Comparison of Power Spectral Density (PSD) of Normal and Abnormal ECGs

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ABSTRACT

Periodogram is a graph showing the power spectrum density (PSD) of a signal, having power by frequency (dB/Hz) in y-axis and frequency (Hz) in x-axis. In other words it shows the corresponding power of the frequency components of the signal. Abnormalities in electrocardiograms (ECGs) show different frequency components in their power spectrum density. In this paper power spectrum density of the QRS complexes has been obtained from normal as well as diseased ECGs to compare the differences between their frequency components. QRS complexes are chosen because it shows distinct differences for different heart diseases. This process can be an effective way to identify abnormalities in ECGs**.**

Keywords

Periodogram, power spectrum density, electrocardiograms, QRS complexes

1. INTRODUCTION

Electrocardiogram or ECG is a very popular and useful biosignal which has been used by doctors and physicians for the purpose of diagnosis of heart diseases. Some reasons for its popularity are that the method to obtain ECG is completely non-invasive and free of any dangers unlike x-rays or other diagnostic tools. However, ECG that is normally used showing the PQRST waveforms is the time and amplitude representation. The signal is obtained from patients by placing electrodes on the body and real-time recordings of the amplitudes are continuously plotted on the screen of the electrocardiograph.

A brief discussion about ECG waveform is beneficial to know about the relation between the different parts of the waveform like P, Q, R, S and T and the parts of the heart which are involved in generating those. This wave consists of certain parts named as the P wave, PR interval, QRS complex, ST segment, T wave, QT interval and then the infrequent presence of U wave. The sino- atrial node or the SA node is positioned on the left atrium and this initiates the electrical signal causing atrial depolarisation. Although the atrium is anatomically divided into two parts, electrically they function as one part. Atria have very little muscle and produce a wave of small amplitude called the P wave. The PR segment is the subsequent part after the P wave and occurs as the electrical impulse is conducted through the atrio-ventricular node or the AV node, bundle of His and Purkinje fibres. The PR interval can be defined as the time between the onset of atrial depolarisation and the onset of ventricular depolarisation. After the PR interval, QRS complex occurs. This complex is generated by the depolarisation wave which travels through the interventricular septum via the bundle of His and bundle branches and reaches the ventricular myocardium via the Purkinje fibre network. The impulse first depolarises the left side of the septum, and then spreads towards the right. The left ventricle has larger muscle mass and thus its depolarisation dominates the ECG wave. The QRS complex ends at the J point and from here starts the ST segment. The ST segment which lies between the J point and the onset of the T wave, represents the period between the end of ventricular depolarisation and repolarisation. The T wave is the result of ventricular repolarisation. This wave in a normal ECG is asymmetrical as the first part of this wave is more gradual than the subsequent part. The QT interval is measured from the beginning of the QRS complex to the end of the T wave. Measurement of this interval is done by taking into account the heart rate as this interval elongates as heart rate decreases. The last part of the ECG is the U wave which is found just after the T wave ends. It is a small deflection and generally upright [1-2].

The heart diseases that have been taken for this paper are normal sinus beats from a normal person, ventricular tachyarrhythmic beats [3], atrial fibrillation [4] beats and ventricular or supraventricular beats [5]. For each of the datasets ten data have been used. All the diseased ECG data have been taken from PhysioNet.

The ventricular tachyarrythmic beats contain ventricular tachycardia, ventricular flutter and fibrillation. Ventricular fibrillation is a serious condition of the heart which may lead to stoppage of the heart if untreated. Precursor of fibrillation is often ventricular tachycardia or flutter. So it is important to detect flutter and tachycardia in the ECG. Ventricular tachycardia is defined as three or more ventricular extrasystoles in succession at a rate of more than 120 beats per minute. The tachycardia may be self terminating but is described as "sustained" if it lasts longer than 30 seconds [2]. This kind of tachycardia falls under broad category tachycardia which maybe of ventricular or supraventricular in origin but is mostly ventricular. In ventricular tachycardia the sequence of cardiac activation is altered, and the impulse no longer follows the normal intraventricular conduction pathway. As a consequence, the morphology of the QRS complex is bizarre, and the duration of the complex is prolonged [ecg books]. These ten data from PhysioNet is named cu01 to cu10 and have sampled at 250 samples per second [3].

