Identification of Cardiac Ischemia Using Bispectral Analysis of ECG

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Abstract—**Cardiac Ischemia (CI) is the most common type of cardiac arrhythmia. CI is caused by narrowing of arteries which makes less oxygenated blood to reach the heart muscle. 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 person from that of CI patient. Normal spectral analysis of ECG provides only the power within frequency components but doesn't give any phase relations. Bispectral analysis - Bispectrum, Bicoherence and Quadratic Phase Coupling techniques are used to detect and characterize phase coupled harmonics in ECG. Normal Sinus Rhythm Data is obtained from MIT-BIH Database. CI data is obtained from European ST-T Database. The algorithm was tested on MIT-BIH database and European ST-T Database. This concept can be utilized to identify other heart diseases also.**

Keywords—**ECG, CI, Bispectrum, Bicoherence, Quadratic Phase Coupling, MIT-BIH.**

I. Introduction

Electrocardiogram (ECG) is an interpretation of the electrical activity of the heart over a period of time. All recorded electrical activity of the ECG corresponds to net electrical current in the heart over a time, depolarizing 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 and the T wave is due to the repolarisation of the ventricles. The ventricles relax and pump the blood to rest of the body. The heart beat process shown in Fig1 is the ECG signal representation of Normal person.

Cardiac Ischemia [7] is a heart disease that is caused by narrowing of the arteries which makes less oxygenated blood to reach the heart muscle. When the coronary arteries cannot supply enough oxygen-rich blood to the heart, symptoms of CI can occur. This disease may lead to heart attack with no prior warning and without pain. CI is also called as myocardial ischemia that can damage to heart muscle and reducing its ability to pump blood efficiently. Myocardial ischemia can cause serious abnormal heart rhythms. These events are most often initiated with symptoms like shortness of breath, persistent coughing or wheezing.

A heart attack on the other hand occurs when the blood flow to a part of the heart is suddenly and permanently cut off due to blood clot. This can lead to serious heart damage.

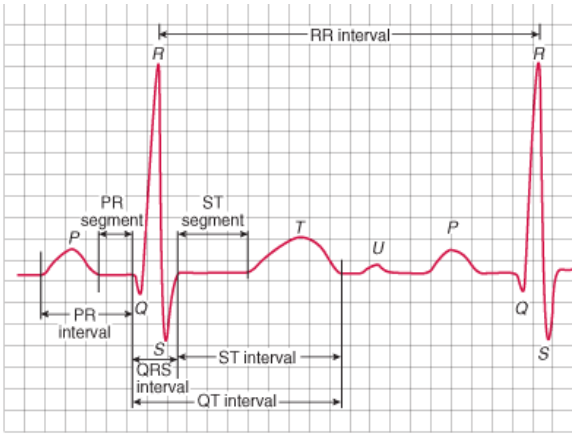

Fig 1: ECG signal representation of Noramal person

Spectral analysis is a good tool for the analysis of power distribution of stationary process as a function of frequency. But it is not an appropriate tool for the detection of phase correlations among different frequencies. These processes are based on the gaussianity and linearity of the system. It is phase blind and hence, it doesn't contain any 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 to quantify the deviation of the measured ECG signal from gaussianity by utilizing the bispectrum. This approach often detects important quadratic phase correlations present among the other higher order correlations. This concept has provided the motivation to perform this work in Bispectral analysis of ECG signal to enable the physicians to identify heart diseases.

The objective of the paper is to analyze and compare normal person ECG with a patient ECG who prone to cardiac ischemia. The Normal Person ECG Data is obtained from MIT-BIH NSR Database, Ischemia data is obtained from European ST-T Database. The different

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parameters such as kurtosis, skewness and variance that the signal represented were calculated. The bispectrum and bicoherence of the signal data was performed. The bispectral analysis was able to provide a clear view of the phase coupling in the data.

