Semiautomatic Detection of Cardiac Diseases employing Dual Tree Complex Wavelet Transform

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Article Info	ABSTRACT
	Electrocardiogram (ECG) contains lot of information which can be utilized for a mechanism to detect cardiac abnormalities. The ECG signal is too sensitive to various types of noises as it is of low frequency and has weak amplitude, these noises reduce the diagnostic accuracy and may lead to the incorrect decision of the clinician. So, denoising of ECG signal is an essential requirement for an accurate detection of Heart disease. In this paper, a Dual-Tree Complex Wavelet Transform technique (DTCWT) is presented to denoise the noisy ECG signal and to extract the Principal features followed by implementation of Peak Detection Algorithm. The performance is evaluated on the basis of performance metrics and an increase in SNR is achieved using the technique. With the proposed technique, calculated heart rate is in consensus with the gold standard of the various bench mark databases used and accurate heart disease was determined.

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1. Introduction

ECG indicates an electrical activity of heart which provides cardiologists to extract the useful information about the functioning of the heart [1],[2],[3]. Any disorder in the heart, leads towards the Heart Disease often detected by an ECG signal [4],[5],[6],[7]. Some of the common heart diseases are Coronary, Arrhythmia, and Myocardial Infarction. A correct analysis of ECG features is required for an early detection of Heart disease. But the presence of noise artifacts at different levels can change the signal amplitude and frequency which creates the major problem to detect the actual abnormalities [8],[9],[10].Earlier, feature extraction of an ECG signal analysis has been done by time domain based method, which made researchers difficult to study. Therefore, the signals are studied and processed in frequency domain. In this context, the Fast Fourier Transform (FFT) technique has been introduced which further failed to provide the information regarding an exact location of frequency components. This problem has been resolved by introducing a Short-Term Fourier Transform (STFT) which has limitations of seeking the optimal time-frequency precision. To overcome these limitations, many techniques and algorithms have been developed in recent years for signal denoising. Among all, Discrete Wavelet Transform (DWT) has become an important computational tool for performing signal

processing. It overcomes the shortcomings of time window size which does not vary with frequency [11],[12],[13],[14]. Further use of DWT for low-frequency biomedical signals noticed some of the limitations such as lack of shift invariance property, aliasing, oscillations and lack of directionality. To overcome these limitations and to provide an efficient tool for signal denoising a Dual-Tree Complex Wavelet Transform (DTCWT) technique has been introduced that has shift invariance property and anti-aliasing effect for biomedical signals [15],[16],[17]. Some of the methods such as Fourier transform infrared spectroscopy (FTIR), Nuclear magnetic resonance spectroscopy (NMR), Fluorescence spectroscopy are used for Nanoparticle and Protein interaction in biomedical applications [18].

This paper outlines the DTCWT technique to denoise the ECG signal and Peak Detection Algorithm for an accurate detection of peaks along with computation of peak intervals. The DTCWT technique has been evaluated based on performance metrics such as the Signal to Noise Ratio (SNR), Mean Square Error (MSE), and Percent Root Mean Square Difference (PRD). By comparing the performance parameters of the presented technique with other techniques, DTCWT was found well suited for an ECG denoising. Later different databases are used to verify the diseases on the basis of Heart rate (bpm) and RR interval (sec). Table 1 signifies the Heart diseases related to Peak morphology which indicates various diseases at particular Heart Beat rate, complexes, and intervals. This paper is further organized as: section 2 explains methodology which is followed by the experimental results and their comparison with existing papers in Section 3 and concluded in section 4.

