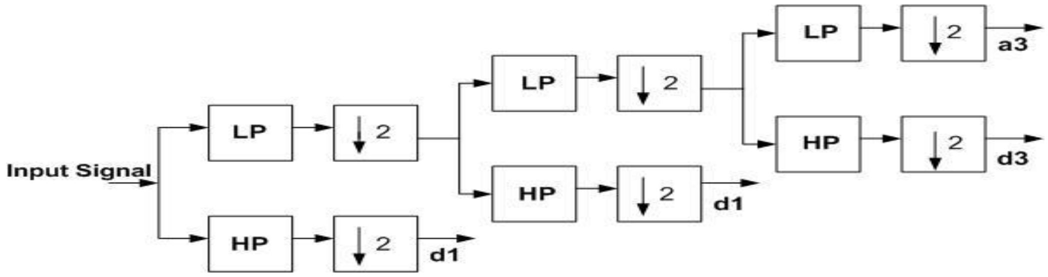

Fig. 2: Wavelet Transform Filter Structure Block Diagram.

The basic blocks of the neural network are: multiplier block, adder block and the activation function block. (Tansig) activation function is used in implementing the neural network in this design [8,9,13].

3. Design Implementation and Simulation Results

XILINX Virtex6 board is used as the target FPGA board for implementing this design. Table 1 indicates the device utilization for the design .

The classifier passes through Training Phase and Testing Phase. This design uses a total of 90 training sets, with 48 normal ECG sets and 42 abnormal ECG sets in Training Phase (each set corresponds to one feature vector, a3). Testing Phase uses 45 testing sets, divided to 24 normal ECG sets and 21 abnormal ECG sets.

Test results are listed in a form of a confusion matrix listed in Table 2. From the confusing matrix, it is shown that all normal test beats are diagnosed successfully, with accuracy of 100% in identifying the normal samples, only one abnormal test beat out of 21 abnormal test beats is incorrectly diagnosed as normal ECG beat with accuracy of 95.23% for identifying abnormal ECG beats. The total accuracy is 97.78%.

In [3] the accuracy ranges from 90% to 100%. [4] achieves the same accuracy of 97.8%. [10] achieves total accuracy of 92%, and [11] achieves accuracy of 97.3%. [12] achieves accuracy of 99.17%. In [4,12], the design is not implemented on a hardware device, so, it is not possible to examine hardware utilization efficiency in [4,12] compared to this design. From the above it is shown that the design achieves good accuracy with good resource utilization. Total accuracy comparison is indicated in Table 3.

4. Conclusions

Least-Square Linear Phase FIR design for analyzing ECG signals is presented in this paper. This design employs Discrete Wavelet Transform as a feature extraction methodology to analyze ECG signals. Total accuracy of 97.78% is achieved.

Table 1: Device utilization summary

Number of Slice Registers	5924
Number used as Flip Flops	5920
Number of Slice LUTs	6163
Number of bonded IOBs	169
Number of occupied Slices	1867

Table 2: Neural network confusion matrix

	Classes classification		
Number of inputs	**Normal Class**	**Abnormal Class**	**Accuracy (%)**
Normal Class (24)	24	0	100
Abnormal Class (21)	1	20	95.23

Table 3: Total accuracy comparison.

	This design	**[3]**	**[4]**	**[10]**	**[11]**	**[12]**
Total Accuracy	97.78%	90% - 100%	97.80%	92.00%	97.30%	99.17%

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