ISSN: 2319-8753

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 10, October 2013

Comparative Analysis of Various Wavelet Families used for R-Wave Detection of ECG Waveforms

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Abstract: Automatic interpretation of ECG Signals from ECG Machines has become need of the hour. Digital processing of the ECG signals via Discrete Wavelet Transform (DWT) is a fruitful option for Features' Extraction and Disease Classification. Selection of correct mother wavelet as the basis for DWT plays an important role in whole processing of ECG signals. This research paper proves how various mother wavelets affect the Noise and Detection performance of the Features' Extractor used.

Keywords:Discrete Wavelet Transform, ECG Signals, ECG Features' Extraction, Mother Wavelets

I. INTRODUCTION

The analysis of ECG signal has been widely used for diagnosing many cardiac diseases. The Electrocardiograph is a graphic record of the direction and magnitude of the electrical activity of heart, which is generated by depolarization and repolarization of the atria and ventricles. One cardiac cycle in an ECG signal consists of the P-QRS-T waves [1]. Clinicians can evaluate the conditions of a patient's heart from the ECG signal and can perform further diagnosis.

The recorded ECG data is often contaminated by noise and artifacts, such as electrical activity of muscles (EMG), that can be within the frequency band of interest and can manifest with similar characteristics of the ECG signal. In order to extract useful information from these noisy ECG signals, they need to be processed to eliminate noises. After the Pre-processing step the signal undergoes the process of Features' Extraction. This paper proposes a comparative analysis of various mother wavelets being used for decomposing the ECG signal with Discrete Wavelet Transform, for the detection of "R" wave of the ECG Signal.

II. MATERIALS

A. *Wavelet Transform*

The first step of De-noising procedure using wavelet transform is selection of mother wavelet $\psi_{m,n}(t)$ which forms a set of basis functions (family of wavelets). The Wavelet Transform is given as the convolution of the wavelet function $\psi(t)$ with the signal $x(t)$. Orthonormal dyadic discrete wavelets are associated with scaling functions $\varphi(t)$. The scaling function can be convolved with the signal to produce approximation coefficients S [4]. The discrete wavelet transform (DWT) can be written as

$$T_{m,n} = \int_{-\infty}^{\infty} x(t).\psi_{m,n}(t)dt. \qquad (1)$$

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 location n can be written as:

$$S_{m,n} = \int_{-\infty}^{\infty} x(t).\varphi_{m,n}(t)dt. \qquad (2)$$

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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:

$$x_0(t) = x_M(t) + \sum_{m=1}^{M} d_m(t) \quad (3)$$

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

$$d_m(t) = \sum_{n=0}^{M-m} T_{m,n}\psi_{m,n}(t). \quad (4)$$

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

$$x_m = x_{m-1}(t) - d_m(t) \quad (5)$$

B. ECG Database

The Database has been prepared from the MIT-BIH Arrythmia Database directory of ECG Signals from Phyionet Bank, where the source of ECG signals is Beth Israel Hospital Arrhythmia Laboratory [5]. The database contains 48 records.

The database is described by – a text header file (.hea), a binary file (.dat) and a binary annotation file (.atr). Header file describes the detailed information about the number of samples, sampling frequency, format of the ECG signal, type and number of ECG leads, patient's history and the other clinical information. In Binary Data file (.dat), the signal is stored in 212 format. The Annotation file contains the beat annotations.

C. WFDB Toolbox

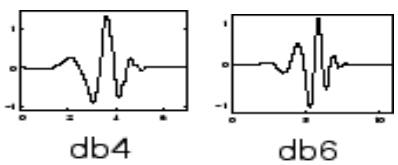
The WFDB Toolbox obtained from Physionet Bank provides MATLAB functions that are interfaces to some of the most useful stand-alone applications [6].

III. METHODOLOGY

The ECG signals in the form of .dat files are first made readable in MATLAB and only the lead-II signals are used for processing. Then the signal is de-noised by filtering, thresholding and de-trending the signal and its details, using DWT as the tool.

The obtained signal then undergoes the process of R wave detection by using the detection algorithm based on DWT. The DWT uses following mother wavelets as its basis function, used for comparative analysis:

- Debauchies 4 wavelet
- Debauchies' 6 wavelet
- Symlet 4 wavelet
- Symlet 6 wavelet



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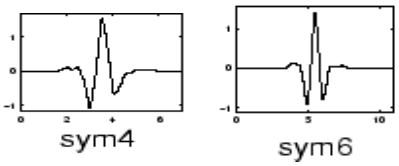

Fig. 1: Debauchies' 4 & 6 wavelet and Symlet's 4 & 6 waveform

IV. RESULTS AND VALIDATIONS

The database contains 48 MIT-DB records, each of 30 min of duration, but 15 of these records are tested for 30 s in this experiment. Each record comprises of the signal file, annotation file and the file specifying the signal attributes. First of all, the signal file is made readable in MATLAB using the WFDB toolbox [6]. Then the program for removal of different types of noises and detection of "R" wave from the raw ECG data is run.

