Study and Investigate life threatening ECG arrhythmias using morphological patterns and Wavelet transform method

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Abstract: *The work in this paper is to investigate the detection of another group of arrhythmias, which might not be need immediate attention but critically life threatening that decline health of heart and become cause of cardiovascular disease. The Electrocardiogram plays an imperative role to diagnose such cardiac disease. It is used to monitor and analyze all cardiovascular functioning and cardiac signal processing. But recorded ECG often contaminated by various noise and artifacts like power line interference, baseline wander and movement of patient muscles. Hence, for accurate diagnosis of heart disease and characterize normal rhythm from arrhythmic wave, the first step is to obtain clear ECG signal. As compared to conventional filtering methods, Wavelet transform has better denoising capability of such non-stationary signals, like ECG. Therefore, the proposed method used a discrete wavelet transform (DWT) based de-noising procedure for pre-processing of signal to obtain dynamic features and morphological patterns of ECG arrhythmia. The algorithm was implemented on MATLAB and used MIT BIH arrhythmia database.*

Keyword: Cardiac arrhythmia, ECG, Wavelet transform, Standard deviation, Mean square Error**.**

1. INTRODUCTION

Cardiac arrhythmia, a type of Cardiac Vascular Disease (CVD) is due to malfunctioning of heart when the heart does not function properly in the mechanism of blood pumping. It proves fatal if not detected in its early stage or interpret properly. Globally 17.3 million people died of CVDs in 2008 which was about 30% of all the deaths in the world. It is estimated that such causalities may grow further to 23.3 million by 2030 [1]. The detection of cardiac arrhythmia play a vital role to determine the condition of heart and for further, treatment. But the effective diagnostic process involves high accuracy in examine of every single heart beat from physiological signals. Electrocardiogram (ECG) reported all electrical activity of cardiac muscular cells and has a non-invasive nature. By analyzing the output of ECG, it can easy to detect any such abnormality in physiological functions of cardiac cells. Morphology patterns of ECG signal wave and measured value of heart beat, directly reflects condition of human heart. These measurements are important tool in medical instrumentation. Recommended by the AAMI (The Advancement of Medical Instrumentation) arrhythmias are classified in two categories, 1) Morphological Arrhythmia, and 2) Rhythmic Arrhythmia. The former is consists of one single irregular heart beat and the later is formed by a set of irregular heartbeats. These heartbeats can be identified through morphological patterns in ECG signal wave. Fig 1, shows a normal ECG waveform:

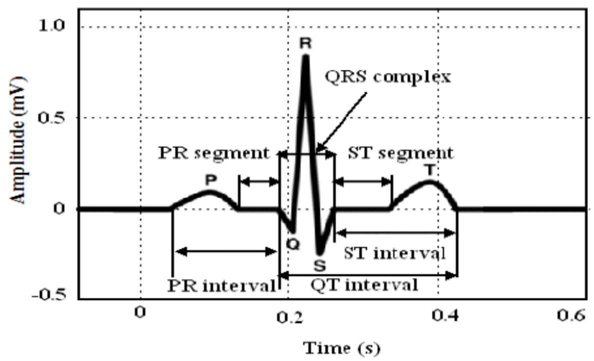


Fig 1: Schematic of Normal ECG signal waveform

As shown from above figure, ECG constitutes sequence of P, Q, R, S, QRS complex and T wave, accompanied by many intervals and segments. Each of them is used to represent two events in the form of electrical activity in cardiac cycle, ie. Depolarization, contraction of cardiac muscles and Re-polarization indicates their relaxation state during one heart beat. The first upward deflection is termed P wave, represents contraction of the right and left atria, and collectively called atrial de-polarization. Its shape is smooth and rounded. QRS complex indicate ventricular depolarization, consists of first downward deflection Q wave, first upward deflection with larger amplitude R wave, and sharp downward deflection S wave. This QRS complex gives information about conduction path in the ventricles. T wave reflects ventricles re-polarization. It has slightly symmetrical shape [2].

