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Feature Extraction and Classification of ECG Signal Based on The Standard Extended Wavelet Transform Technique: Cardiology Based Telemedicine

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Abstract

For early detection of cardiac abnormalities, an ECGs cardiac signal is relied upon due to it includes a lot of information that can be utilized for heart disease classification. The ECG signal is too sensitive to various types of noise since it is low frequency and has a small amplitude, these noises decrease the diagnostic accuracy and may outcome in a wrong decision by the clinician. Therefore, rejecting the ECG signal is a necessary condition for successful diagnosis of heart attacks. In this manuscript, the standard extended of Discrete Wavelet Transform called Dual-Tree Complex Wavelet Transform (Dual-Tree (CWT)) method is utilized to denoise the noisy ECG signal and extract the key features followed by the implementation of the peak detection algorithm. The quality is measured based on performance metrics, and an increase in Signal to Noise Ratio (SNR) is achieved utilizing the technique. The heart rate (HR) calculation is in line with the gold standard of the various benchmark databases utilized for the proposed procedure and precise heart failure has been calculated.

Keywords: Electrocardiogram (ECG Signal), Dual-Tree Complex Wavelet Transform (Dual-Tree (CWT)), Peak Detection Algorithm, Blackman windowing(BmW).

1. Introduction

The ECG shows an electrical activity of the heart that helps cardiologists to gain valuable information on whether well the heart functions. Any disorder in the heart, leads towards the Heart Disease often detected by an ECG signal. Some of the common heart diseases are



Coronary, Arrhythmia, and Myocardial Infarction. An accurate ECG feature analysis is needed for heart disease detection. Changing the amplitude and frequency of the cardiac signal (ECG signal) due to noise effects at various levels creates a major problem and the biggest challenges for actual distortion detection[1].

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 the frequency domain. In this context, the Fast Fourier Transform (FFT) technique has been introduced which more information concerning the exact location of the frequency components was not provided. 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 [2]. Among all, DWT has become a significant computational tool to perform the signal processing. It can overcome a limitation of the size of Time window that does not vary with the frequency [3].

Further utilize 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 bypass those limitations and provide an effective signaling tool for a dual-tree (CWT) technique that has shifted invariance and anti-aliasing effect for biomedical signals. There are some techniques such as FTIR (Fourier-Transform-Infrared-Spectroscopy), NMR (Nuclear-Magnetic-Resonance-Spectroscopy), FSp (Fluorescence-Spectroscopy) are utilized for Nanoparticle and Protein interaction in biomedical applications[4][5].

This manuscript outlines the Dual-Tree (CWT) technique to denoise the ECG signal and peak detection algorithm for an accurate detection of peaks along with computation of peak intervals. Based on metrics-peformance, the Dual-Tree (CWT) technique has been evaluated, 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, Dual-Tree (CWT) was found well suited for an ECG denoising. Later various databases are utilized to verify the diseases on the basis of HR (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[6][7].

This manuscript is prepared as a follows: Section 2, explains the methodology of this technique which is followed by the experimental outcomes and their comparison with existing manuscripts in Section 3 and concluded in Section 4.

Table 1, shows the symptoms of various Heart diseases based on complexes and intervals

Associated Diseases with QRS wave	Indications on ECG wave (Symptoms)
Bradycardia	HR < 60 bpm, PR interval: 0.12 - 0.20 sec, RR interval:0.6-1.2
Tachycardia Auricular	100bpm < HR < 175 bpm, Wave of missing P, 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
Sinus-sick syndrome	HR < 40 bpm
Premature contraction in the ventricle	Skipped Heartbeat, QRS > 0.12 sec
Tachycardia sinus	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
Fluttering Ventricular	HR > 250 bpm
Tachycardia ventricle	HR > 100 bpm, < 0.6sec RR Interval
Natural Rhythm	0.6 seconds < RR < 1.2 seconds, 60bpm < HR < 100bpm

2. Related Works

ECG signal denoising was addressed in various ways in ECG signal processing studies by artifacts elimination occurred during ECG signal acquisition for signal classification or other purposes. Some of these studies are presents as follows:

In [8] researchers was presented an ECG signal waveform denoising method for various artifacts. ECG signal is denoised by utilizing CEEMD, LMS, NLMS methods. In [9] ECG signal is analyzed utilizing the cluster analysis technique, this method involves three phases; the first, extracting the QRS waveform phase, the second phase is choosing qualitative features, and the third phase is heartbeat determination. This technique analyses and classified normal and abnormal heartbeat. In [10] ECG signal artifacts reductions are provided via the new method of combination of DWT and ANN. The work of the WT is decomposed the ECG signal and remove the artifacts then the second phase of the ANN is performed the IDW and adaptive filtering for remaining noise elimination . In [11], researcher introduced a classifier of KNN algorithm for QRS complex detection. In [12], the researcher has performed an R-peak detection algorithm to detect the peaks of ECG signals . In [13], researchers have utilized three kinds of classification that are; BP neural network, FF neural network, and MLP neural network.

3. Research Methodology

ECG Signal is gained from 100 records of MIT- BIH Arrhythmia Physio-Bank-ATM. These signals input has a total of 1536 samples that is sampled at the 360 Hz rate. The entire Dual-Tree (CWT) technique implementation process along with peak detection algorithm with the aid of flows graph is seen in Fig.1[14].

3.1 Preprocessing Phase

Utilizing a BmW method to eliminate wandering noise on base line with cutoff frequency 0.5 Hz, digital FIR High-pass filter was fed to the input ECG signal. The filter order is taken $N=10$ by determining the length of the window, i.e. $N+1=11$ [15].

3.2 Denoising Phase

ECG signal is a non-stationary signal that cannot be denoised utilizing normal filter. In most recent studies, wavelet transform has been utilized to denoise these non-stationary signals by virtue of its high performance and qualitative characteristics. In this work, Dual-Tree (CWT) has been employed in this phase as explained in the following section[16].

3.3 Dual-Tree (CWT)

The dual-complex wavelet transformation (CWT) fixes the shift variety and low directional selectivity issues in two and larger sizes found with the commonly utilized DWT[17].

The Dual-Tree (CWT) utilized two independent DWT decompositions (tree a and tree b) to measure the dynamic transformation of a signal. If the filters utilized in one are constructed in a different way from those utilized in the other, the actual coefficients can be generated by one DWT and the imaginary by the other[18].

3.3.1 Signal Decomposition Utilizing Dual-Tree (CWT)

Dual-Tree (CWT) has been applied at the output obtained from preprocessing phase. 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 utilize two separate filter sets with each one satisfying the conditions of Perfect-Reconstruction (PR). Both are separate sets of real filters are constructed together so that wavelet almost analytical result coefficients are complex numbers expressed by Equation (1)[19].

$$\psi_{(t)} = \psi_h + j\psi_g(t) \quad (1)$$

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

$$\psi_g(t) \approx H \psi_h(t) \quad (2)$$

where H is the Hilbert transform. In Dual-Tree (CWT), 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 time transformation leads to expansion of the DWT coefficients, because N coefficients in DWT turn into $2N$ coefficients in Dual-Tree (CWT)[18] [20].

In Fig. 2, x is the input signal, $h_o(n)$ is the low-pass filter output and $h_1(n)$ constitutes upper Filter Bank High-pass Filter and $g_o(n)$ and $g_1(n)$ denotes Low-pass and High-Pass Filter pair respectively for lower filter bank. The advanced phase comprises of two digital filters and two-down devices to generate the digital signal. The down sampled output of $h_o(n)$ and $h_1(n)$ give approximation coefficient and the detail coefficient for upper filter bank respectively.

Approximation coefficient is low frequency components called as a scaling function which were extracted at the end of a set level of decomposition whereas, detail coefficient are high frequency components known as wavelet functions. Likewise, the output of $g_o(n)$ Low-Pass Filter and $g_1(n)$ High-Pass Filter provides approximation coefficient and the information coefficient respectively for the lower filter row. The coefficient of approximation is then decomposed, and the process must continue to the point of decomposition. In this process, Dual-Tree (CWT) technique is implemented up to 4 levels of decomposition to compute the absolute value of the real and imaginary coefficients[19][20]. 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 selected such that the classification of the signal is preserved in the wavelet coefficient [21].