The next data set is of atrial fibrillation. Atrial fibrillation is caused by multiple activations sweeping around the atrial myocardiogram. In an electrocardiogram it is seen as a wavy, irregular baseline made up of fibrillation waves. It is a combination of absent P waves, fine baseline fibrillation base oscillations and irregular ventricular complexes [1-2]. These

data, named n01 to n10 have been sampled at 250 samples per second [4].

The third arrhythmia data which have been used, is supraventricular or ventricular ectopy. An arrhythmia is any abnormal cardiac rhythm. One category of arrhythmias occurs when the trigger to depolarize originates outside of the SA node, in another part of the myocardium (known as ectopic depolarization, leading to ectopic beats). Common causes of ectopy include a drug effect (e.g., caffeine) or a viral infection of the myocardium, or other inflammation or damage of part of the heart (e.g., ischemia) [1]. When the ectopic beat originates in the atria, it leads to a premature atrial beat, also known as an atrial premature contraction (APC). When it originates in the ventricles, it leads to a premature ventricular beat or ventricular premature contraction (VPC) [1]. These arrhythmic data are named from 100 to 110 and the recordings were digitized at 360 samples per second per channel with 11-bit resolution over a 10 mV range [5].

To obtain indicative physiological information for real time monitoring of the ECG, an effective algorithm is to be chosen for extracting diagnostically useful information. For this purpose, QRS peaks should be detected accurately and quickly. There are several approaches for QRS detection including non linear filtering with thresholding, artificial intelligence using hidden Markov models, time-recursive prediction techniques, and wavelet transforms [6]. The presence of noise, like motion artefacts in this signal is inevitable. Cubic Spline technique and digital filters have been used for base line drift removal [7]. One way of removing various noise is to use the established Pan Tompkins' algorithm of QRS detection [8-9]. After Pan Tompkins' algorithm, frequency or spectrum analysis of the signal can be done using FFT algorithm. Power spectrum estimate represents the distribution of the signal power over frequency. From the spectrum, the frequency content of the signal can be estimated directly from the frequency sample values that correspond to the peak value. It is calculated based on the frequency representation of the discrete-time waveform [10].

In this paper Pan Tompkins algorithm has been applied on an ECG from a normal person and on three sets of arrhythmia data. Then the QRS detected signals are taken and power spectrum density (PSD) from each of the signals is obtained for analysis.

2. PROCEDURE

2.1. Pan Tompkins' Algorithm

The ECG waveform which is obtained is overshadowed with noise signal due to which essential features cannot be identified from it. In Pan Tompkins' algorithm, feature extraction is restricted to QRS detection from the original signal by passing the signal through a band pass filter and a differentiator and then squaring of the resulting signal. The band pass filter is the one which eliminates noise and the differentiator is used to provide information about the slope of the QRS complex. Squaring of the signal is done so that all negative values in the waveform are changed to positive values. This process is a nonlinear operation which amplifies the output of the differentiator nonlinearly. Then the signal is passed through a moving integrator to obtain the QRS complexes [9].

On both normal and arrhythmia data, Pan Tompkins algorithm has been applied to eliminate noise and to extract the QRS complexes from the data. For this, the software for technical computing MATLAB has been used (version 7.6.0.324 R2008).