Generally, ECG signals can be contaminated with several types of noise which may change its characteristics and features. The major noise components are, 1) Power line interference (50 Hz from power lines), due to interference of main supply power on to measuring ECG recording leads; and 2) Baseline Wander Noise or Baseline drift (0.5Hz), caused by motion of patient while examining ECG recording. These noises degrade the signal of interest, accuracy of detection and overall diagnosis. To remove such physiological and instrumentation content from ECG signal is the main challenge in medical engineering [3].

There exist a number of different techniques for removal of low and high frequency noise contents and obtain possibly smooth ECG signal. Filtering is the simplest noise removal technique, but it alters original signal morphology and gives unsatisfactory results for non-stationary signal. In last decades, the wavelet transform based methods has been widely used in the bio-medical signal processing and also applied for de-nosing of signals. Wavelet transforms has property to represent temporal characteristics of signal in frequency domain. It can effectively reduced noise components while preserving the characteristics of the signal [4]. The ECG signal characteristics and timing information is given in table 1.

Table 1: Amplitude and timing information of Normal ECG signal

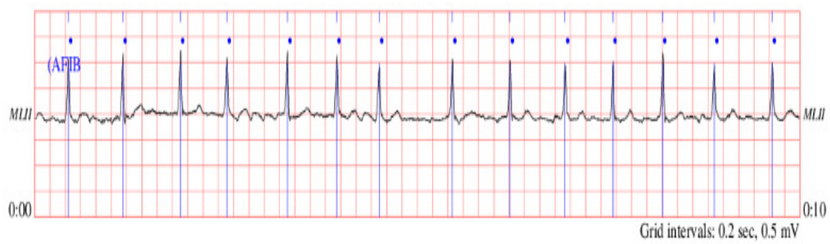
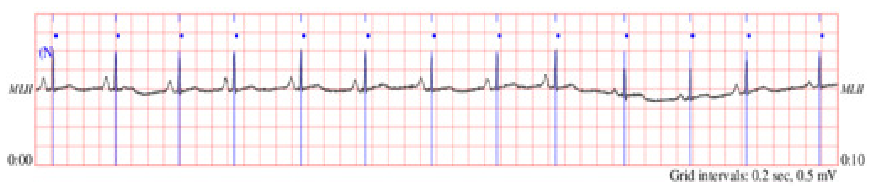
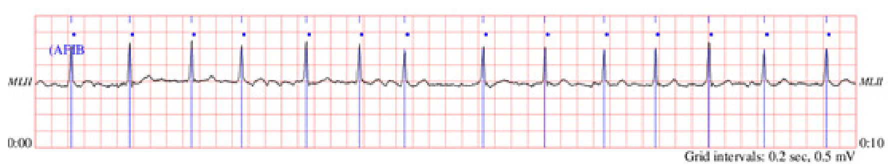
Waves	Amplitudes
P wave	0.25mV
R wave	1.6 mV
Q wave	25% R wave
T wave	0.1 to 0.5 mV

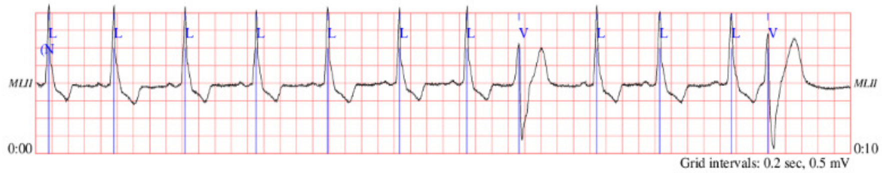
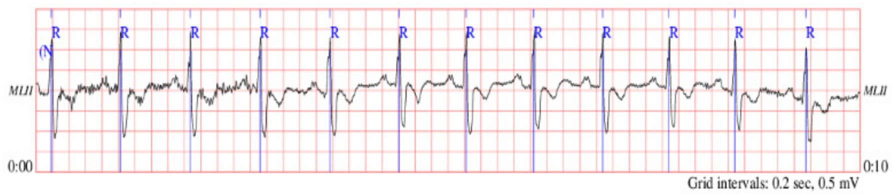
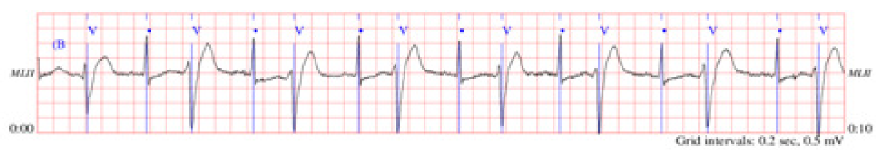
Interval	Duration (sec)
P-R	0.12 to 0.2
QRS P wave	0.09 0.11
S-T	0.05 to 0.15
Q-T R-R	0.35 to 0.44 0.6 to 1.0