Accuracies and False Detection of the 15 ECG wave forms of the detector that uses different mother wavelets as the basis function for DWT, are calculated and tabulated in Table 1 and Table 2 respectively. Table 3 gives the comparison of Standard Deviations of ECG waveforms using different mother wavelets in DWT.

Table 1: Comparison of Accuracies of Detector by using: (1) Debauchies' 6 wavelet (Db6), (2) Debauchies' 4 wavelet (Db4), (3) Symlet's 6 wavelet (Sym6) and (4) Symlet's 4 wavelet (Sym4)

Accuracy in %				
ECG Name	**Db6**	**Db4**	**Sym6**	**Sym4**
mitdb/100	91.89	100.00	94.59	100.00
mitdb/101	97.06	100.00	100.00	97.06
mitdb/102	69.44	66.67	72.22	58.33
mitdb/103	79.41	88.24	85.29	88.24
mitdb/104	56.41	64.10	64.10	7.69
mitdb/105	95.12	95.12	95.12	95.12
mitdb/106	80.00	82.86	77.14	85.71
mitdb/107	91.67	66.67	72.22	63.89
mitdb/108	12.12	6.06	21.21	27.27
mitdb/109	48.94	44.68	55.32	48.94
mitdb/111	68.57	62.86	62.86	39.82
mitdb/112	88.37	90.70	88.37	38.70
mitdb/113	93.10	96.55	96.55	83.49
mitdb/114	0.00	3.70	0.00	22.70
mitdb/115	67.74	83.87	67.74	62.69

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Table 2: Comparison of False Detection Rate of Detector by using: (1) Debauchies' 6 wavelet (Db6), (2) Debauchies' 4 wavelet (Db4), (3) Symlet's 6 wavelet (Sym6) and (4) Symlet's 4 wavelet (Sym4)

False Detection in %				
ECG Name	Db6	Db4	Sym6	Sym4
mitdb/100	10.53	2.63	7.89	2.63
mitdb/101	5.71	2.86	2.86	5.71
mitdb/102	16.67	29.41	7.14	32.26
mitdb/103	22.86	14.29	17.14	25.00
mitdb/104	42.11	44.44	34.21	41.03
mitdb/105	7.14	7.14	7.14	7.14
mitdb/106	24.32	29.27	30.77	33.33
mitdb/107	62.07	72.09	67.90	71.25
mitdb/108	55.56	50.00	30.00	18.18
mitdb/109	60.34	60.38	51.85	54.90
mitdb/111	33.33	38.89	38.89	38.89
mitdb/112	13.64	11.36	13.64	6.82
mitdb/113	12.90	20.00	17.65	22.22
mitdb/114	100.00	50.00	100.00	100.00
mitdb/115	53.33	38.10	48.78	36.59

Table 3: Comparison of Standard Deviations of ECG waveforms after applying DWT using the following mother wavelets: (1) Db6, (2) Db4, (3) Sym6 and (4) Sym4 Wavelet

Comparison of SD4 for different Mother Wavelets				
ECG Name	Db6	Db4	Sym6	Sym4
mitdb/100	34.04	34.03	34.03	34.03
mitdb/101	39.52	39.51	39.52	39.51
mitdb/102	35.51	35.50	35.50	35.50
mitdb/103	62.51	62.51	62.51	62.50
mitdb/104	57.76	57.76	57.76	57.76
mitdb/105	61.40	61.40	61.40	61.40
mitdb/106	76.61	76.61	76.61	76.61
mitdb/107	170.61	170.61	170.61	170.60
mitdb/108	31.69	31.68	31.69	31.68
mitdb/109	79.45	79.44	79.45	79.44
mitdb/111	39.82	39.82	39.83	39.82
mitdb/112	38.70	38.69	38.70	38.70
mitdb/113	83.49	83.49	83.49	83.49
mitdb/114	22.71	22.70	22.70	22.70
mitdb/115	62.70	62.69	62.70	62.69

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V. CONCLUSION

Depending upon the type of application of ECG waveforms different mother wavelets are suitable. For the purpose of carrying out Pre-processing of ECG waveforms Db4 and Sym4 wavelets show good results but for carrying out Features' Extraction Db6 and Sym6 wavelets show good results.

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