2.2. FFT of QRS detected signal

For frequency analysis of any signal the algorithm that is used is called Fast Fourier Transform (FFT) algorithm. This algorithm can extract the frequency contents of the signal being analysed. If a discrete time aperiodic signal exists as a set of sampled data, with a sampling period of T, then the angular sampling frequency is $\omega_{s=} \frac{2\Pi}{T}$. The time domain representation of the signal can be written as [9],

$$x(t) = \sum_{n=-\infty}^{\infty} x(n)\,\delta(t - nT) \quad (1)$$

The Fourier transform of the above expression is,

$$X(\omega) = \int_{-\infty}^{\infty} x(t) e^{-j\omega t}\, dt \quad (2)$$

The equations for FFT can be written as,

$$X(k) = \sum_{j=1}^{N} x(j) \omega_N^{(j-1)(k-1)} \quad (3)$$

where,

$\omega_N = e^{(-2\Pi j)/N}$ is an Nth root of unity.

3. RESULTS AND DISCUSSIONS

3.1. Pan Tompkins' Algorithm

3.1.1 Band pass filter

The band pass filter that has been used has been done by using a low pass filter and then a high pass filter in cascade. The purpose low pass filter is to suppress high frequency noise [9]. Filter design using digital filters having integer coefficients allows real time processing speeds. No floating point processing required so speed is high. This band pass filter for QRS detection algorithm reduces noise in the ECG signal by matching the spectrum of average QRS complex, eliminating noise due to muscle artefacts, 60 Hz power line interference, baseline wandering and T wave interference. QRS energy is maximised by the pass band of approximately in the 5 to 15 Hz range. The filter is an integer filter which has poles located such so as to cancel out the zeroes.

The second order low pass filter has the transfer function of as shown in equation (4).

$$H(z)= (1- z^{-6})^2/(1- z^{-1})^2 \quad (4)$$

The cut- off frequency of the filter is 11 Hz, delay is 5 samples and the gain is 36. The difference equation of the filter is as shown in equation (5).

$$y(nT)= 2y(nT- T) - y(nT - 2T) + x(nT) – 2x(nT – 6T) + x(nT – 12T) \quad (5)$$

The high pass filter is implemented by subtracting a first order low pass filter from an all pass filter with delay. The transfer function of the low pass filter is as shown in equation (6).

$$Hlp(z)= Y(z)/X(z)= (1 – z^{-32})/(1 – z^{-1}) \quad (6)$$

The transfer function of the high pass filter is as shown in equation (7).

$$Hhp(z)= P(z)/X(z)= z^{-16} – Hlp(z)/32 \quad (7)$$

It is finally obtained as in equation (8).

$$Hhp(z)= (-z^{32} + 32z^{16} – 32z^{15} + 1)/(32z^{32} – 32z^{31}) \quad (8)$$

The difference equation of the filter is as in equation (9).

$$p(nT) = x(nT - 16T) - 0.0313[y(nT - T) + x(nT) - x(nT - 32T)] \quad (9)$$

The low cut off frequency of the filter is about 5 Hz and delay is 80 ms. The gain is 1.

3.1.2 Derivative

To provide information about the slope of the QRS complex, differentiation of the signal is done, after it has been through the band pass filter [9]. A five point derivative is implemented using the transfer function as shown in equation (10).

$$H(z) = 0.1(2 + z^{-1} - z^{-3} - 2z^{-4}) \quad (10)$$

The difference equation for this transfer function is as shown in equation (11).

$$y(nT) = (1/8)*[2x(nT) + x(nT - T) - x(nT - 3T) - 2x(nT - 4T) \quad (11)$$

The fraction 1/8 in equation (11) is an approximation of the actual gain of 0.1. This derivative approximates the ideal derivative in the dc through 30 Hz frequency range, and it has a filter delay of 10 ms [9].