2. ECG ARRHYTHMIA

Cardiac muscles follow specific orders of events and take certain amount of time while doing contraction and relaxation in pumping blood to the lungs and vice-versa, it is called electrical activity of heart. These events generate a bio-potential on the body surface, which is measured by placing ECG electrodes on fixed body locations. Due to any physiological disturbance, significant deviation in normal functioning of heart is found, and it is well reflected in ECG waveform. In addition, ECG recording specifying those areas of heart which performed abnormally [5-7]. The main life-threatening arrhythmias are categories in following manner, is shown in table 2:

Table 2: Dynamic and morphological features of ECG arrhythmia

Types of Arrhythmia	**Electrical Events**	**ECG features and morphological pattern** (downloaded from Physionet)
Atrial Fibrillation	Un-synchronized electrical activity. Heart beat > 150 bpm	 -Absence of P wave -Irregular R-R interval -Narrow QRS complex
Atrial Flutter	Rapid atrial contraction/de-polarization result. Regular heart beat of Heart beat 240-360 bpm	 Aberrancy in QRS complex -Absence of T wave -Saw tooth shape of ECG wave
Premature Atrial Contraction	-Other region of Atrial de-polarize other -Irregular heart beat	 -Premature and different P wave morphology -Prolonged R-R interval

Bundle Branch Blocks **RBBB** **LBBB**	Block in conduction path. Slow and abnormal de-polarization and re-polarization of left ventricles in RBBB and in left ventricles in LBBB.	 -Widened QRS complex and deflected upward -Broad S-wave  -Widened QRS complex (>120 ms) and downward deflected. -Inverted T wave
Premature Ventricular Contraction	-Conduction is outside ventricles. - No atrial activity.	 - Narrow QRS complex - large T wave

Hence, from above table, it says abnormality in ventricular function is displayed in wider QRS complex, bizarre in shape, as compared to normal beat. And atrial abnormality is reflected in various morphology of P waves or it may be absence. In order to extract these characteristics in the time-varying ECG signal, it is needed to be pre-processed the signal for effective signal analysis.

3. WAVELET TRANSFORM

Wavelet transform is a time-frequency representation of non-stationary signals. It provides multi-resolution analysis of signal, i.e good time and poor frequency resolution for higher frequency bands and vice versa, for lower frequency bands. The DWT of signal x[n] of length L , which is iteratively decomposed through low-pass and high-pass filters and produced various wavelet coefficients at each decomposition level. The signal is down-sampled with 2 followed by decomposition to remove redundancy and discontinuities in higher derivatives of signal in signal . In such hierarchical approach, the output from the low-pass filter used as input to a new pair of filters, and further decomposed, as shown in fig 2.