Table 1. Symptoms of different Heart Diseases based on Complexes and intervals

Diseases related with QRS wave	Symptoms on ECG wave
Bradycardia	$HR < 60$ bpm, PR interval: 0.12 - 0.20 sec, RR interval:0.6-1.2
Atrial Tachycardia	100bpm $< HR < 175$ bpm, Missing P wave, RR interval < 0.6 sec
Atrial flutter	250bpm $< HR < 400$ bpm, QRS: less than 0.10 sec
Supra Ventricular Tachycardia	$150bpm > HR > 250$ bpm, Prolonged QT interval, P wave difficult to visualize, RR interval < 0.6sec
Sick Sinus Syndrome	$HR < 40$ bpm
Premature Ventricular Contraction	Skipped Heartbeat, $QRS > 0.12$ sec
Sinus Tachycardia	100 bpm $< HR < 180$ bpm, $QRS < 0.10$, PR interval : 0.12 - 0.20 sec
Sinus Arrhythmia	60bpm $< HR < 100$ bpm, $QRS < 0.10$, PR interval : 0.12 - 0.20 sec
Ventricular flutter	$HR > 250$ bpm
Ventricular Tachycardia	$HR > 100$ bpm, RR interval < 0.6sec
Normal Rhythm	60bpm $< HR < 100$bpm, 0.6 sec $< RR$ interval < 1.2 sec

2. Methodology

Input signal of ECG category i.e. MIT-BIH Arrhythmia v5 is taken from Physio Bank ATM database of 100 records [19]. This input ECG signal has length of 1536 samples which is sampled at rate of 360 Hz. The whole process of implementation of DTCWT technique along with peak detection algorithm with the help of flow graph is shown in "Fig.1".

2.1 Preprocessing Stage- Input ECG signal was fed to digital FIR High pass filter using Blackman windowing technique to remove Base Line Wander noise with cut-off frequency 0.5 Hz. The order of filter is taken $N = 10$ by defining the window length i.e. $N + 1 = 11$ [20].

2.2 Denoising Stage - ECG signal is a non-stationary signal that cannot be denoised using normal filter. In most recent studies, wavelet transform has been used to denoise these non-stationary signals by virtue of its high performance and qualitative characteristics. In this work, DTCWT has been employed for this stage as explained in the following section.

2.2.1 Signal decomposition using Dual Tree Complex Wavelet Transform (DTCWT)-DTCWT has been applied at the output obtained from preprocessing stage. This technique is composed of two DWTs in which first DWT give real part and second DWT gives the imaginary part. These two real DWTs use two different sets of filter with each satisfies Perfect Reconstruction (PR) conditions. The two set of real filters are jointly designed so that wavelet is approximately analytic resulted coefficients are complex numbers which is expressed by "equation (1)".

$$\Psi(t) = \Psi_h(t) + j\,\Psi_g(t) \qquad (1)$$

where $\Psi_h(t)$ values are real and even part while $\Psi_g(t)$ values are real and odd such that

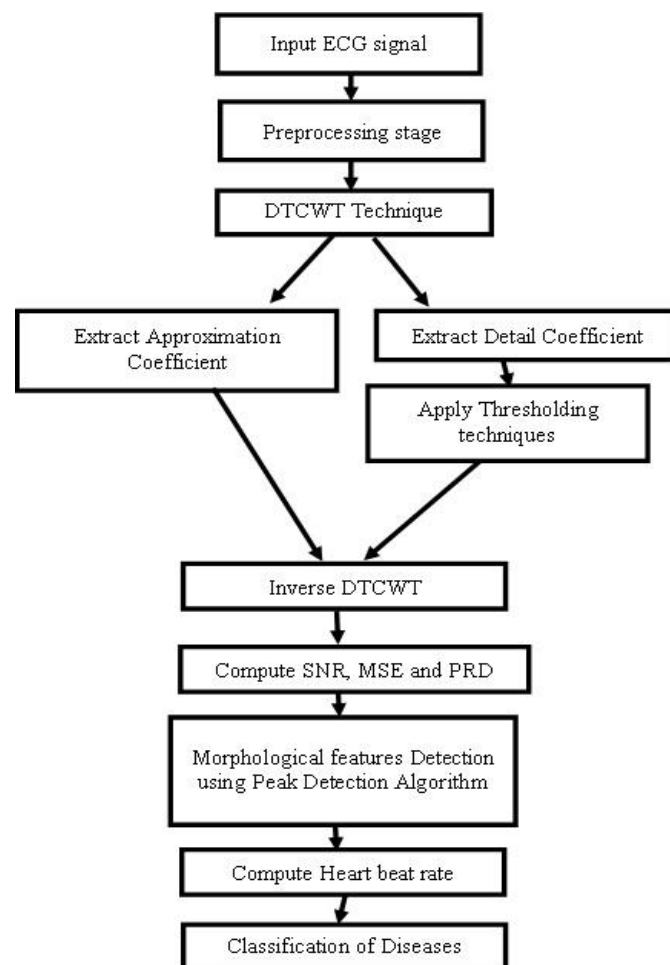$$\Psi_g(t) \approx H\,\Psi_h(t) \qquad (2)$$