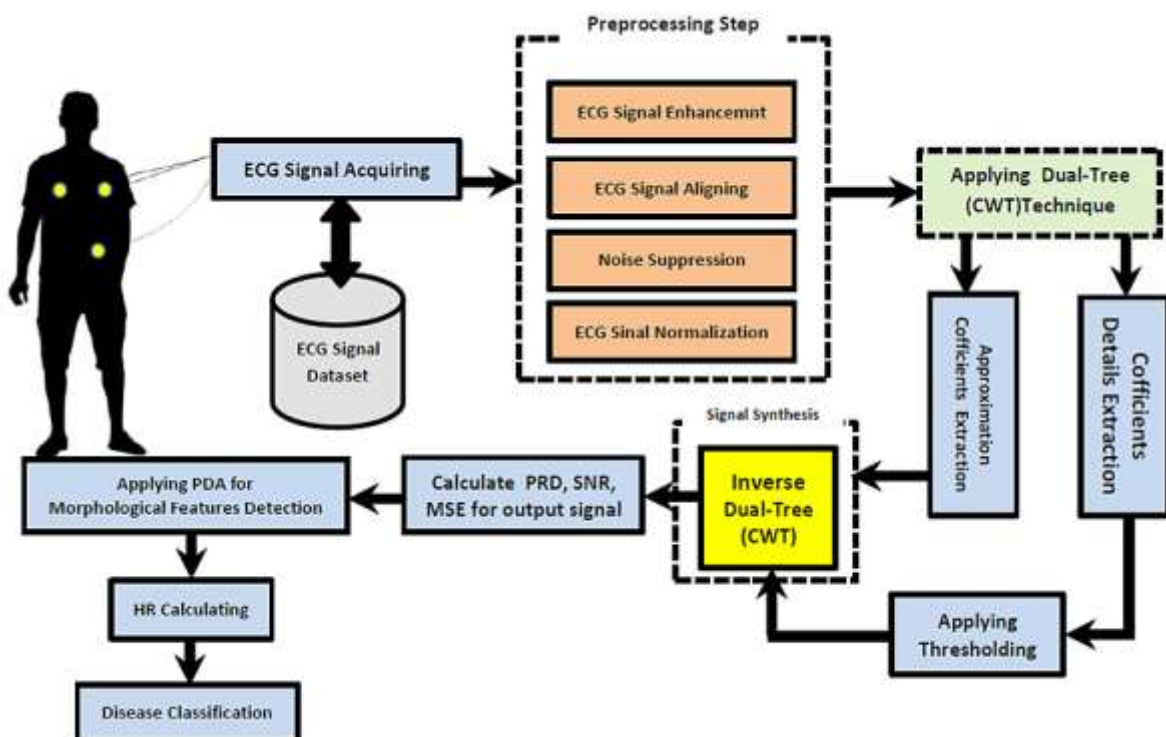


Fig.1, The System Flowgraph

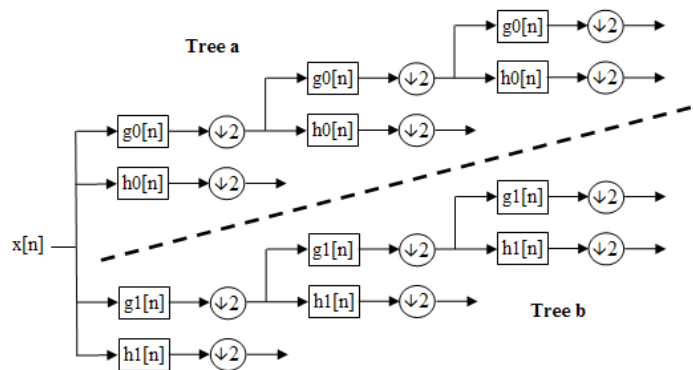


Fig. 2, Multilevel decomposition utilizing Dual-Tree (CWT)

Table 2, shows coefficient at each sub band of detail and approximation level, assuming the 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	$wt1Com = d1a + i d1b$	768
2.	90	$wt2Com = d2a + i d2b$	384
3.	45	$wt3Com = d3a + i d3b$	192
4.	22.5	$wt4Com = d4a + i d4b$	96
5.	22.5 (Approximation)	$wt5Com = a4a + i a4b$	96

3.3.2 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 manuscript. Noise level δ is calculated by the Eq. (3).

$$\delta = (\text{median} \{|\chi_{iv}|\} / 0.6745) \quad (3)$$

where represent the detail coefficients at finest level. Threshold value λ is calculated utilizing Eq. (4) which is expressed as

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

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 Eq. (5).

$$Y = \text{sign}(x) \cdot (|x| - \lambda) \quad (5)$$

Where output is Y , and the input value is x . In soft thresholds, the magnitude coefficients above the threshold value are lowered to zero by removing the threshold value from the coefficient value [24].