3.1.3 Squaring

Now, the signal is to be squared. This is the non linear processing of the signal. It is done to get all positive values so that later these values can be processed to get the corresponding squared waves. Also this processing emphasizes the higher frequencies of the ECG signal which are due to the presence of the QRS complexes [9]. Point by point squaring of the signal obtained from the differentiator is implemented by equation (12).

$$y(nT) = [x(nT)]2 \quad (12)$$

3.1.4 Moving Integrator

The slope of the R wave is not the absolute way to detect QRS complexes in an ECG. There may be many long duration and large amplitude QRS waves in the ECG which is abnormal. Only slope of R wave cannot detect these waves [9]. So a moving window integrator is used so that these waves can be detected as well. The difference equation for this moving window integrator is as shown in equation (13).

$$y(nT) = (1/N)\ [(x(nT) - (N-1)T) + (x(nT) - (N-2)T) + \ldots + x(nT)] \quad (13)$$

It is important to choose an appropriate value for N, which is the number of samples in the width of the moving window [8].

The results obtained, as the QRS detected ECG signals after this block are shown in Figure (1) for the normal ECG and Figure (2), Figure (3) and Figure (4) for the three different arrhythmic ECG data.

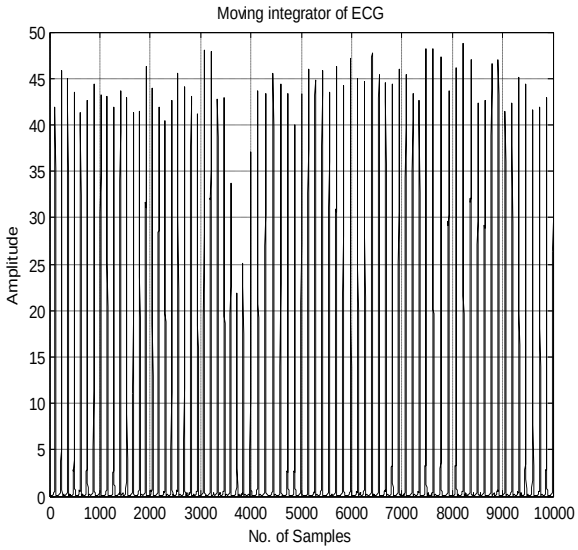

Fig 1: QRS of normal ECG

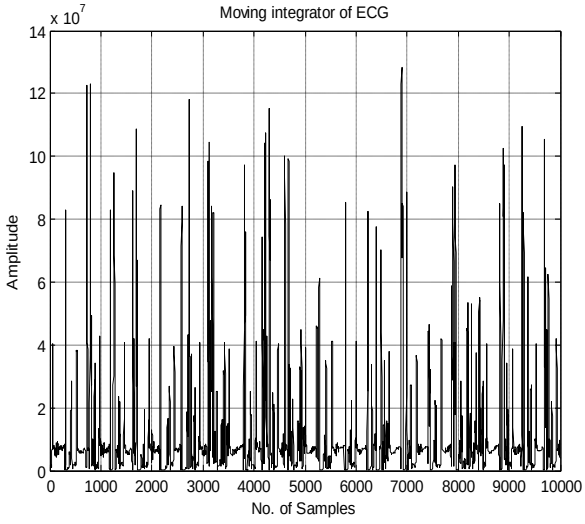

Fig 2: QRS of arrhythmia ECG (data cu04)

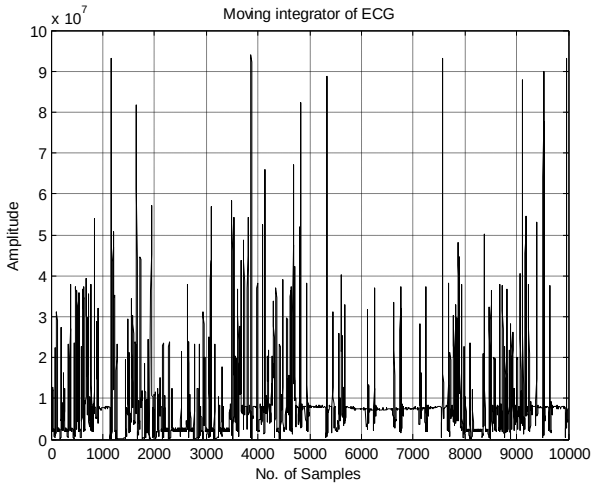

Fig 3: QRS of arrhythmia ECG (data n01)

