International Journal of Advanced Information Science and Technology (IJAIST) ISSN: 2319:2682
Vol.5, No.1, January 2016 DOI:10.15693/ijaist/2016.v5i1.98-105

Analysis of Radio Frequency Exposed Electrocardiogram Signal Using Hilbert Huang Transform

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***Abstract*—Hilbert Huang transform, a new signal processing tool for analyzing non linear and non stationary signals is used in this paper to analyze the effect of Radio frequencies on the Electrocardiogram signal. Mobile phones are the most commonly used device these days which uses radio frequencies. So, to analyze the effect of radio frequencies, mobile phones were used for radio frequency exposure while ECG signals were recorded. ECG of 10 healthy young post graduate students were recorded (i) without using mobile phone,(ii) receiving a call using 2G mobile phone and (iii) transmitting a call using 2G mobile phone. Low frequency/high frequency (LF/HF) and high frequency/all frequency (HF/AF) ratios which contributes to the parasympathetic and sympathetic nervous system activities have been analyzed. The result shows that LF/HF ratio increased and corresponding HF/AF ratio decreased in 70% subjects during RF exposure. The increase in tone of sympathetic nervous system and the decrease in the tone of parasympathetic nervous system are observed in 70% subjects during RF exposure. The results show that the radio frequencies influences and changes the autonomic balance.**

Index terms - Autonomic nervous system (ANS), Electro-Cardio gram(ECG),Empirical mode decomposition (EMD), Hilbert-Huang Transform (HHT), Heart rate variability (HRV), Mobile phones(MP) .

I. INTRODUCTION

These days we are living in the environment of electromagnetic radiations due to widely used of mobile communication devices. Mobile phones (MP) are the most commonly used radio device that receive and transmit electromagnetic (EM) waves. The effect of these electromagnetic radiations on human health has become a matter of concern. It is investigated in many studies that EMF radiations affect the autonomic nervous system (ANS) [1, 2, 3, and 4]. In this paper Hilbert spectrum (HS) and Hilbert marginal spectrum (HMS) is used for analysing the effect of radio frequencies on HRV signal [6]. Electro-Cardio Gram (ECG) is the recording of the electrical activity of the heart. The waveform generated by the ECG is used to measure the rate and regularity of the heart beat [8]. Autonomic nervous system (ANS) is the automatic control system which regulates individual organ functions and homeostasis and the most part is subject to involuntary control [9]. ANS plays a direct role in the stimulation of the sinoatrial (SA) node which is responsible for the electrical activity of the heart [9, 10, and 11]. ANS controls cardiovascular system through its branches known as Sympathetic and parasympathetic nervous system [11]. The parasympathetic nervous system function is to control homeostasis and the body's rest-and-digest response, while sympathetic general action is to mobilize the body's fight or flight response [12]. In a normal and healthy person there is a balance between the sympathetic and parasympathetic system known as sympthovagal balance. HRV is a non-invasive tool for analysing cardiovascular autonomic control of the heart from the surface ECG [6]. HRV reflects the heart's ability to adapt to changing environment by detecting and quickly responding to unpredictable stimuli. The analysis of HRV using spectral methods provides quantitative information about sympathetic and parasympathetic modulation of the ANS [14].There are three main spectral components of human HRV in three main frequency zones, a very low frequency component (VLF) below 0.04 Hz, low frequency (LF) component from 0.04 to 0.15 Hz and a high-frequency (HF) component from 0.15 to 0.4 Hz [6]. The LF (Low frequency.0.04Hz to 0.15Hz) is believed to be account for both the sympathetic and parasympathetic nervous influence, and HF (High frequency.0.15Hz to 0.4Hz) component is believed to be dominated by parasympathetic nervous system [1, 3, and 6]. The LF/HF ratio obtained from spectral analysis reflects the balance of sympathetic and vagal or parasympathetic nervous [6]. A large LF/HF ratio suggests predominantly sympathetic control, where as a small LF/HF ratio indicates predominantly vagal control [6, 14]. Many studies have stressed the importance of non-linear techniques in analysing bio-signals to understand the health of a person [15, 16]. Hilbert-Huang transform is recognised as a new tool for analysing non-linear and non-stationary bio-medical signals [15, 16]. Hilbert Huang Transform is used in this paper for analysing the RF exposed ECG signals.

II. METHODOLOGY

The procedure followed in analysing the RF exposed ECG signal using Hilbert-Huang Transform is shown in Fig. 1. In the first step ECG data was collected and then pre-processed to remove the noise. R-peak and HRV complex was detected from the noise free ECG signal. After that Hilbert Huang transform was applied on HRV signal from which Hilbert spectrum and Hilbert Marginal spectrum were obtained. In the last step LF/HF & HF/AF ratio were calculated for the analysis purpose. The subsequent section describes the methodology used in details.