3.3.3 Inverse Dual-Tree (CWT)

Dual-Tree Inverter (CWT) is computed on the threshold wavelet coefficients to obtain the denoised signal [25].

3.3.4 Performance Parameter Evaluation

The functioning metrics, SNR, MSE and PRD for example, are calculated to analyze the denoising process. The best outcomes are achieved when the recovered signal has highest SNR, smallest PRD and has lowest MSE [26][27].

3.4 Morphological Feature Extraction by Peak Detection Algorithm Utilization

Morphological features of an ECG signal such as amplitude and locations of P , Q , R , S , T peaks and their intervals have been detected utilizing peak detection algorithm [25].

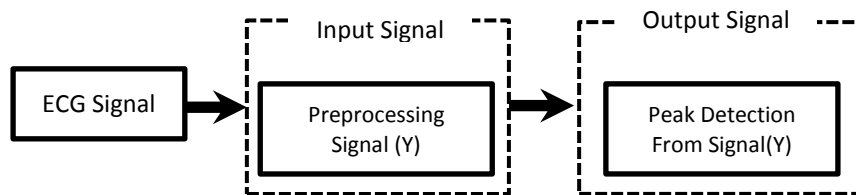


Fig. 3, The Structure of Peak Detection Algorithm

3.5 Peak Detection Algorithm Steps

The steps of peak detection algorithm could be listed below:

Step 1: Determine the Sample Rate.

Step 2: R peak detecting of: The R peak position is given by the point with maximum amplitude. In each cycle (Rpeak) If R peak is located, then the following methods detect varying other peaks:

Step 3: P peak detecting: Detection of peak locations P is given as

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

$$P \quad \text{peak amplitude} = \max(Y(a));$$

Step 4: Q peak detecting: Detection of peak position Q is given as

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

$$Q \quad \text{peak amplitude} = \min(Y(b));$$

Step 5: S peak detecting: Detection of peak position S is given as

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

R peak amplitude = $\min(Y(c))$;

Step 6: T peak detecting: Detection of peak position T is given as

$$d = \left[R_{Peaks} - \left(\frac{\text{Sample Rate} \times 10}{\text{Beat}} \right) \right] : \left[R_{Peaks} - \left(\frac{\text{Sample Rate} \times 30}{\text{Beat}} \right) \right]$$

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

Step 7: Heart Beat Rate Calculation: Lastly, heart beat rate of denoted signal is calculated utilizing Eq. (6).

$$\text{Heart Rate} = \frac{\text{Sample Rate} \times 60}{R_2 - R_1} \quad (6)$$

Where R_2 and R_1 are the positions of two corresponding Time Scale R peaks.

Step 8: End [28][29].

4. Outcomes and discussions

Based on this section, the methodology which is explained in Section 2 was implemented utilizing MATLAB. The first phase is preprocessing phase. In preprocessing phase, the effects of an ECG signal have been obtained after eliminating wandering noise on base line as shown in Fig.3. In the second phase, detailed and approximate coefficients are calculated by applying Dual-Tree (CWT) technique on preprocessed signal as shown in Fig.4 and Fig.5. On implementation of the proposed algorithm to keep the noise off the ECG signal, inverse Dual-Tree (CWT) is applied to reconstruct the signal shown in Fig.6. The performance parameters SNR, MSE and PRD of denoised signal utilizing the proposed algorithm are tabulated in Table 3.