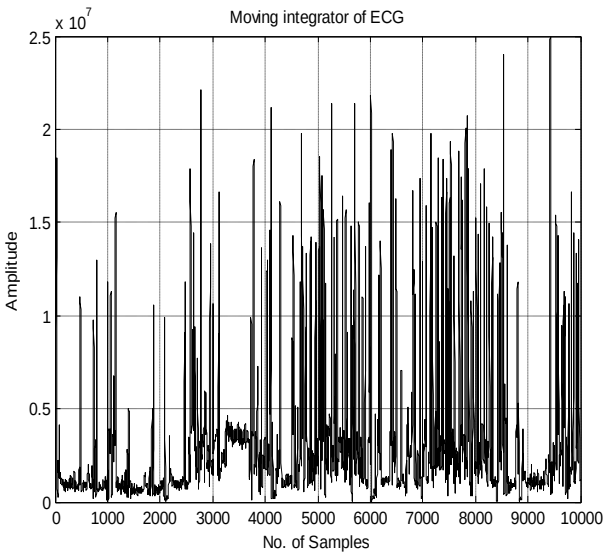

Fig 4: QRS of arrhythmia ECG (data 106)

3.2. Frequency Analysis of QRS detected signal

The frequency analysis of QRS detected ECG signals are shown in Figure 5, Figure 6, Figure 7 and Figure 8 respectively. The amplitude of the FFT in case of the QRS detected signals show marked differences when compared between normal and arrhythmic data. In case of normal ECG data the highest frequency shows an amplitude within a small value. But in case of the arrhythmic ECG data the amplitudes of the frequency components are much higher and also different for different disease data. Also the shapes of the power spectrum density plots are different for different ECGs.

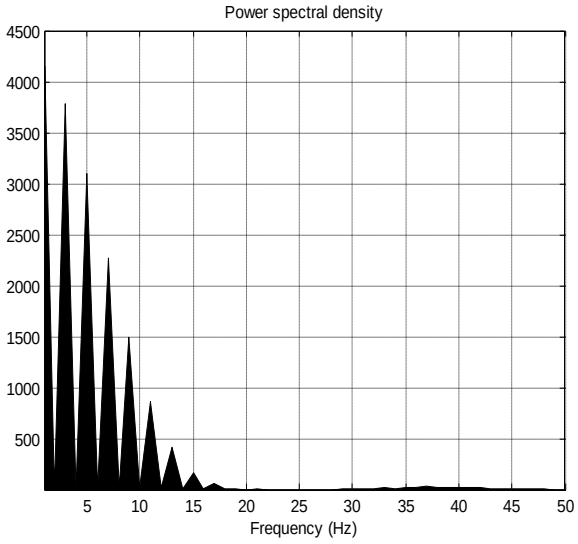

Fig 5: Power spectrum density of normal ECG

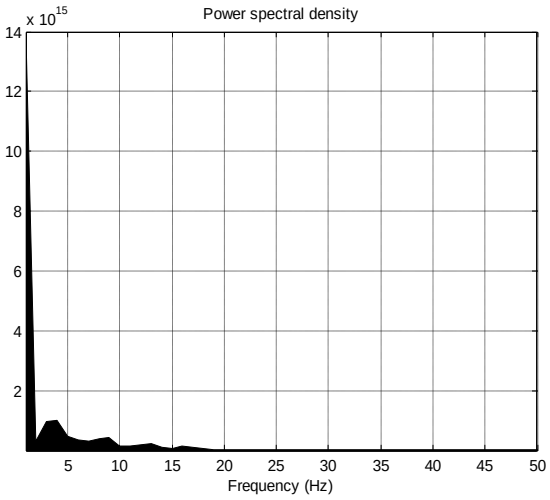

Fig 6: PSD of arrhythmia ECG (data cu04)

