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Heart Rate and Heart Rate Variability Estimation using Spectral Analysis

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ABSTRACT: Electrocardiogram records the different electrical activity of the heart. This record can be used to extract the different features of heart such as heart rate, respiratory rate etc. Heart rate plays an important role to determine the abnormalities in the heart. Hence in this work calculation of heart rate and heart rate variability by analysing the ECG signal is carried out. Heart rate is calculated using Spectral Domain Analysis. The results obtained from these methods are compared. Spectral Domain Analysis was found to give accurate results for calculation of heart rate.

KEYWORDS: Heart rate, Heart rate variability, MATLAB, Electrocardiogram, Spectral Domain Analysis.

I. INTRODUCTION

Electrocardiogram (ECG) is the test that records the electrical activities of the heart by placing the electrodes on the patient's body.The P-QRS-T deflections of ECG signal are recorded as the waves called impulses of the heart. The ECG shows complex called QRS complex. R peak in the QRS complex gives the knowledge about the ventricular contraction of the heart. R peak has the highest magnitude among the QRS complex.The R peak is a key sign of heart rate variability and can demonstrate irregularities such as late or accelerated heart rates. Due to the various types of noise present in the ECG signal, the detection of QRS complex becomes difficult. The power-line interference, muscle noise, baseline wander and artefacts are the different types of noise present in the ECG signal.

II. RELATED WORK

The suggested [1] strategy is basic but quick algorithm to extract QRS at distinct sampling frequency rates with no de-noising. The disadvantage is that it takes care of only baseline drift as removable component but other noise components are not taken into account. In [2] suggested that R peak detection algorithm using S-Transform and Shannon energy. The demerit of the proposed algorithm is that it cannot be used in real time. The filter utilized for QRS detection with Kaiser Windowing provides the low mean square error for a narrow bandpass FIR filter with least order of 20 [3]. The limitation is that least order of the filter must be 20 or higher and not least than that.

To prevent the shortcomings, Pan- Tompkins system and wavelet transform were designed [4]. It helps to find the rate of heart beat from profoundly exact RR interval time arrangement. However, it makes multiple non practical assumptions in the calculation of thresholds. For example, if the flicker or interference interrupts the signal noise cannot be removed in real time and hence derivative based operators give noisy results**.** To overcome these limitations a novel technique namely Spectral Domain Analysis is proposed. This method decomposes a complex signal into simpler parts to facilitate analysis.

In this paper the heart rate is calculated using Spectral Domain Analysis. The heart rate calculated using this method is compared with MIT- BIH Arrhythmia database records. MIT/BIH (Massachusetts Institute of Technology-Beth Israel Hospital) Arrhythmia has been taken as standard reference input of ECG data to validate the performance of our method where MIT-BIH database consists of 48 records each of 30 min, 1 min and 10 secs duration, having two leads(leads (modified limb lead II and one of the leads V1, V2, V4 or V5) and each record has sampled at a rate of 360 samples per second.

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The organization of the paper is as follows: section II explains the heart rate and heart rate variability calculations using Spectral Domain Analysis. Section III highlights the test cases and experiment results obtained. Section IV discusses on the conclusion of the proposed paper.

III. THE METHOD

Several steps involved in Spectral Domain Analysis method are: Fast Fourier Transform (FFT), de-noising, fundamental frequency detection, heart rate calculation and heart rate variability, as shown in Fig. 1.

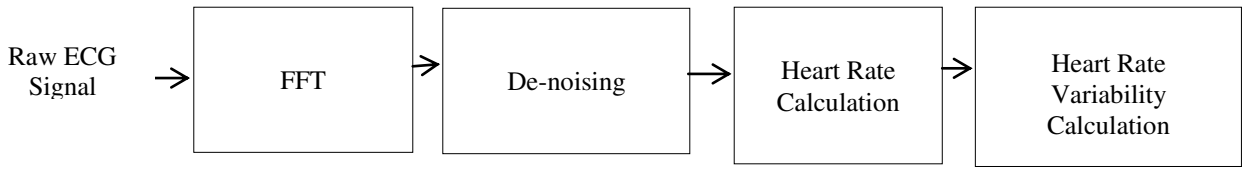

Fig. 1. Spectral Domain Analysis

Raw ECG signal: To test the proposed method, 19 records of 30 min (650000 samples) with a sampling frequency Fs = 360 Hzare taken to calculate heart rate and 7 records for the calculation of heart rate variability

