Bispectral Analysis of ECG for identification of Atrial Fibrillation

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Abstract: Atrial Fibrillation (AF) is the one of the most common type of cardiac arrhythmia. AF is caused by irregular contraction of atria in pumping of blood to body. It results in blood pooling in the heart chambers, which increases the risk of blood clot formation. This condition may lead to heart attack with no prior warning. This paper introduces the work that has been done to distinguish the Electrocardiogram (ECG) of a normal healthy human from that of AF patient. Normal Spectral analysis of ECG provides only the power within frequency components but doesn't give phase relations. Bispectral analyzing technique is considered in this paper to indentify the phase correlation. The components like Bispectrum, Bicoherence and Quadratic Phase Coupling technique are used to detect and characterize phase coupled harmonics in ECG signal. Normal Sinus Rhythm Data which is related to a normal person is obtained from MIT-BIH NSR database and AF data which is related to AF infected person is obtained from MIT-BIH Atrial Fibrillation database. This Bispectral technique is tested on MIT-BIH database and results using MATLAB are verified.

Keywords: Atrial Fibrillation, ECG, Bispectrum, Bicoherence, Quadratic Phase Coupling, MIT-BIH.

1. Introduction

Electrocardiogram is an interpretation of the electrical activity of the heart over a period of time. All recorded electrical activity of the ECG corresponds to the net electrical current in the heart over a time, depolarizes various parts of heart in a sequence. The electrical impulse is initiated by Sinoatrial (SA) node. This causes the atria to contract and is evident on the ECG as P-wave. The QRS complex on the ECG is due to depolarization of ventricles and occurs when ventricles contract. Finally T wave is due to the repolarization of the ventricles. The ventricles then relax and pump the blood to rest of the body. The heart beat process shown in figure 1, starts all over again in the SA node.

Atrial fibrillation [1] occurs when the electric current in the heart is generated from all over the atria at very high speed between 300 to 500 impulses per minute. This does not allow the atria to contract in a synchronized fashion. Because of high number of impulses generated by the heart, the atria begin to quiver. This condition is known as Atrial Fibrillation, which increases the blood clot formation. These blood clots can get dislodged and travel to brain and lungs where they could block the flow of blood which causes a heart stroke. AF patients may have symptoms like chest pain and light-headness may even faint. Anticoagulation or blood thinning process is administered to decrease the chance of blood clot formation.

Hence for the diagnosis of these AF effects, there is a need to identify the non-linearities that were introduced in rhythmic events of the human ECG signal. Phase correlations among rhythmic events at different frequencies are introduced only by non-linear interactions. Thus non-linear analysis methods have to be applied for the detection of non-linear correlations. Most of the biomedical signals are non-linear, non-stationary and non-Gaussian in nature and therefore it can be more advantageous to analyze them with Phase correlations and High Order Spectral analysis [2] compared to the use of second order correlations and power spectra.

Spectral analysis is a good tool for the analysis of power distribution of stationary process as a function of frequency. This process is mainly depends on the Gaussianity and linearity of the system. However spectral analysis is not an appropriate tool for the detection of phase correlations among different frequencies. It is phase blind and hence contains no information about the phase of the signal.

Phase correlations are possible in ECG signal. Phase correlations among rhythmic events at different frequencies are introduced only by non-linear interactions. Thus non-linear analysis methods have to be applied for the detection of non-linear correlations. One such method for the study of such non-linear effects is the Bispectrum analysis. This method quantifies the deviation of the measured ECG signal from Gaussianity. This approach often detects important quadratic phase correlations present among the other higher order correlations.