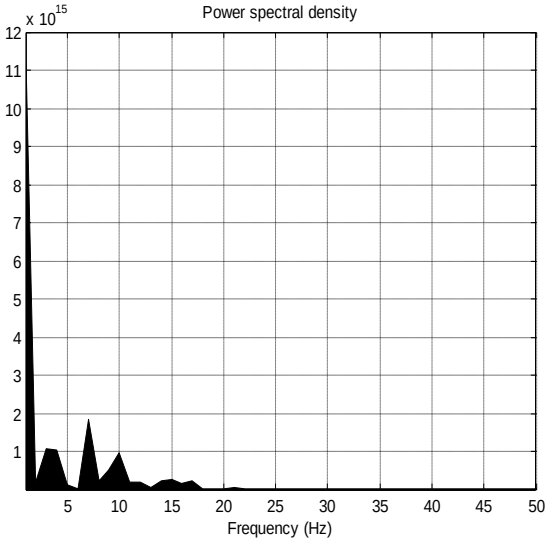

Fig 7: PSD of arrhythmia ECG (data n01)

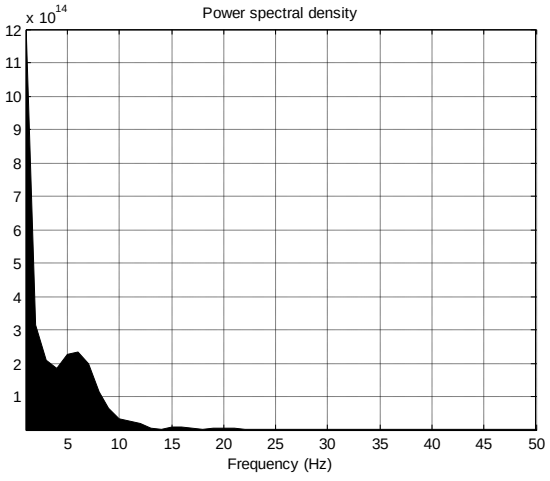

Fig 8: PSD of arrhythmia ECG (data 106)

4. CONCLUSION

Determination of power spectrum density (PSD) of QRS detected electrocardiogram signal can be thus an effective method to detect arrhythmia.

5. REFERENCES

[1] Gary D. Clifford, Francisco Azuaje, Patrick E. McSharry, Advanced Methods and Tools for ECG Data Analysis. Engg. in Medicine & Biology.

[2] Francis Morris, June Edhouse, William J. Brady, John Camm, ABC of Clinical Electrocardiography.BMJ Books.

[3] PhysioBank, available at www.physionet.org/physiobank/database/cudb/

[4] PhysioBank, available at www.physionet.org/physiobank/database/aftdb/

[5] PhysioBank, available at www.physionet.org/physiobank/database/mitdb/

[6] Hong Wan, Joseph P. Cammarota, Ata Akin, Hun H. Sun, "Comparison of QRS peak detection algorithms in extracting HRV signal", in Proceedings - 19th International Conference - IEEE/EMBS, Oct. 30 - Nov. 2, 1997.

[7] Rizwan R. Sheikh, Imtiaz A. Taj, "Cardiac disorder diagnosis based on ECG segments analysis and classification" in IEEE 978-1-4244-4361-1, 2009.

[8] J. Pan, W.J. Tompkins, "A real-time QRS detection algorithm", IEEE Trans. Biomed. Eng. 1985, vol.32, pp. 230-236.

[9] W.J. Tompkins, Biomedical Digital Signal Processing. Prentice Hall.

[10] Norhashimah Mohd Saad, Abdul Rahim Abdullah and Yin Fen Low, " Detection of heart blocks in ECG signals by spectrum and time-frequency analysis", 4th Student Conference on Research and Development (SCOReD 2006), Shah Alam, Selangor, Malaysia, 27-28 June, 2006.