Figure1. Flow Graph

where H is the Hilbert transform. In DTCWT, output is computed by two filter banks; each filter bank consists of two high pass and low pass filter pair as shown in "Fig.2". Two times transformation leads to expansion of the DWT coefficients, because N coefficients in DWT turn into $2N$ coefficients in DTCWT. In "Fig. 2", x is the input signal, $h_o(n)$ is the low pass filter output and $h_1(n)$ constitutes High pass filter for upper filter bank and $g_o(n)$ and $g_1(n)$ denotes Low pass and High pass filter pair respectively for lower filter bank. Each stage comprises of two digital filters and two down samplers by 2 to produce digital signal. The down sampled output of $h_o(n)$ and $h_1(n)$ give approximation coefficient and detail coefficient for upper filter bank respectively. Approximation coefficient are low frequency components called as scaling function which were extracted at the end of set level of decomposition whereas, detail coefficient are high frequency components known as wavelet functions. Similarly, output of low pass filter $g_o(n)$ and high pass filter $g_1(n)$ give approximation coefficient and detail coefficient for lower filter bank respectively. The approximation coefficient is further decomposed and the process continues till the set level of decomposition. In this process, DTCWT technique is implemented up to 4 level of decomposition to compute the absolute value of the real and imaginary coefficients. Complex detail coefficients have been extracted at each level of decomposition scale which provides 4 detail sub bands designated as weight 1 complex (*wt1Com*, *wt2Com*, *wt3Com* and *wt4Com*). Similarly, complex approximation coefficients are extracted as *wt5Com* sub band. The details of coefficients at each sub band of approximation level and detail level are depicted in Table 2. The number of decomposition level is chosen such that classification of signal is retained in the wavelet coefficient.
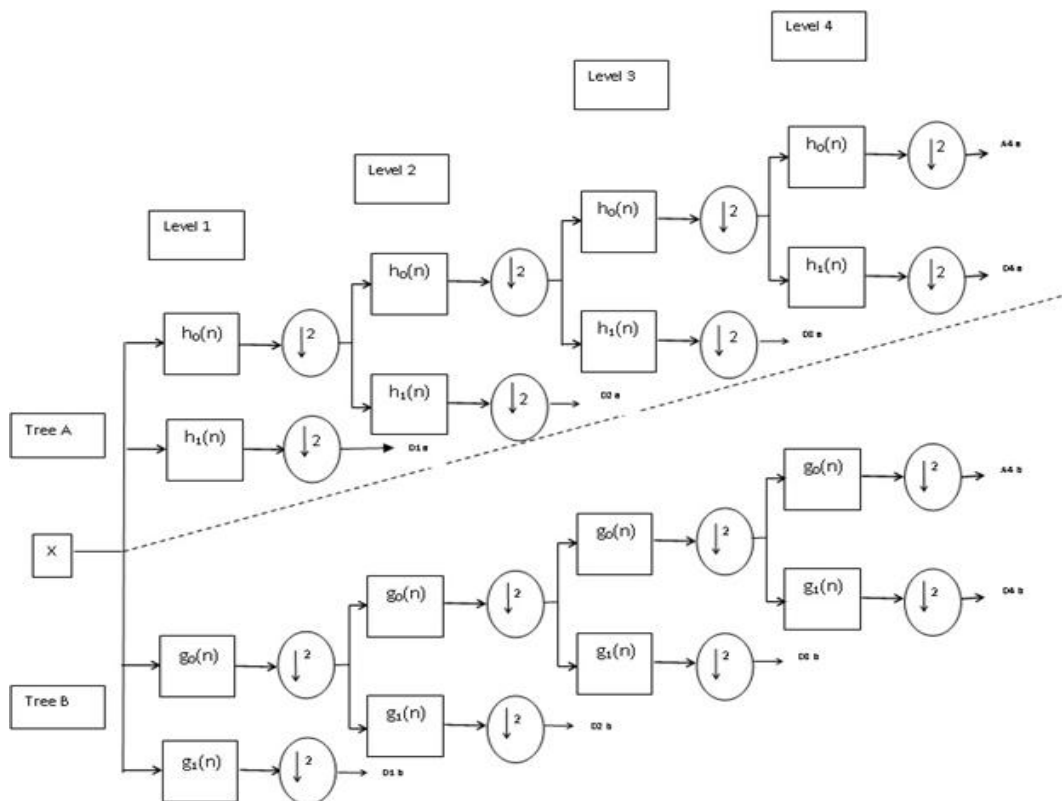