II. LITERATURE REVIEW

The literature review section describes various spectral techniques in detail and their applications and utilizations in the human ECG signal analysis. The third order spectrum that is Bispectrum has received a lot of attention and also examining the concepts of variance, skewness and kurtosis.

A. Power Spectrum

Power spectrum is one of important tools used in signal processing. It provide the signals power (energy per unit time) falling within its frequency components. The power spectrum is a real quantity which contains no phase information. It is a phase blind, all the phase information is suppressed.

B. Higher Order Statistics

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

1) *Variance:* It is a measure of the spread of the data from the mean.

2) *Skewness:*The third order mean is called skewness and is a measure of eth asymmetry of the processes. For symmetric distributions, skewness is identically zero.

3) *Kurtosis:*It is a fourth moment about the mean 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 pdf if more peaked around its center than a Gaussian distribution.

C. Bispectrum

Bispectrum of a signal is defined as the second order Fourier transform of the third order cumulants of a signal. It is given by

$$S_3^x(\omega_1,\omega_2)=\sum_{\tau_1=-\infty}^{\infty}\sum_{\tau_2=-\infty}^{\infty}c_2^x(\tau_1,\tau_2)\exp\left[-j(\omega_1\tau_1+\omega_2\tau_2)\right]$$

The bispectrum is a function of two-frequency variables f1 and f2. The bispectrum analyses the frequency components at f1, f2, f1+f2 (f1-f2).

D. 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. Bifrequency triplets and the corresponding phases:

$f_1,f_2,2\,f_1$	$\Phi_1, \Phi_2, 2\,\Phi_1$
f_1,f_2, f_1+f_2	$\Phi_1, \Phi_2, \Phi_1+\Phi_2$
f_1,f_2, f_1-f_2	$\Phi_1, \Phi_2, \Phi_1-\Phi_2$

E. 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.

III. PROPOSED METHOD

The proposed method is shown in Fig.2 for analyzing ECG signal. 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.

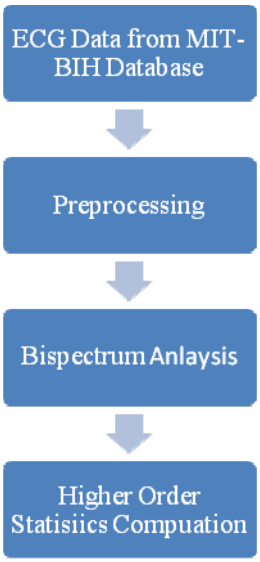

Fig. 2. Block diagram of proposed process

Bispectral analysis[3] is performed on the filtered data. Finally higher order statistics[5] such as skewness, kurtosis and variance are computed from the filtered data. This process is applied on the two different databases.

IV. RESULTS AND DISCUSSIONS

In Bispectral analysis, the bispectrum of the Normal Sinus Rhythm(NSR) data found first, later bicoherence of the signal was found. The length of FFT used was 2048. A Hanning window was used to compute the bispectrum. The Bispectrum plot of NSR person (Fig 3) exhibits peaks around -0.3 to +0.3 in Bifrequency plane. The Bicoherence plot for NSR person (Fig 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 (Fig 5) of NSR person, there is no significant phase coupling is present. Afterwards this technique was applied on CI patient data.

The Bispectrum plot of Cardiac Ischemia person (Fig 9) exhibits peaks around -0.2 to +0.2 in Bifrequency plane. The Bicoherence plot for CI person (Fig 10) scattered around frequencies -0.2 to +0.2 in the Bifrequency plane. Bicoherence magnitude is 11.3328for CI data which is more than NSR. High degree of phase correlation is possible in CI. The results are also verified with higher order statistics (Tab I). The method is applied on number of subjects; the inference was verified by the bispectral analysis.