FFT of the Signal: Raw ECG signal is converted from time domain to frequency domain by the computationally efficient FFT algorithm yielding a symmetricspectrum property withfrequency resolution= (sampling frequency/2)/(Nsamp/2)where Nsamp= 650000.Region of interest is determined considering heart rate range is from 30bpm(0.5Hz) to 300bpm(5Hz) and normal HR is around 72 bpm(1.2Hz). For in the spectrum this corresponds to Hr_Min= 902.5 samples andHr_Max = 9025 samples respectively. Including up to 10 harmonics, the normalized HR frequency band limit will be (10* Hr_max)/(Nsamp/2) = 0.277 in our case study. The average (DC) component of the signal is removed before FFT.

De-noising: De-noising will improve the signal to noise ratio (SNR) by square root of N times in Spectral Domain Analysis than in time domain. In proposed algorithm, the following steps are adopted as part of this process:

1. Baseline wander is removed by assigning zeros to frequencies below 0.5Hz of the ECG signal
2. AC power line interference is removed by using simple filter by assigning zeros to frequencies greater than mean plus 3 sigma limit threshold line between 45 Hz to 70 Hz.
3. Then the spectrum is smoothened using 3346 stage LPF FIR filter with Kaiser Window in the range 0.5 Hz to 5Hz, for a given sampling rate (360 Hz in our case), with a normalized cutoff frequency of 0.277 and passband gain of unity and stopband gain of -80 dbm. The filter is designed using FDA Tool which is a powerful user interface for designing and analysing filters quickly. FIR filter is chosen because of its stability and zero phase distortion although it is more computationally intensive.

Hear Rate Detection: In the band 0.5 to 5Hz of the spectrum, the point corresponding to first maximum amplitude (fundamental frequency) is identified from the de-noised ECG signal in order to calculate heart rate. Based on the frequency corresponding to this maxima, the heart rate is calculated as Fmax*60 bpm.

Heart Rate Variability Estimation: Heart rate variability is the representation ofhow much heart rate is deviated from the mean heart rate. The rms value (σ) of spectral noise is estimated from the base line in the region above 10 Hz to 40 Hz of the denoised spectrum. The points where the maximum decends below 3 σ threshold line is taken as the variability of HR beyond uncertainty due to noise. Uedge is the upper frequency intersect point and ledge is the lower frequency intersect point at the 3 sigma threshold line. Then HR variability is given by $HRV = (uedge - ledge) \times Frequency\ Resolution$. %variability is calculated as HRV/HR*100.

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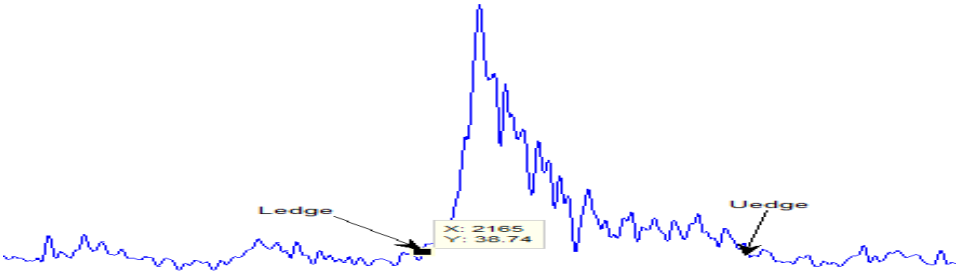

Fig. 2. lower and upper edge of the fundamental frequency of signal to find the heart rate variability.