Figure 2. Multilevel decomposition using DTCWT

Table 2. Coefficient at each sub band of Detail and Approximation level assuming sampling frequency (f_s) 360 Hz

S.No.	Sampling Frequency at each decomposition level	Sub Bands of Detail and Approximation Coefficients (upper filter bank + lower filter bank)	Number of Coefficients (In Complex form)
1.	180	$wt1Com = d_{1a} + i\,d_{1b}$	768
2.	90	$wt2Com = d_{2a} + i\,d_{2b}$	384
3.	45	$wt3Com = d_{3a} + i\,d_{3b}$	192
4.	22.5	$wt4Com = d_{4a} + i\,d_{4b}$	96
5.	22.5 (Approximation)	$wt5Com = a_{4a} + i\,a_{4b}$	96

2.2.2 Thresholding Technique-Thresholding technique has been applied to every detail coefficient to denoise the data [21]. Many thresholding techniques have been developed in literature which includes Donoho Method [22], Neigh Block, Savitzky method by [23], Hard thresholding and Soft thresholding. A robust estimation method of noise level δ is proposed by Donoho and Jhonstone based on Median Absolute Deviation (MAD) has been applied in this paper. Noise level δ is calculated by the "equation (3)".

$$\delta = \left(\frac{median\{|\chi_{iv}|\}}{0.6745} \right) \tag{3}$$

where χ_{iv} represent the detail coefficients at finest level. Threshold value λ is calculated using "equation (4)" which is expressed as

$$\lambda = \delta \sqrt{2\log(k)} \tag{4}$$

where k is the size of signal at particular detail level. After computing the threshold value for each decomposition level, soft thresholding technique is applied at each level to remove the noise given by "equation (5)".

$$Y = sign(x).\left(|x| - \lambda\right) \tag{5}$$

where Y is the output, and x is the input value. In soft thresholding, the coefficients in magnitude greater than threshold value are shrunk towards zero by subtracting the threshold value from coefficient value.

2.2.3 Inverse DTCWT-The inverse DTCWT is computed on the threshold wavelet coefficients to obtain the denoised signal.

2.2.4 Performance Parameter Evaluation– The performance metrics such as Signal to Noise Ratio (SNR), Mean Square Error (MSE) and Percent Root Mean Square Difference (PRD) are computed to analyze the denoising process. The best results are achieved when the recovered signal has highest SNR, smallest PRD and has lowest MSE.

2.3 Morphological Feature Extraction using Peak Detection Algorithm–Morphological features of an ECG signal such as amplitude and locations of *P*, *Q*, *R*, *S*, *T* peaks and their intervals has been detected using Peak Detection Algorithm.

<div align="center">

Peak Detection Algorithm

Input – Pre-processed signal (*Y*)

Output – Peak Detection

</div>

1.   Define Sample Rate
2.   Detection of *R* peak : The point with maximum amplitude gives the *R* peak location.

If *R* peak is located for each cycle (R_{peak}), then different other peaks are detected by the following methods:

3.   Detection of *P* peak :*P* peak location detection is given as

$$a = \left[R_{peak} - \left(\frac{Sample\ Rate \times 25}{Beat} \right) \right] : \left[R_{peak} - \left(\frac{Sample\ Rate \times 5}{Beat} \right) \right]$$

<div align="center">

P peak amplitude = max(*Y*(*a*));

</div>

4.   Detection of *Q* peak :*Q* peak location detection is given as

$$b = \left[R_{peak} - \left(\frac{Sample\ Rate \times 10}{Beat} \right) \right] : \left[R_{peak} - \left(\frac{Sample\ Rate \times 1}{Beat} \right) \right]$$