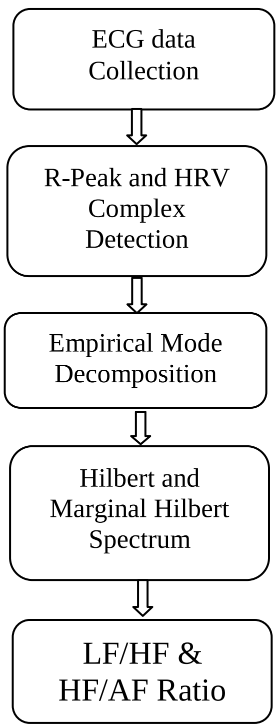

Figure.1. Block diagram of the procedure followed

A. ECG data collection

The real ECG data was collected from ten healthy young post graduate students between the age group of 23 to 27 years. The ECG was recorded using Biopac MP150 system in three conditions using (i) without using mobile phone (ii) using 2G mobile phone during transmitting a call (iii) using 2G mobile phone during receiving a call.

B. R-peak and HRV complex detection

The second step is to obtain HRV signal from the recorded ECG data. For the purpose of obtaining the Heart Rate variability (HRV) signal from the ECG signal, R peaks were detected in the signal. First of all, signal was normalized for making it useful for good analysis. Fig. 2 shows the normalized ECG signal of subject 1. Then, Soft thresholding technique was used for detecting the R peaks in the entire signal. A window was scanned over to the whole signal and each sample of the signal was checked for the threshold level. If the value at that sample exceeds the threshold then it was considered as a peak value. By doing so, a signal was made, which has values of the original signal only at the peaks (i.e. R-peaks), and zeros elsewhere.Fig.3 shows R-peaks on the ECG signal of subject1. To obtain the missing values in the signal one dimensional linear interpolation was done. This signal then served as the HRV signal for further analysis. Fig.4 shows the HRV signal of subject1.