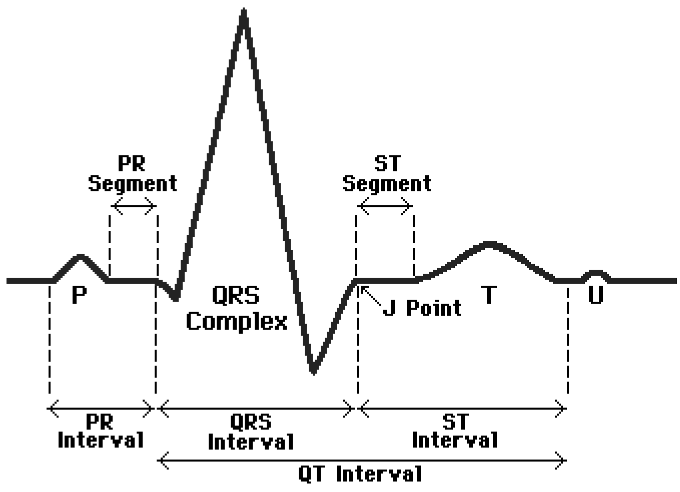

Fig 1: ECG signal representation of Normal person

The above explained concept provided the motivation to perform this work in Bispectral analysis of ECG signal to help enable physicians to identify diseases. Furthermore, future aim is to identify diseases based on Bispectrum that are not at all detected in spectral domain.

The objective of the paper is to analyze and compare normal person ECG with a patient ECG who prone to Atrial fibrillation. Normal Sinus Rhythm Data is obtained from MIT-BIH [3] NSR database and AF data is obtained from MIT-BIH Atrial Fibrillation database. The different parameters such as kurtosis, skewness and variance that the signal represented are calculated. The Bispectrum and Bicoherence [4] of the signal data are performed. The bispectral analysis is able to provide a clear view of the phase coupling in the data. In this paper, the application of HOS and QPC are used to analyze the non-linearities for ECG signals.

2. Evolution of technology in AF analysis

In the literature the description about various spectral techniques and their applications and utilizations in the human ECG signal analysis are available. Some of the important techniques that are available in the literature which are very helpful in analyzing the ECG signals are as follows:

2.1. Power Spectrum

Power spectrum calculation is considered as one of important tools in signal processing. It provides the clear analysis of signal power (energy per unit time) falling within its frequency components. The power spectrum is a real quantity which contains no phase information. It is phase blind, all the phase information is suppressed. Hence this method is not considered in this paper.

2.2. Higher Order Statistics

The variance, skewness and kurtosis are three statistics [5] considered for analysis of ECG signal.

- *Variance:* It is a measure of the spread of the data from the mean.
- *Skewness:* The third order mean is called skewness and is a measure of the asymmetry of the processes. For symmetric distributions, skewness is identically zero.
- *Kurtosis:* It is a fourth moment about the mean and is related to the degree of flatness of a distribution near its center. For a Gaussian distribution, the value of kurtosis is 3. The values greater than 3 indicate that the probability distribution function, if more peaked around its center than a Gaussian distribution.

Hence by using these statistical parameters the ECG signals can be easily analyzed.

2.3. Bispectrum

The third order spectrum that is Bispectrum has received a lot of attention along with examining the concepts of variance, skewness and kurtosis. Bispectrum of a signal is defined as the second order Fourier transform of the third order cumulants of a signal. It is given by the following expression:

$$S_3^x(w_1, w_2) = \sum_{t_1}^{\infty} \sum_{t_2}^{\infty} C_2^x(\tau_1, \tau_2) \exp[-j(w_1\tau_1 + w_2\tau_2)]$$

for $w_2>0$, $w_1 \geq w_2$, $w_1+w_2 \leq \pi$

The Bispectrum is a function of two-frequency variables $f_1$and f_2. The Bispectrum analyses the frequency components at f_1, f_2, f_1+f_2 (f_1-f_2).

2.4. Quadratic Phase Coupling

In a non-linear system an interaction between two harmonic components causes contribution to the power as their sum or difference of frequencies. Quadratic phase coupling occurs when two waves interact non-linearly and generate a third wave with a frequency equal to the sum/difference of the first two waves. Since the power spectrum suppresses all phase information, it cannot be utilized to detect phase coupling.

The Bispectrum is capable of detecting and characterizing quadratic phase coupling. Harmonically related peaks in the power spectrum are necessary conditions for the presence of quadratic non-linearities in the data. The Bispectrum preserves phase and is used to extract phase information quantitatively. The relation between Bifrequency triplets and the corresponding phases are described in table 1.