<div align="center">

Q peak amplitude = min(*Y*(*b*));

</div>

5.   Detection of *S* peak :*S* peak location detection is expressed as

$$c = \left[R_{peak} + \left(\frac{Sample\ Rate \times 1}{Beat} \right) \right] : \left[R_{peak} + \left(\frac{Sample\ Rate \times 5}{Beat} \right) \right]$$

<div align="center">

S peak amplitude = min(*Y*(*c*));

</div>

6. Detection of *T* peak: *T* peak location detection is represented as

$$d = \left[R_{peak} + \left(\frac{Sample\,Rate \times 10}{Beat} \right) \right] : \left[R_{peak} + \left(\frac{Sample\,Rate \times 30}{Beat} \right) \right]$$

T peak amplitude $= \max(Y(d))$;

End

Computation of Heart Beat Rate– Finally, Heart beat rate of denoised signal is computed using "equation (6)".

$$Heart\,Rate = \frac{Sample\,Rate \times 60}{R_2 - R_1}$$

(6)

where R_2 and R_1 represents the location of two subsequent R peaks on time scale

3. Results and discussions

In this section methodology which is explained in Section 2 was implemented using MATLAB. First stage is preprocessing stage. In preprocessing stage, output of an ECG signal has been obtained after removing baseline wander noise as shown in "Fig.3". In second stage, detailed and approximate coefficients are calculated by applying DTCWT technique on preprocessed signal as shown in "Fig.4" and "Fig.5". After applying the proposed algorithm for removing the noise from ECG signal, inverse DTCWT is applied to reconstruct the signal shown in "Fig.6". The performance parameters SNR, MSE and PRD of denoised signal using proposed algorithm are tabulated in Table 3.
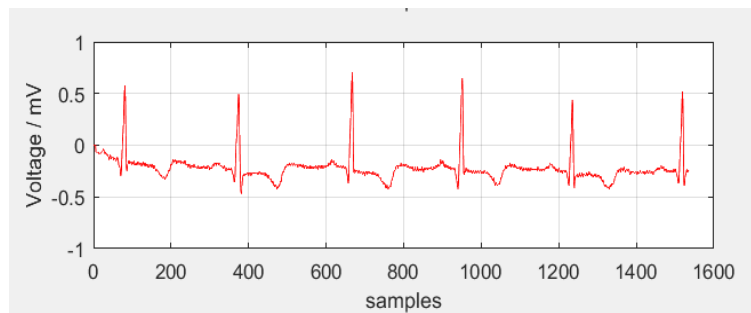

Figure3. Time domain analysis of ECG signal filtered by FIR High Pass filter using Blackman window
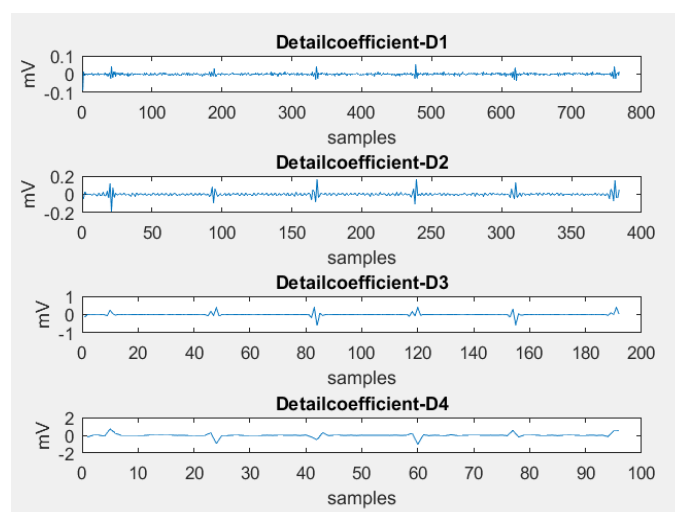