IV. TEST AND RESULTS

The database of MIT/BIH is utilized as a part of the analysis for execution assessment. The19 records are taken for the calculation of heart rate and 7 records for heart rate variability. Recordings were captured from 10 women (age: 23 to 87) and 9 men (age: 32 to 77) whose heart rate calculations for Spectral Domain Analysis are shown in Table 1 and heart rate variability calculations are shown in table 2

Table 1: Heart rate calculations of SDA method by using MIT-BIH database

Record number	Heart rate using SDA (bpm)	Heart rate from MIT-BIH database
100	74.5324	70-89
102	73.2032	72-78
104	74.5988	69-82
105	83.8365	78-102
107	71.2095	68-82
108	56.2565	44-78
109	84.2352	77-101
111	83.8365	64-82
114	55.4922	51-82
116	80.5468	74-86
117	51.8038	48-66
118	72.3060	54-91
122	87.0597	67-97
123	50.6740	41-65
124	57.3863	47-64
208	127.9312	91-134
212	91.8114	63-108
228	83.8365	50-88
230	77.5562	63-99

Table 2:Heart rate variability calculations of SDA method by using MIT-BIH database

Record number	% of heart rate variability from MIT-BIH database(%)	% of heart rate variability using SDA(%)
100	23.89	18.7147

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117	31.5	28.3436
118	51	25.51
123	45.28	33.9647
124	30.6	29.3911
212	50.2	52.3355
230	44.4	54.522

The record 100 in which the person with normal sinus rhythm is taken as an example for this study. It contains the information about rhythm and heart rate .The results obtained using Spectral Domain Analysis is shown in Fig. 3. Fig.

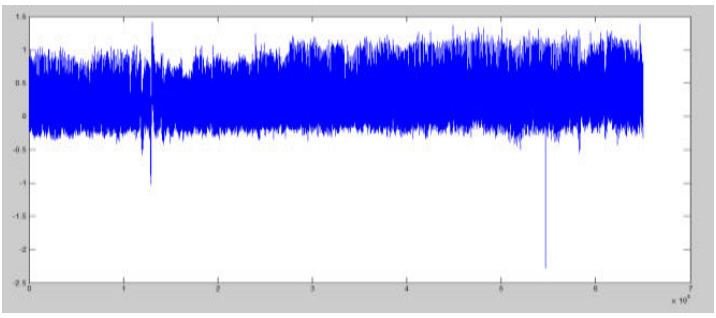

Fig 3(a) Raw ECG Signal of record 100 from MIT-BIH Database

Fig 3(a) shows the raw ECG signal of the record 100 taken from MIT-BIH database of 30 min(650000 samples)

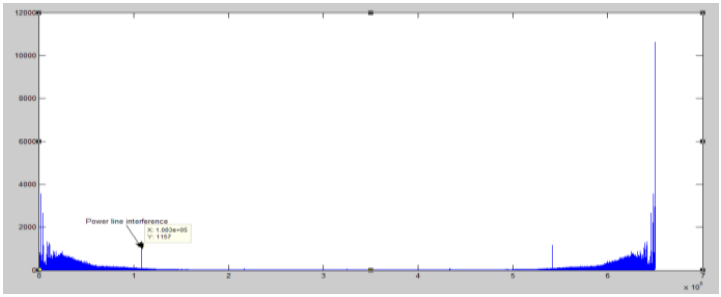

Fig 3(b) FFT of the signal

Fig. 3(b) shows the FFT of the signal where it finds the frequency component of a signal buried in a noisy time domain signal.

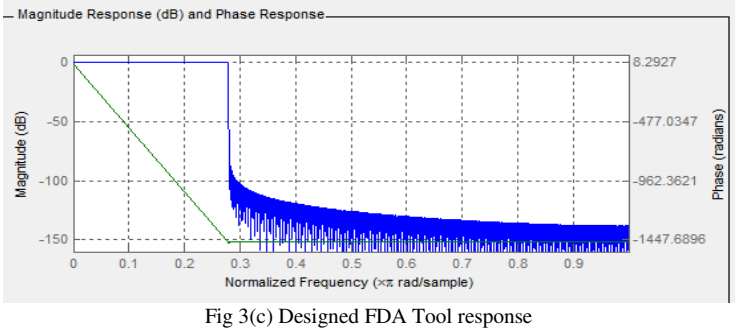

Fig 3(c) Designed FDA Tool response

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Fig. 3(c) shows the FDA Tool response using which the noises and artefacts exist within the frequency band of the signal are removed.