Table 1. Frequency and Phase relations

f_1,f_2, 2 f_1	Φ_1, Φ_2, 2 Φ_1
f_1,f_2, f_1+ f_2	Φ_1, Φ_2, Φ_1+ Φ_2
f_1,f_2, f_1- f_2	Φ_1, Φ_2, Φ_1- Φ_2

2.5. Bicoherence

It is the squared-magnitude of the normalized Bispectrum. Due to the finite data length of processes, peaks may appear in the Bispectrum at locations where there are no significant phase coupling. A normalized Bispectrum or Bicoherence is used to avoid incorrect interpretations. The strength of phase correlation can be quantified by the magnitude of Bicoherence which is given by the following equation:

$$B_{norm}(f_1, f_2) = \frac{E[X(f_1)X(f_2)X^*(f_1+f_2)]}{\sqrt{E[P(f_1)P(f_2)E[P(f_1+f_2)]]}}$$

3. Implemented Method for AF analysis

The flow structure of the implemented method is shown in figure 2.

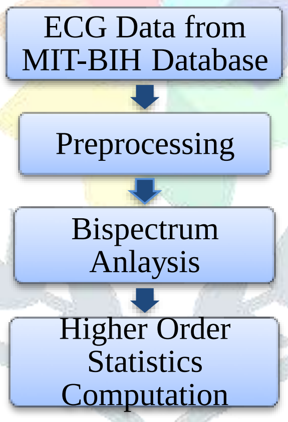

Fig. 2 Block diagram of implemented method

This process is helpful in analyzing ECG signal and diagnosing positively as suffering from Heart problem. In preprocessing stage the mean is removed from the data, so that DC Level can be removed. Butterworth low pass filter is applied to remove power line interference. Bispectral analysis is performed on the filtered data. Finally higher order statistics like skewness, kurtosis and variance are computed on the filtered data. This method is applied on the two different databases.

4. Results and discussions

In Bispectral analysis, the Bispectrum of the NSR person data is done first, in order to compare it with the observation of the disorder person's data. The Bispectrum is computed using an indirect estimate. That is the Fourier transform of an estimate of the third cumulant of the time series using the higher order spectral analysis is calculated for the given data. The mean values are removed from each block using Hanning window. The Bicoherence was computed using the direct FFT method in the HOS toolbox [6]. In the direct method, the Bispectrum is estimated as an averaged biperiodogram.

The Bispectrum of the data is obtained and then the Bicoherence of the signal data is performed. The length of FFT used is 2048. A Hanning window was used to compute the Bispectrum. The Bispectrum plot of NSR person shown in figure 3, exhibits peaks around -0.3 to +0.3 in Bifrequency plane. The Bicoherence plot for NSR person which is in figure 4, scattered throughout the bifrequency plane in random manner. Bicoherence magnitude indicates the strength of phase correlation, which is low 3.0198 for

NSR data. The corresponding QPC plot shown in figure 5, of NSR person, there is no significant phase coupling present. Afterwards this technique was applied to the ECG signal of the AF patient data.

The Bispectrum plot of AF person shown in figure 6, exhibits peaks around -0.1 to +0.1 in Bifrequency plane. The Bicoherence plot for NSR person shown in figure 7, scattered around frequencies -0.3 to +0.3 in the bifrequency plane. Bicoherence magnitude is 8.0259 for AF data which is more than NSR person. So, phase correlation is possible in AF. The corresponding QPC plot shown in figure 8, of AF person significant phase coupling is present.