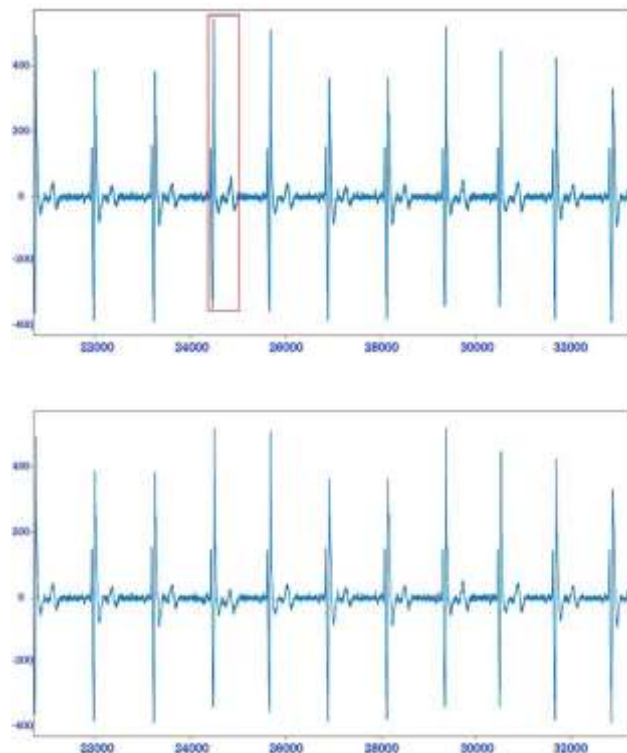


Fig.3, Time-analyzed ECG signal filtered by FIR High Pass filter utilizing BmW

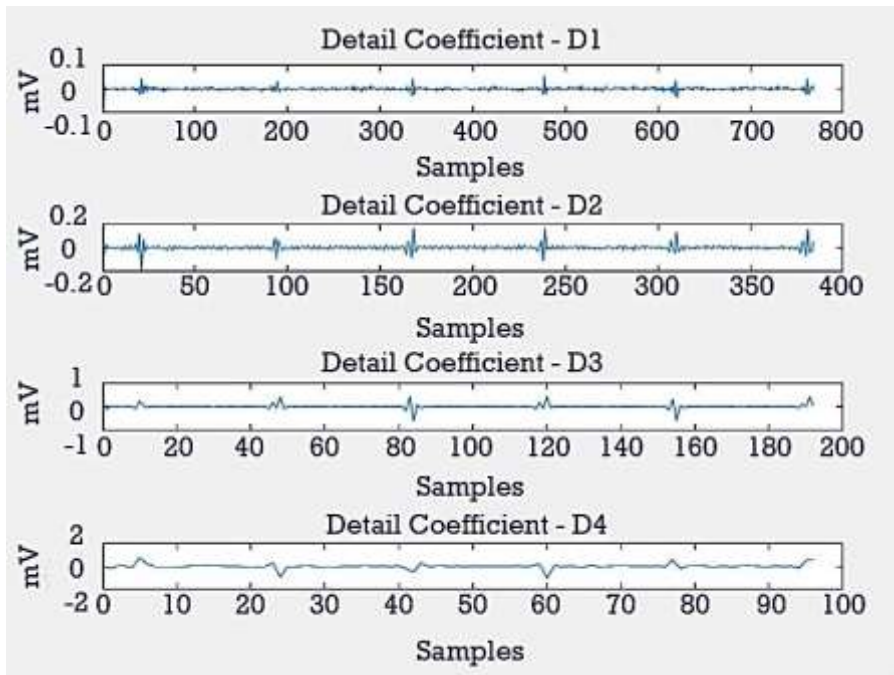


Fig. 4, Coefficients details utilizing Dual-Tree (CWT) at various levels.