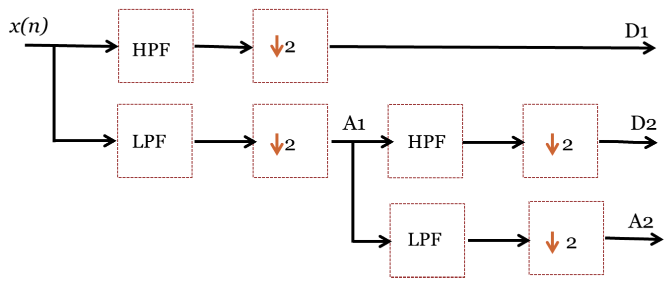


Fig 2: One-dimensional DWT structure at level 2

As shown from above figure, low pass filtering and high pass filtering of signal produce wavelet coefficients. The former result approximation coefficient is the identity of the signal and the later one is detail coefficient respectively, which imparts flavor in signal. In mathematical representation of DWT, a wavelet basis function ψ (*t*), related to varying scaling function φ (t) using the following equation:

$$A[n] = \sum_{k=0}^{L-1} h(n)\varphi(2n-k) \quad (1)$$

$$D[n] = \sum_{k=0}^{L-1} g(n)\psi(2n-k) \quad (2)$$

Here h(n) is the transfer function of low pass filter related to scaling function and g(n) is the transfer function of high pass filters represent wavelet function. Therefore, wavelet transform is a combination of two orthogonal functions including time dilation by ψ(*t*) , which causes shifting and compression of magnitude of frequency spectrum by φ (t) , of the mother wavelet $X_{j,k}$ can be expressed as-

$$X_{j,k}(t) = 1/\sqrt{2^j}\; x\,(t-k\,2^j)/2^j \quad (3)$$

j and k, are integers. $\varphi = 2^j$ is a scaling factor, ψ is time translation or shifting factor = k 2^j .

Wavelet transform based signal de-nosing consists of four basic steps: 1) Decomposing the signal at level N which depends on the dominant frequency components of the signal, 2) Choice of wavelet family, depends on wavelet basis functions which is closely resemble the shape of waveform, 3) Shrinkage of wavelet coefficients using thresholding, and 4) Inverse wavelet transform (IDWT).

Thresholding of wavelet coefficients: Donoho and Johnstone (1994) proposed a universal thresholding method of sample length N is:

$$T = \sqrt{(2\log N)} \times \sigma \quad (4)$$

Here σ is estimated noise level in each frequency sub-band after applying DWT [8-12].

4. PROPOSED METHODOLOGY

The wavelet transform based de-noisy procedure is based on the hypothesis that ECG signal which is corrupted from White Gaussian noise, low frequency Baseline Wander noise and high frequency noise, can be de-noised by truncated and shrinkage of selective wavelet coefficients. Generally, larger value wavelet coefficients may result from the signal portion, while the small-valued wavelet coefficients have more noise contents. Thus, thresholding of all wavelet coefficients in a synchronous manner is required to reconstruct the signal, which would provide a de-noised signal. Inverse DWT (IDWT) is performed for reconstruction of signal. However, the proposed algorithm is intended to filter the most noisy wavelet coefficients in DWT of ECG signal. Generally, DWT denoising procedure is based on following steps:

The de-noising stage consists of:

i. Apply High pass filtering of the noisy ECG signal, corresponding to sub-band frequency 45-90Hz at level 3, represented by detail coeff. D3, to suppress Power line interference noise components.

ii. Apply Low-pass filtering with frequency sub-band of 0.5Hz corresponds to approximation coeff. A9, at level 9 to remove low frequency noise component with baseline correction.

iii. Performed non-linear thresholding process on the wavelet coefficients at all levels.

iv. Applying IDWT on the resultant wavelet coefficients for signal reconstruction.

v. Determine Standard deviation, Mean Square Error (MSE) and Variance to evaluate the performance of proposed method and represent total amount of deflection.