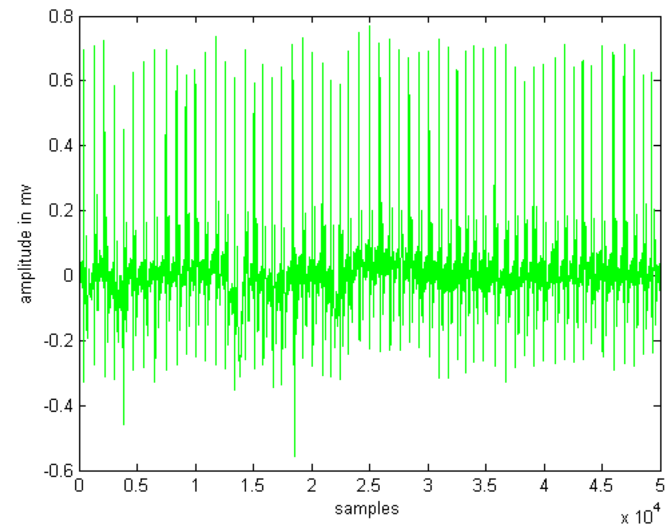

Figure. 2. Normalized ECG signal with zeros mean

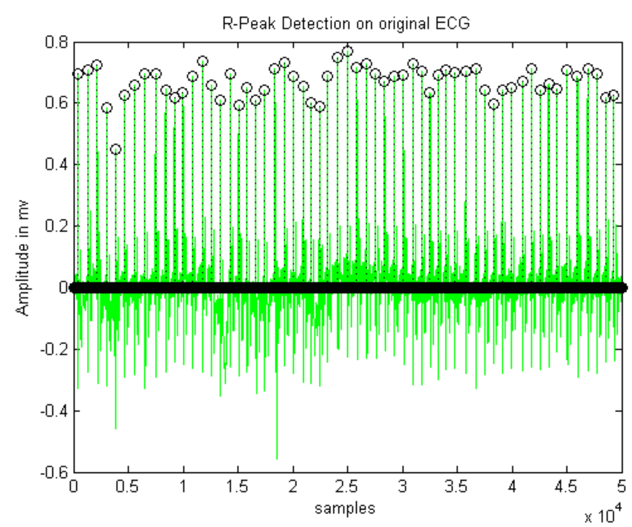

Figure.3. ECG signal with R-peaks overlaid

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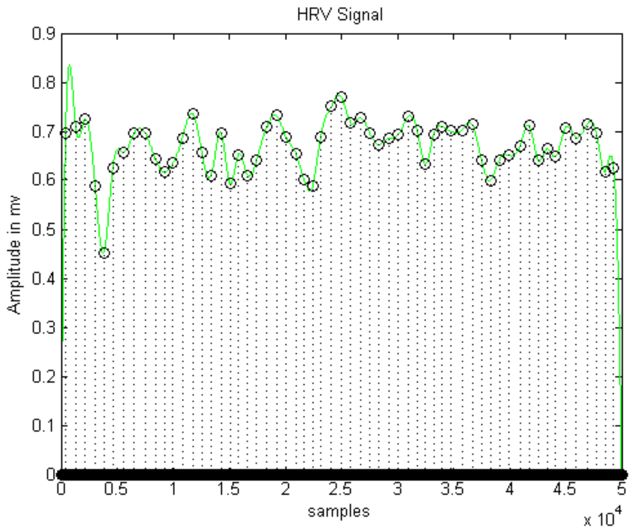


Figure. 4. HRV signal

C. Empirical Mode Decomposition

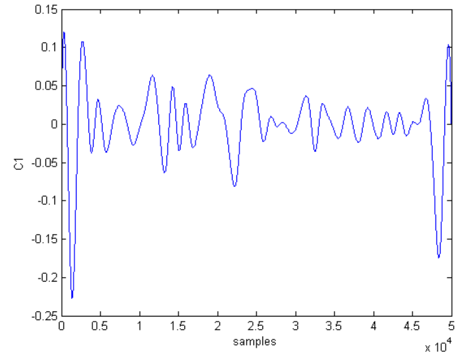
Hilbert Huang Transform (HHT) is a new tool for analyzing non-stationary and nonlinear signals and has been successively applied to various fields of science, such as bio-medical, engineering, machine monitoring failure diagnosis, non-destructive testing, oceanography, geography, medicine, image processing and seismology [15, 16, and 18]. The key part of this method is empirical mode decomposition with which any non-stationary and non-linear signal can be decomposed into a finite and often small number of intrinsic mode functions.

The Empirical Mode Decomposition (EMD) decomposes the original complicated signal into several Intermediate Frequency (IMF) components and every Intermediate Frequency Components meet the following two conditions: (a) In the entire signal length, an IMF with the number of extreme points and zero crossing must equal or differ at most by one. (b) At any moment, the mean value of the envelope defined by the maximum points and the envelope defined by the minimum points is zero [15].

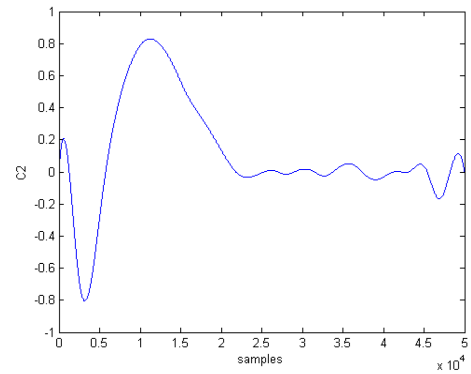
The result of the EMD produces n IMFs $C_i(t)$ for i = 1 to n, and a residue signal $r_n(t)$, so the original sequence can be expressed as sum of all the IMFs and the residue signal as given below.

$$x(t) = \sum C_i(t) + r_n(t) \qquad (1)$$

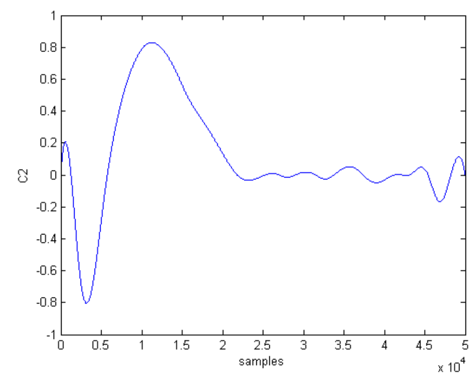
Fig. 5 shows the IMFs of HRV complex of subject 1 without using mobile phone.



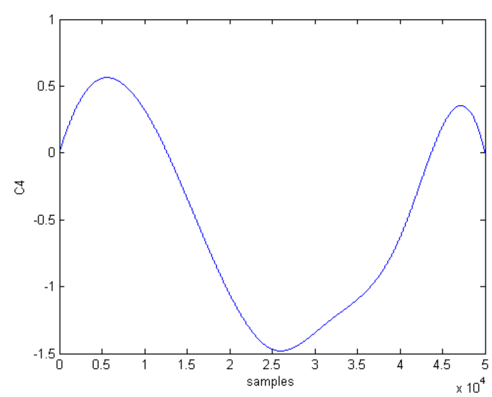
(a)



(b)



(c)



(d)

Figuure.5 (a) to (d) IMF's of HRV signal of subject1without RF exposure

Every IMF sequence is steady, so, it can use Hilbert Transform or other stationary methods for further analysis and processing [18]. This decomposition method is highly adaptive and highly efficient. Since decomposition is based on the local characteristics time scale of the data, it is applicable to non stationary processes.