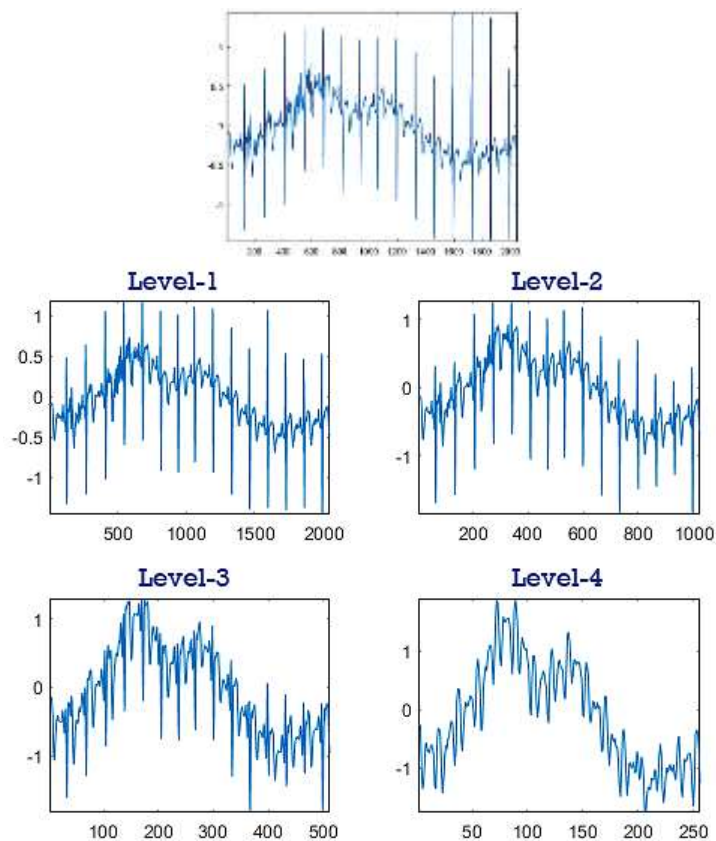


Fig. 5, Approximation coefficient utilizing Dual-Tree (CWT) at 4 level (1,2,3, and 4)

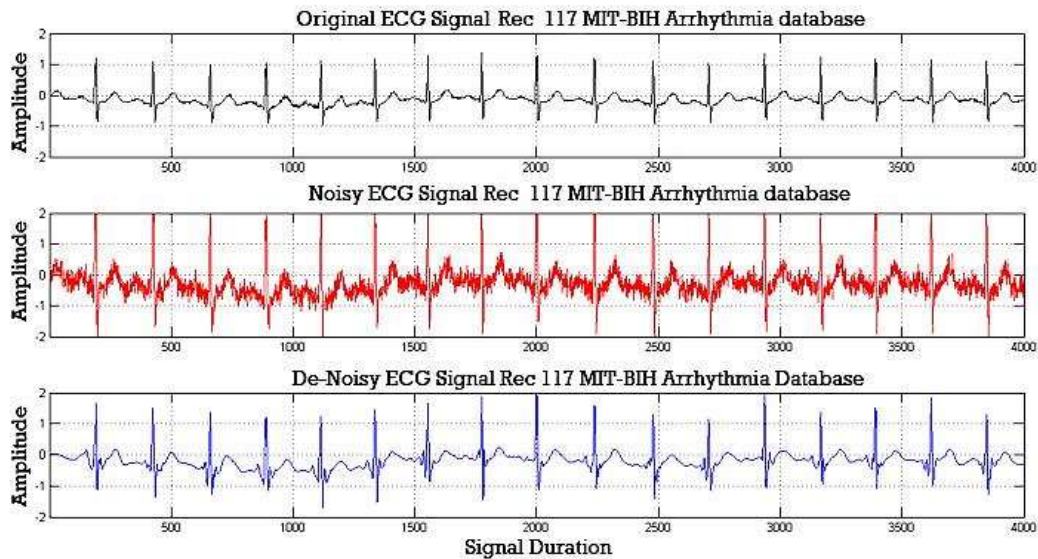


Fig. 6, ECG original signal and Reconstructed signal

Table 3, shows the performance parameters of denoised signal utilizing Dual-Tree (CWT).

S.No.	Wavelet Family	SNR of original Signal	SNR of denoised signal	MSE	PRD
1.	Dual-Tree	- 4.9666	27.7500	1.06887e-	0.0410

5. Related Works Comparison

A comparison of performance obtained with our proposed algorithm with a previous research manuscript is shown in Table 4. When the performance metrics of the technique proposed are compared to other techniques, the outcome of the analysis indicates that the technique proposed is well suited for denoising any ECG signal. Earlier, as illustrated in Fig.7, the different peaks of the denoised and reconstructed ECG signal were identified utilizing peak detection algorithm.