The proposed model is realized according to the following diagram:

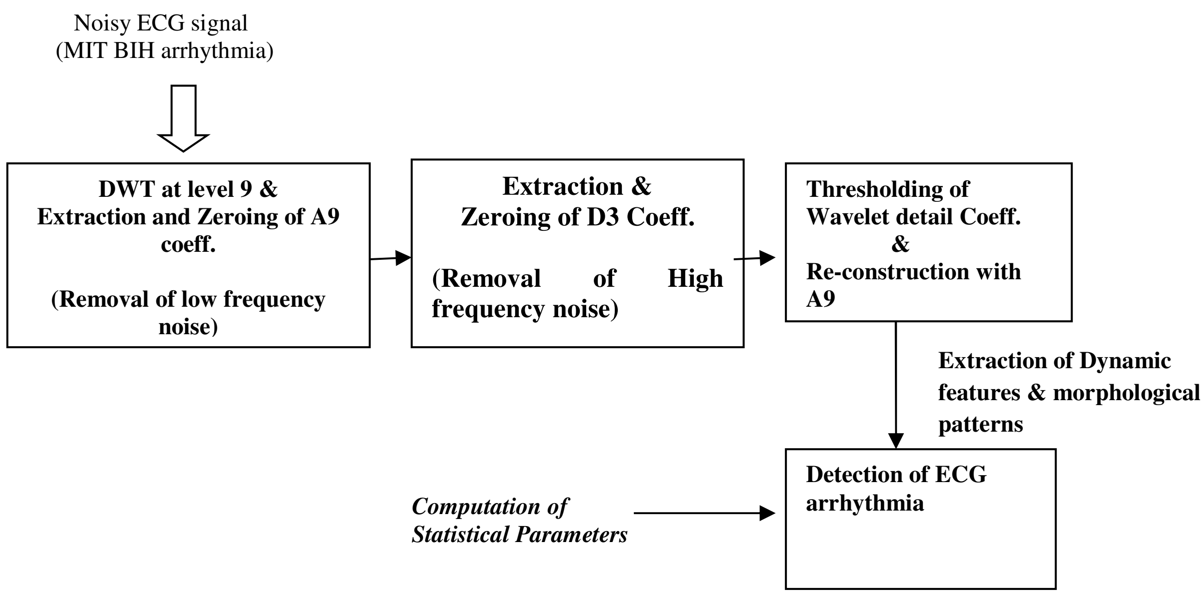


Fig 3: Proposed Method for de-noising of ECG signal

5. EXPERIMENTATION AND DISCUSSIONS

This experiment used large set of ECG beats based on lead MLII of 10sec ECG recording extracted from MIT–BIH Arrhythmia Database. The sampling frequency is 360 Hz with an 11-bit rate resolution over a 10 mV range. The results are obtained through simulation of noisy ECG signal in MATLAB 1D Wavelet GUI toolbox. Figure 3 illustrates the normalized original ECG signal downloaded and figure 4, shows baseline corrected ECG signal by applying DWT using Daubechies 6 wavelet and figure 5 is obtained noise less ECG signal by applying DWT based proposed method.