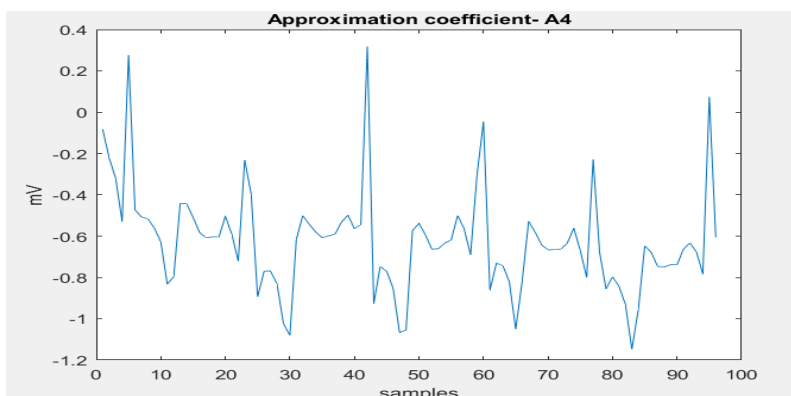Figure 4. Detailed coefficients using DTCWT at different levels.

Figure 5. Approximation coefficient using DTCWT at level 4
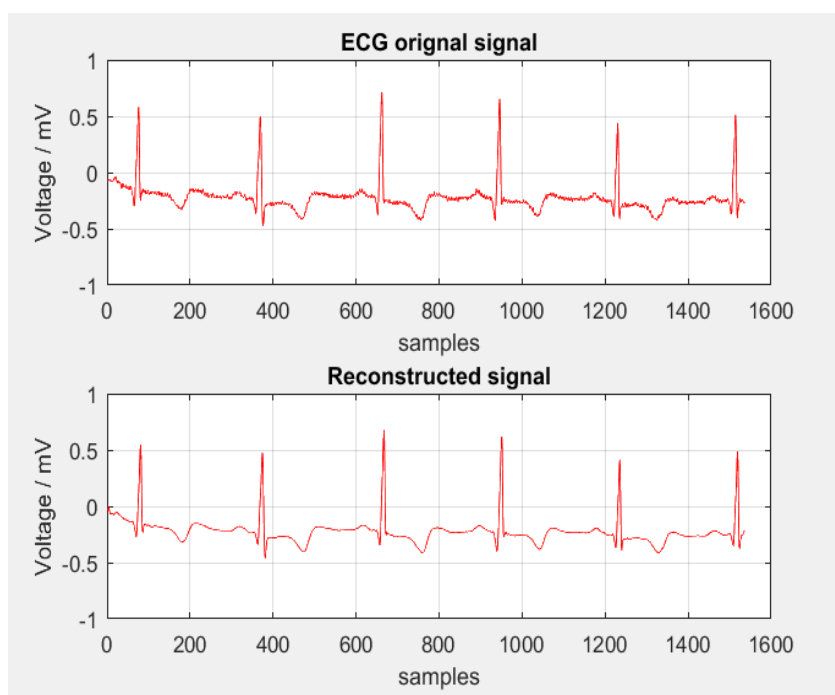

Figure 6. ECG original signal and Reconstructed signal

Table 3. Performance Parameters of Denoised Signal Using DTCWT

S.No.	Wavelet Family	SNR of original signal (dB)	SNR of denoised signal (dB)	MSE	PRD
1.	DTCWT	- 4.9666	27.7500	1.0777e-04	0.0410

3.1 Comparison table with previous work

The results obtained by our proposed algorithm are compared with the previous research papers are shown in Table 4. On comparing the performance metrics of proposed technique with other techniques, the comparative result shows that proposed technique is well suited for denoising any ECG signal.Later, different peaks of the denoised and reconstructed ECG signal have been detected using Peak Detection Algorithm as shown in "Fig.7".