Table 4, shows the 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

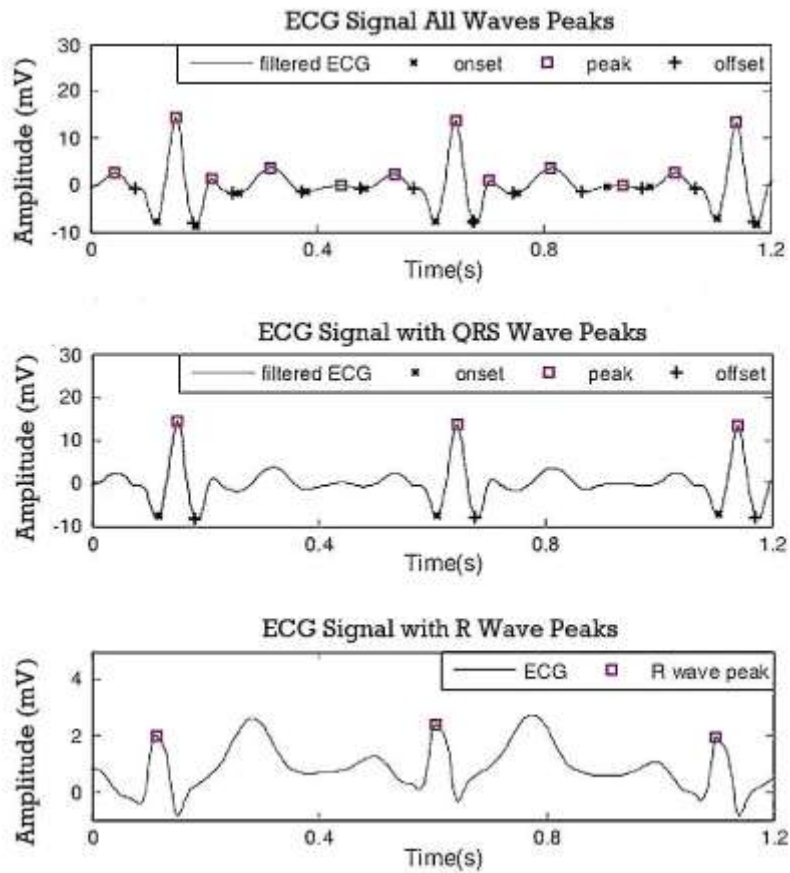


Fig. 7, Detecting Denoised ECG Signal Peaks Utilizing Peak Detection Algorithm

Various 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. The table also gives the comparative outcome of intervals and complexes utilizing two techniques (DWT and Dual-Tree (CWT)).

Table 5, shows the calculation of various peak intervals.

Signal No.	Types of Intervals	DWT Technique (sec)	Dual-Tree (CWT) 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 utilizing Dual-Tree (CWT) 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 explained in Table 6.

Table 6, shows the heart beat rate calculation

Heart beat rate per minute	Calculating the rate of pulse utilizing Dual-Tree (CWT) Method	Heart beat rate mentioned in MIT-BIH Arrhythmia Database (Gold Standard)
	75.1219	70-89

Various diseases based on HR and RR interval expressed are classified in Table 1. The nature of the type of disease related to heart have been calculated in Table 7, on the basis of obtaining the outcomes of HR and RR interval of various standard databases.

Table 7, the types of diseases related to HR and RR interval for various ECG databases

Database	Heart Rate (bpm)	RR interval (sec)	Disease
MIT/BIH Arrhythmia(MLII) 100 record	75.1219	0.7989	Natural Rhythm
MIT/BIH Arrhythmia (MLII) 103 record	161.0799	0.4278	Tachycardia Auricular
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 the next phase, various optimization algorithms like Cuckoo-search, particle swarm optimisation, differential evolution and algorithms for artificial bee colony, Swarm inspired evolutionary algorithm ,Numerical function optimization and Elephant herding optimization (EHO) will be implemented in various ECG databases to attain an ECG features subset from the larger feature pool to attain the best performance of classification.

6. Conclusion

This manuscript discusses the denoising of an ECG signal utilizing of Dual-Tree (CWT) technique. The outcomes from simulation with various techniques indicate that algorithm proposed has the maximum SNR, the minimum PRD and the lowest MSE. This manuscript also discusses the extraction of various features such as object detection point localization, measurements of time intervals, and morphology analysis utilizing peak detection algorithm on the proposed denoted and reconstructed signal. Later various databases are utilized to measure the HR and RR intervals to assess the frequency of the heart disease.

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