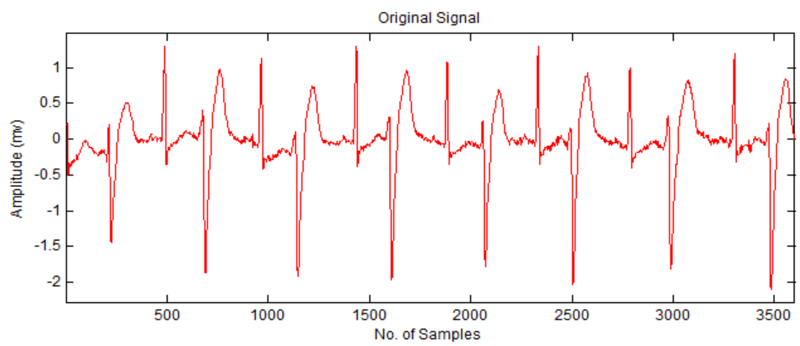


Fig 3 : Original simulated noise contaminated ECG signal #200

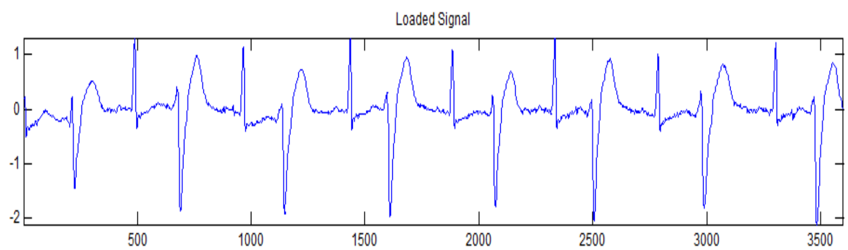


Fig 4: DWT at level 9 for removal of noise

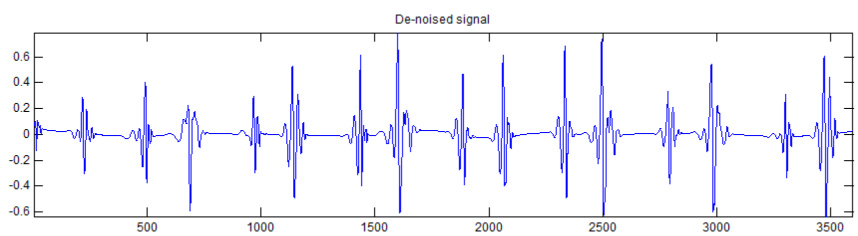
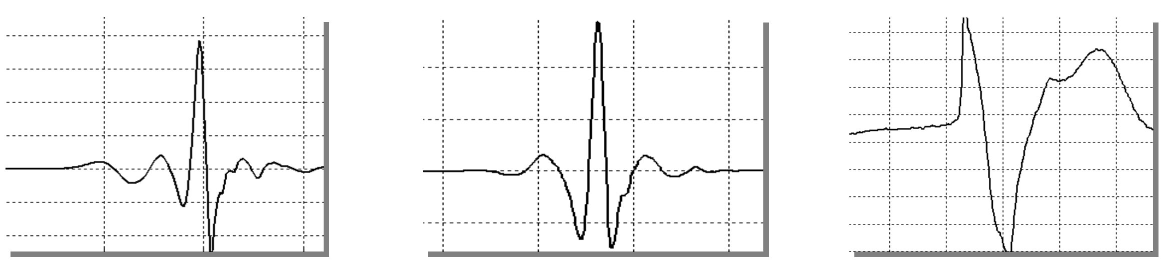
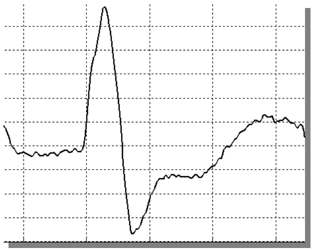


Fig 5 : Simulated De-noised ECG signal

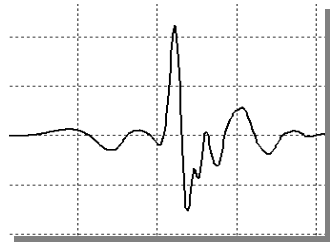
Figure 6 illustrates simulation results of various records and extracted single cycle of noise less ECG waveform from them.