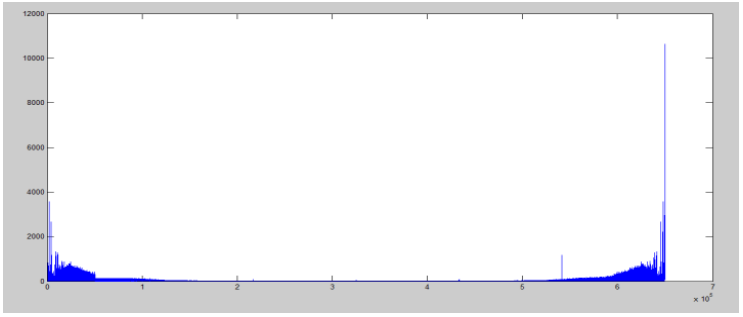

Fig 3(d) power line interference removed signal

Fig. 3(d) shows the powerline interference removed signal present in the FFT signal at 50 Hz by using simple notch filter between 45 Hz to 75Hz.

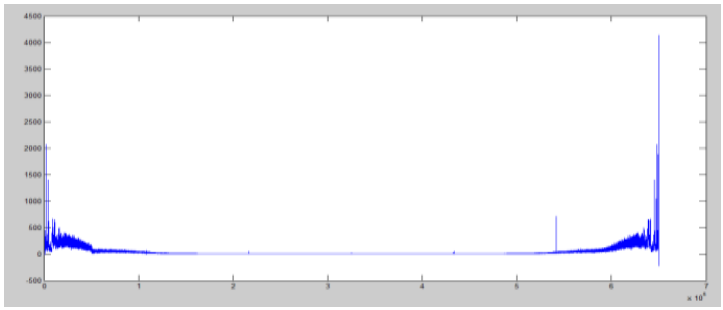

Fig 3(e) Smoothened signal by FIR filter with Kaiser window

Fig. 3(e) shows the output of FIR filter with a range of 0.5 Hz to 5 Hz to smoothen the signal so that interference and artefacts are removed.

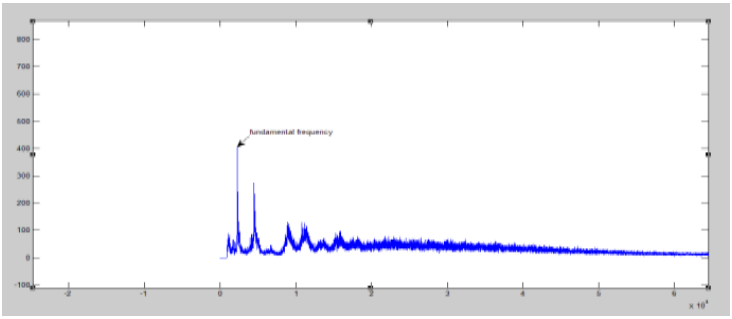

Fig 3(f) Fundamental frequency detection to detect heart rate

Fig. 3(f) shows the identified fundamental frequency of the signal representing average R-R interval using which the heart rate is calculated

It is observed that SDA shows frequency domain converted signal by FFT algorithm which is computationally much less load ($N\log_2 N$) complex addition and multiplication than the time domain processing algorithm. Since only scalar samples are considered for the analysis FFT shows symmetric property. Therefore out of 6,50,000 samples of data 3,25,000(180 Hz of bandwidth) are taken for spectral analysis. Since the filters used in SDA method is in the range of 0.5Hz to 5Hz, it is capable of smoothening the signal more precisely. Heart rate is calculated based on the fundamental frequency of smoothened signal which represents mean heart rate**.** In SDA to calculate heart rate variability the lower and upper edge of the signal called uedge and ledge are used. Heart rates are compared with heart rates of standard

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MIT-BIH records .Out of 19 records SDA gives correct result for 18 records and heart rate variability calculations for 7 records compared with MIT-BIH records are shown in Table 2 which comes within the limits except for 230 record. It is concluded that the heart rate calculated using SDA is very simple and involves less computations than time domain analysis.

V. CONCLUSION AND FUTURE WORK

In Spectral Domain Analysis the mean heart rate and heart rate variability were directly obtained withsimple calculation than complex procedure followed in time domain analysis. If the flicker occurs in time domain ECG signal, de-noising is difficult and that leads to the wrong evaluation of heart rate. But in Spectral Domain Analysis flicker occurs at other frequencies so that it can be easily removed by assigning zero to noisy component. Hence it can be concludedthat the Spectral Domain Analysis is efficient than time domain analysis**.** In future, work can be extended to detect heart rate and heart rate variability for remaining records and also to detect arrhythmias by using these heart and heart variability as a parameters.

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