D. Hilbert and Marginal Hilbert spectrum

The next step is to calculate the Hilbert spectrum and Hilbert marginal spectrum of HRV signal. Hilbert Transform is a mathematical tool widely used in signal theory to describe the complex envelope of a full- scale modulated by a signal. Given a real time function x (t), its Hilbert transform is defined as [19]:

$$x(t)' = H[x(t)] = x(t) * \frac{1}{\pi t} = \frac{1}{\pi}\int \frac{x(\tau)}{t-\tau} d\tau \quad (2)$$

The Hilbert transform is a transformation which is limited to the time domain in contrast to the Fourier transform. Furthermore x (t)' is a linear function of x (t). It is obtained from x (t) applying convolution with a linear system whose the impulse response is 1/πt. x (t) and x(t)' are related to each other in such a way that they together create a strong analytic signal. The analytic signal is expressed as:

$$x_a(t) = x(t) + iH[x(t)] \quad (3)$$

The amplitude of the analytical signal provides the Hilbert envelope of x (t) [19]. Amplitude and phase of the analytical signal is given by

$$a(t) = \sqrt{x(t)^2 + H[x(t)]^2}\ ,\ \theta(t) = \arctan\frac{\mathrm{H[x(t)]}}{\mathrm{x(t)}} \quad (4)$$

Where, a (t) and θ (t) are the amplitude and phase of the analytical signal respectively.

Instantaneous Frequency is defined as the time derivative of phase of the analytical signal and given by:

$$\omega(t) = \frac{d\theta(t)}{d(t)} \quad (5)$$

Now the original signal can be represented in the terms of amplitude and instantaneous frequency can be written as follows:

$$X(t) = \sum_{j=1}^{n} a_j(t) \exp\left(\mathrm{i}\int \omega_j(t)\,\mathrm{d}t\right). \quad (6)$$

The above representation can be seen in inverse manner also, i.e. we can visualize amplitude and instantaneous frequency as the function of time in a three dimensional plot, which is known as Hilbert Spectrum [20].

Hilbert spectrum is denoted by $H(\omega, t)$, which is a function of instantaneous frequency and time, Another useful term, known as Marginal Hilbert Spectrum[20] can be defined as follows:

$$h(\omega) = \int_0^T H(\omega, t)\,\mathrm{d}t. \quad (7)$$

Where, $h(\omega)$ is the marginal Hilbert spectrum, which gives the total amplitude or energy contribution from each frequency component. It can be obtained by integrating the Hilbert spectrum throughout its time span.

E. LF/HF &HF/AF ratio calculations

In HRV Complex of ECG signal, Very Low Frequency (VLF) component exists below 0.04 Hz, Low Frequency (LF) component lies in between 0.04 Hz to 0.15 Hz, and High Frequency (HF) component lies between 0.15 Hz to 0.4 Hz [6]. All the amplitude contributions of the frequencies in the corresponding ranges are calculated and refer to as VLF, LF and HF, where AF is sum of all the contributions, i.e.

AF = VLF + LF + HF,

In the last step the ratios LF/HF and HF/AF, which served as the parameters in the analysis of HRV complex, were calculated for all the subjects.

III. RESULTS

In this section analysis on Hilbert spectrum and Hilbert marginal spectrum is done. All the steps mentioned in the section 2 were conducted on the recorded ECG signal of all the ten subjects without RF exposure and with RF exposure. In the calculations of Hilbert and Marginal Hilbert spectrum, the frequencies were taken from 0 Hz to 0.5 Hz because it is believed that Heart rate variability signal contains frequency up to 0.4 Hz [6]. So, contribution of all the frequencies above 0.5 Hz was neglected (as their contribution was very minor). Fig 6 shows Hilbert spectrum of subject1 without RF exposure. Fig.7 shows the Hilbert spectrum of subject 1 with RF exposure using 2G mobile phone during receiving a call. Fig.8 shows the Hilbert spectrum of subject 1 with RF exposure using 2 G mobile phone during transmitting a call.