Table 4. Comparison with Existing Techniques

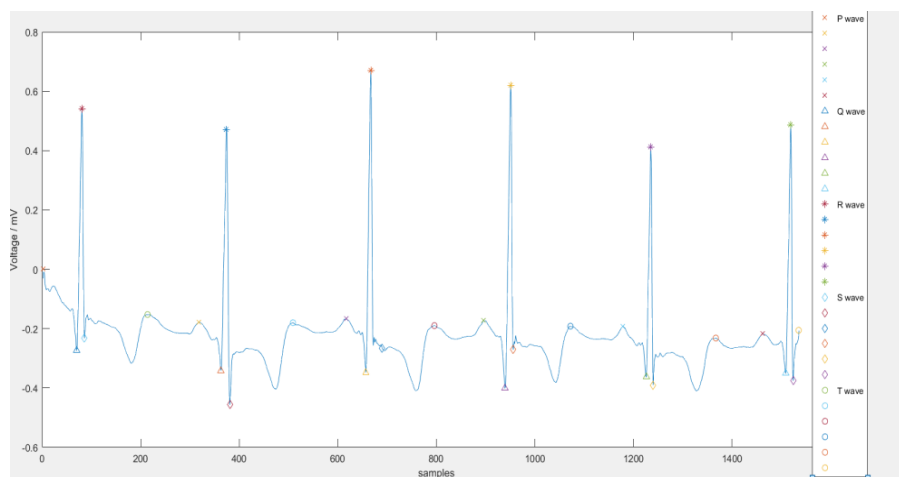| S.No.	Technique	SNR (dB)	MSE	PRD
1.	Proposed Technique	27.7500	1.0777e-04	0.0410
2.	DWT [23]	26.5396	1.4172e-04	0.0471
3.	Neigh Block [17]	4.2177	0.62052	4.8693
4.	Savitzky [17]	2.0434	1.28079	6.9956

Figure 7. Detection of peaks of Denoised signal using Peak detection algorithm

Different peak intervals like *R-R* interval, *P-Q* interval, *QRS* complex and *S-T* interval at each cycle of denoised ECG signal has been computed and, average of every interval is taken which is depicted in Table 5. Table also gives the comparative result of intervals and complexes using two techniques (DWT and DTCWT).

137

Table 5. Calculation of Different Peak Intervals

S.No.	Types of Intervals	DWT Technique (sec)	DTCWT Technique (sec)
1.	*R-R* interval	0.8021	0.7989
2.	*P-Q* interval	0.1333	0.1329
3.	*P-R* interval	0.1628	0.1620
3.	*QRS* complex	0.0517	0.0523
4.	*S-T* interval	0.3479	0.2852

Heart beat rate is computed using DTCWT technique and on comparing this value with the given range of MIT-BIH Arrhythmia database, we observe that the resultant value falls in the range which is illustrated in Table 6.

Table 6. Heart Beat Rate Computation

Heart Beat Rate per minute	Heart Beat Rate computation using DTCWT technique.	Heart Beat Rate mentioned in MIT-BIH Arrhythmia Database (Gold Standard) [18]
	75.1219	70-89

We have already classified the different diseases based on HR and RR interval expressed in Table 1. On the basis of obtained results of Heart rate and RR interval of different standard databases, nature of type of disease related to heart have been computed and tabulated in Table 7.

Table 7. Types of diseases related to HR and RR interval for different ECG databases

Database	Heart Rate (bpm)	RR interval (sec)	Disease
MIT/BIH Arrhythmia(MLII) 100 record	75.1219	0.7989	Normal Rhythm
MIT/BIH Arrhythmia (MLII) 103 record	161.0799	0.4278	Atrial Tachycardia
MIT/BIH Arrhythmia (MLII) 106 record	204.8729	0.4452	Supra Ventricular Tachycardia
MIT/BIH Noise Stress Test (MLII)	58.7456	1.10	Bradycardia

In next phase, different optimization algorithms like Cuckoo-search, particle swarm optimization, differential evolution and artificial bee colony algorithms [24],Swarm inspired evolutionary algorithm ,Numerical function optimization [25] and Elephant herding optimization (EHO) [26] will be implemented on different ECG databases to find a subset of ECG features from larger feature pool to achieve better classification performance.

4. Conclusion

This paper presents the denoising of an ECG signal using Dual Tree Complex Wavelet Transform technique. Simulation results with different techniques, shows that our proposed algorithm has the highest SNR, smallest PRD and lowest MSE. This paper also outlines the extraction of different features like fiducial point localization, time intervals measurements, and morphology analysis using Peak Detection Algorithm on the

proposed denoised and reconstructed signal. Later different databases are used for calculation of heart rate and RR interval for determining the accurate heart disease.

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