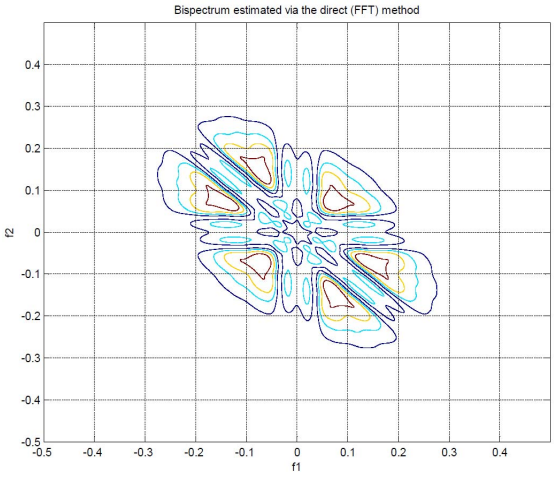

Fig. 3Bispectrum plot : NSR 18177m

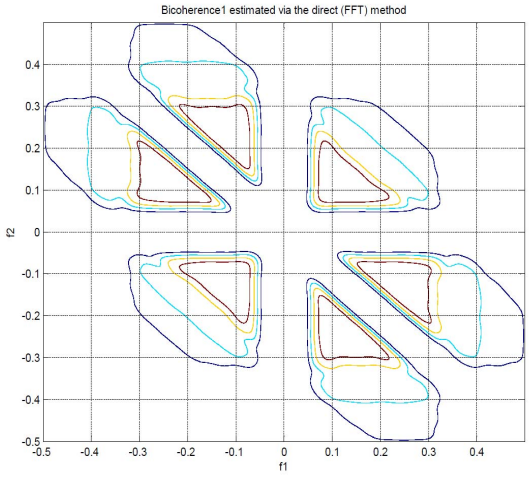

Fig. 4Bicoherence plot : NSR 18177m

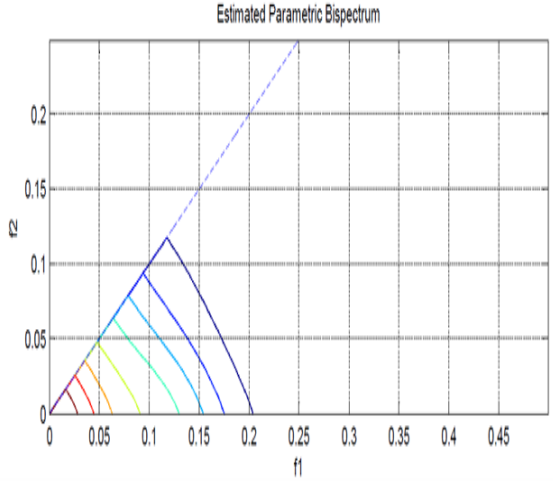

Fig. 5QPC Tor plot : NSR 18177m

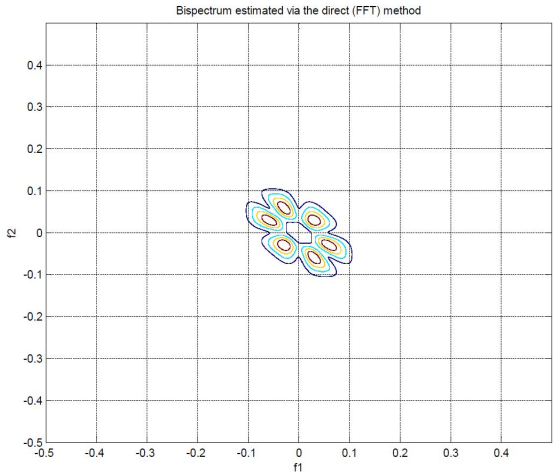

Fig. 6 Bispectrum plot : Cardiac Ischemia e0123m

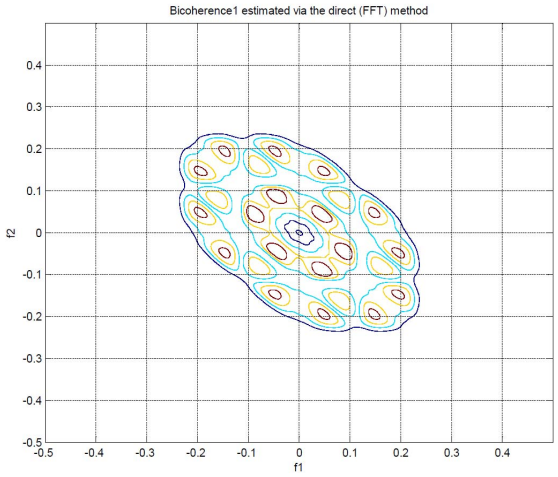

Fig. 7 Bicoherence plot : Cardiac Ischemia e0123m

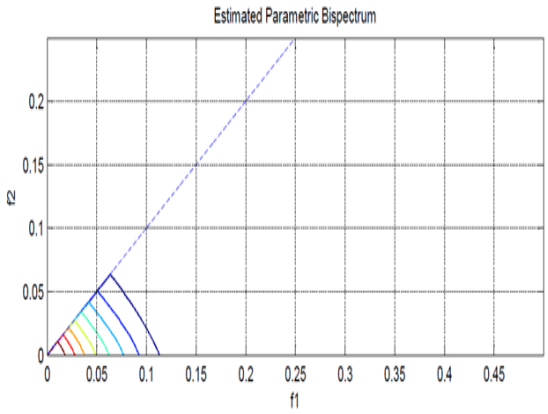

Fig. 8 QPC Tor plot : Cardiac Ischemia e0123m

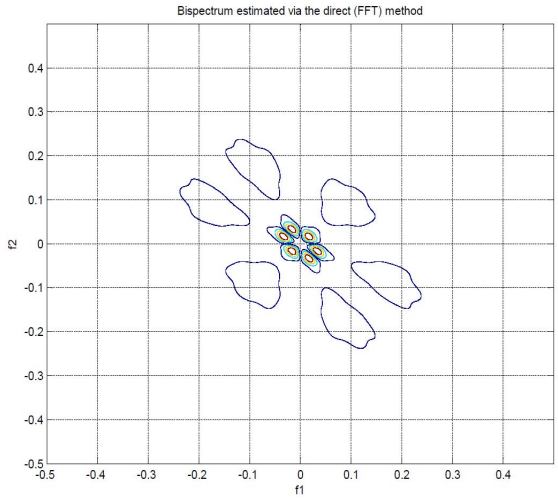

Fig. 9 Bispectrum plot : NSR 19093m