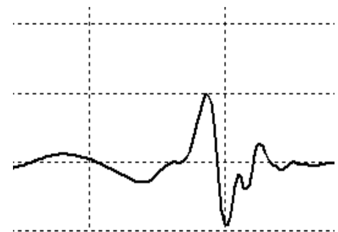
(a) #101 **(b) #107** **(c) #109**



(d) #205

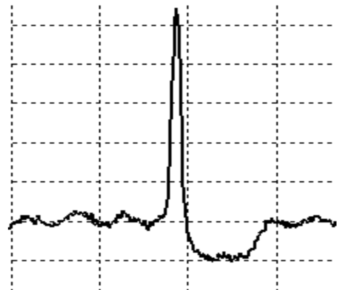


(e) #232

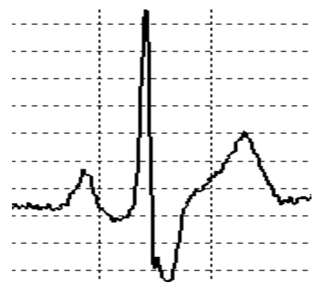


(f) 118

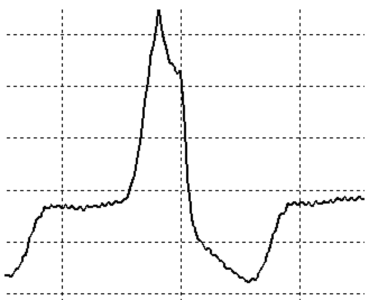
(g) **#101**



(h) #210

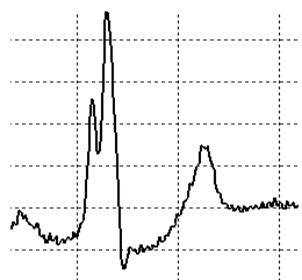


(i)#212

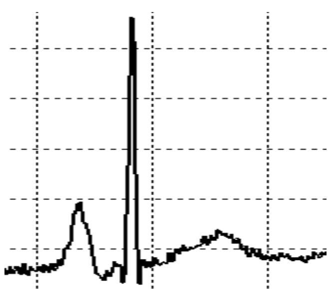


(j) #208

(k)#230

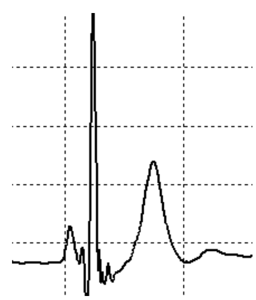


(l) #111



(m) #222

(n) #200



(m)#106

Therefore, the proposed method can remove various noise conditions from ECG signal and make morphological pattern of ECG arrhythmia. The table 3, shows detected abnormal ECG beat for clinical significance through their characteristics, at lead ML II.

Table 3: Detected Arrhythmia through dynamic and morphological features and apply DWT

Records	Dynamic and morphological features	Type of arrhythmia
100	Normal P,QRS, T wave and segments	Normal Sinus rhythm
107	-large Q wave	PVC
109	-large P wave, -Inverted, Wider QRS complex	LBBB
205	-absence of P wave, -Wider QRS complex -deformed S-T segment	Atrial fibrillation
232	-large T wave - Elevation of ST segment	PVC
118	-absence of P wave -deformed QRS complex	Atrial fibrillation
101	-small P wave -larger Q wave as compared to S wave	PAC
210	-large PQ interval -inverted Q wave -deformed ST segment	RBBB
212	-deformed ST segment -large T wave	RBBB
208	-bizarre QRS complex -absence T wave	Atrial flutter
230	-small Q wave -ST prolonged	Atrial Fibrillation
111	-deformed/wider QRS complex -narrow S wave -large T wave	PVC
222	-large P wave -inverted Q wave -missing ST segment	RBBB
200	-large P wave -inverted QRS complex -large S wave -absence T wave	LBBB
106	-Narrow QRS complex -large T wave	PVC

To evaluate performance of proposed de-noising method, quantative analysis of various statistical parameters were performed, as depicts in table following:

Table 4: Performance measuring parameters of proposed method using Daubechies wavelet transform (db6)

Records	Standard deviation	MAD	MSE
100	0212	00453	0.0508
101	0.117	4.3e-3	0.0409
107	0.1443	0.431	0.0749
109	0.231	0.008	0.0451
205	0.1641	0.0329	0.0834
232	0.0979	0.0230	0.0560
118	0.3282	0.0899	0.1991

210	0.228	0.0478	0.1252
212	0.1221	0.0160	0.0530
208	0.0977	0.0102	0.0394
230	0.3378	0.0804	0.1929
111	0.1825	0.0551	0.1217
222	0.1085	0.0385	0.0668
200	0.4371	0.0950	0.2555
201	0.0835	0.0064	0.0386

Hence, the proposed method shows satisfactory results of statistical parameters while denoising of ECG signal.

6. CONCLUSIONS

This paper designed a wavelet transform based algorithm to remove the most dominant noise content into the signal and extract the important features from it. Wavelet transform localize small variations in the heart beat of various arrhythmia through which characterization of ECG signal waveform in time domain is done and remove noise, artifacts and baseline drifts.

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