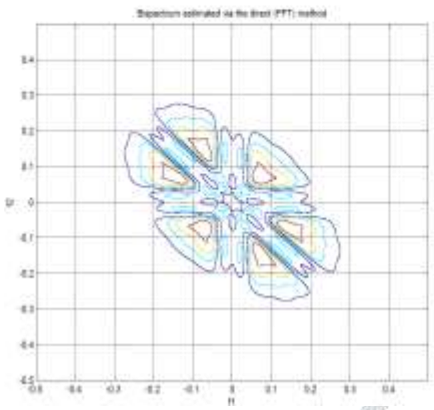

Fig. 3 Bispectrum plot : NSR 18177m

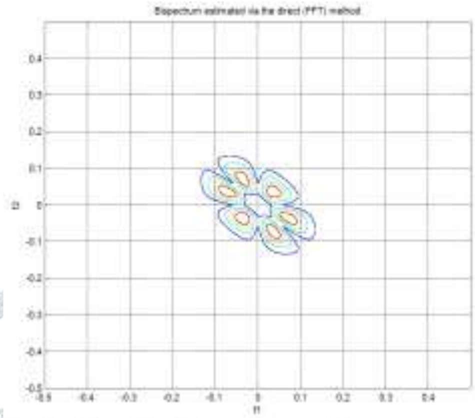

Fig. 6 Bispectrum plot : AF 04126m

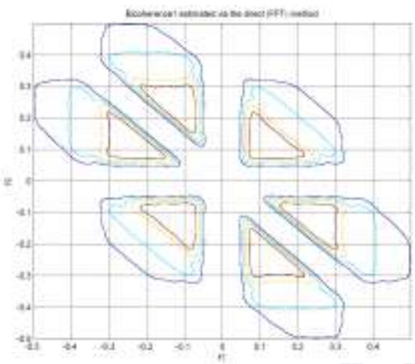

Fig. 4 Bicoherence plot : NSR 18177m

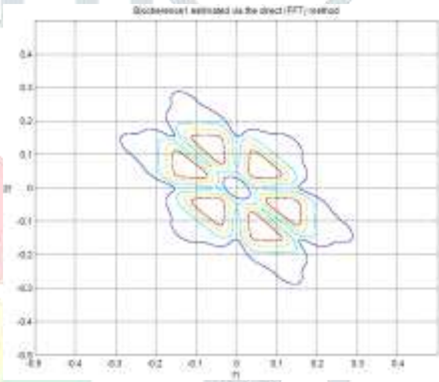

Fig. 7 Bicoherence plot: AF 04126m

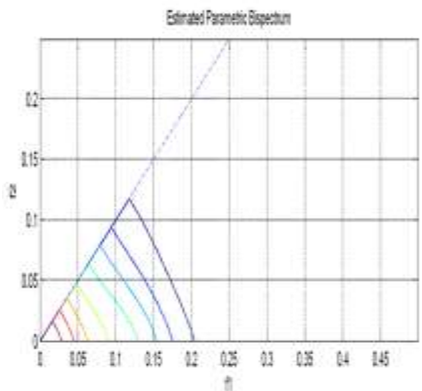

Fig. 5 QPC Tor plot : NSR 18177m

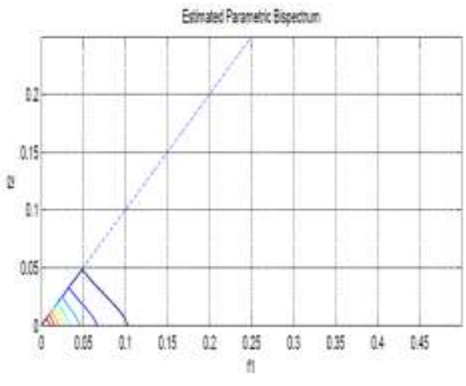

Fig. 8 QPC Tor plot: AF 04126m

The higher order statistics are computed and the parameters like skewness, kurtosis and variance of NSR person are compared with AF person which are available in table 2 below.

Table 2. Higher order statistics comparison

Parameter	NSR	AF
Skewness	0.399	0.9465

Kurtosis	4.0401	9.0218
Variance	2498.59	750.88

5. Conclusion

The Bispectral Analysis could present a novel approach to detect the presence of disease in ECG signal. The Bispectrum and Bicoherence plots are useful for visual interpretation by differentiating NSR person with AF diseased person, which is based on the exhibition peaks in bifrequency plane.

Further this method can be used to identify other heart disorders and classification of cardiac diseases using Artificial Neural Networks using the features of Higher Order Spectral Analysis. Hence this can be considered as the future scope of the work presented in this paper.

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