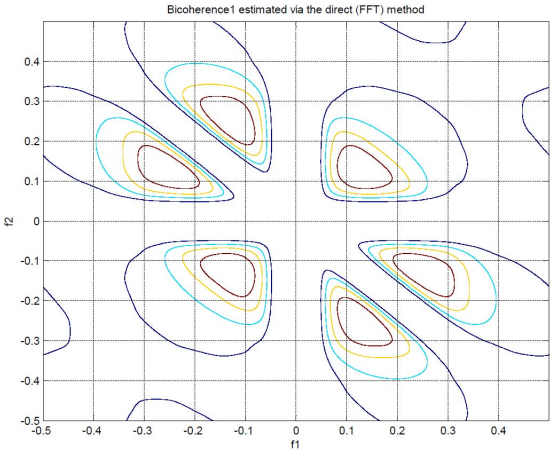

Fig. 10 Bicoherence plot : NSR 19093m

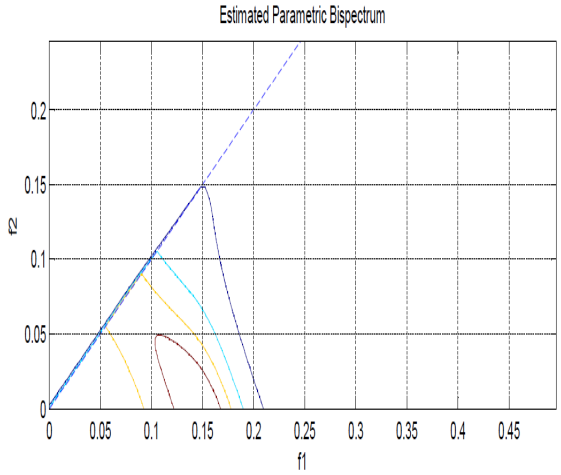

Fig. 11 QPC Tor plot : NSR 19093m

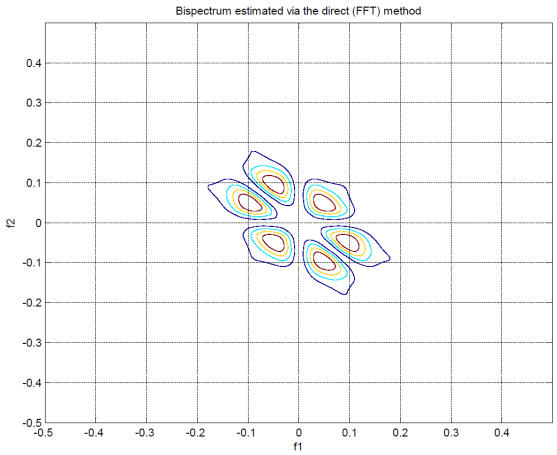

Fig. 12 Bispectrum plot : Cardiac Ischemia e0104m

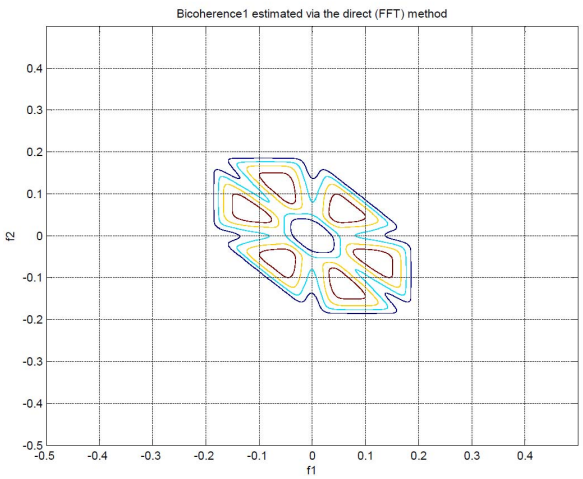

Fig. 13 Bicoherence plot : Cardiac Ischemia e0104

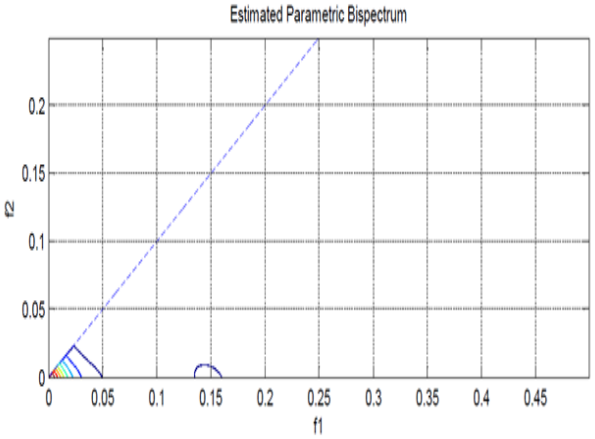

Fig. 11QPC Tor plot : Cardiac Ischemia e0104m

Parameter	NSR	CI
Skewness	0.399	0.8450
Kurtosis	4.0401	15.289
Variance	2498.59	615.18

Table I. Higher order statistics comparison

V. CONCLUSION

The Bispectral Analysis could present a novel approach to detect the presence of disease in ECG signal. Bicoherence magnitude indicates the strength of phase correlation which is low in NSR person, more in CI person. This result proves that high degree of phase correlation exist in diseased person ECG signal than NSR person. The Bispectrum and Bicoherence plots are useful for visual interpretation by differentiating NSR person with diseased person. Further this method can be used to identify other heart disorders.

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