Comparing the Hilbert spectrums of HRV complex for RF exposed ECG case with the Hilbert spectrums of HRV complex for without RF exposure of subject1; it is observed that spectrum converged towards lower frequency. Most of the dominant contributions lie below 0.15 Hz in the spectrum. Low frequency band power increases during RF exposure.

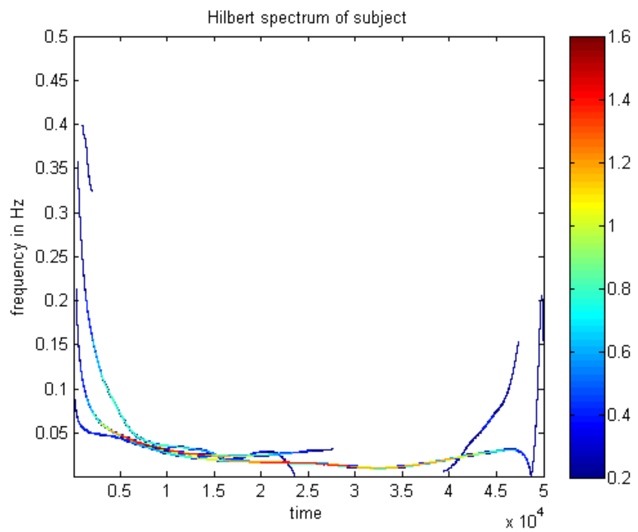


Fig.6.Hilbert Spectrum of subject 1without RF exposure

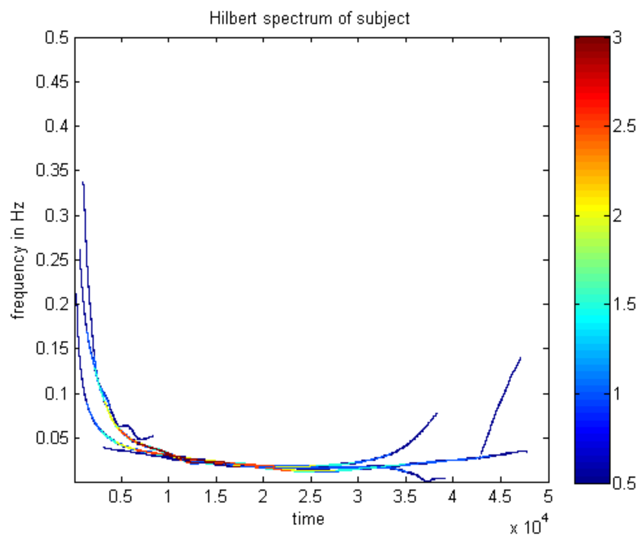


Fig.7. Hilbert spectrum of subject1 during receiving a call

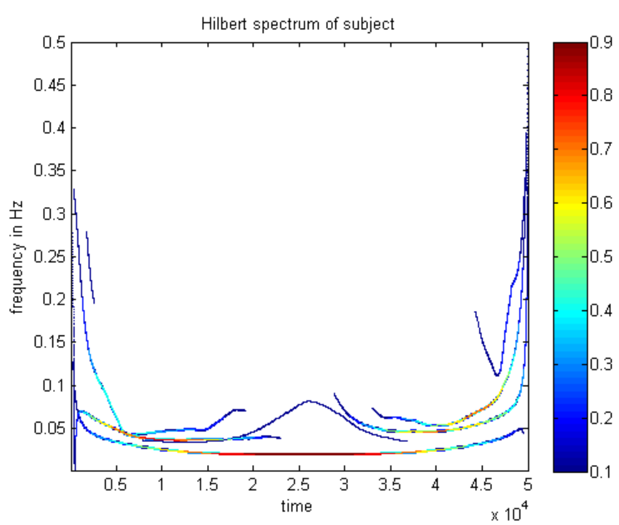


Fig. 8 Hilbert spectrum of subject 1 during transmitting a call

Marginal Hilbert spectrum can be obtained from Hilbert spectrum by integrating it along the time axis. In our experiment, each 0.05 Hz increment in frequency accounts for 50 samples increase in Marginal Hilbert spectrum. Frequency contribution of the HRV complex of ECG signal can be easily obtained from the samples of Marginal Hilbert spectrum. Fig.9 shows the Marginal Hilbert Spectrum of subject 1 without RF exposure and Fig.10 shows the Marginal Hilbert Spectrum with RF exposure using 2G MP in receiving mode and Fig.11 shows the Marginal Hilbert Spectrum with RF exposure using 2G MP in transmitting mode. It can be seen that during RF exposure amplitude contribution of low frequency components increases and amplitude contributions of high frequency components decreases in both the transmitting and receiving mode.

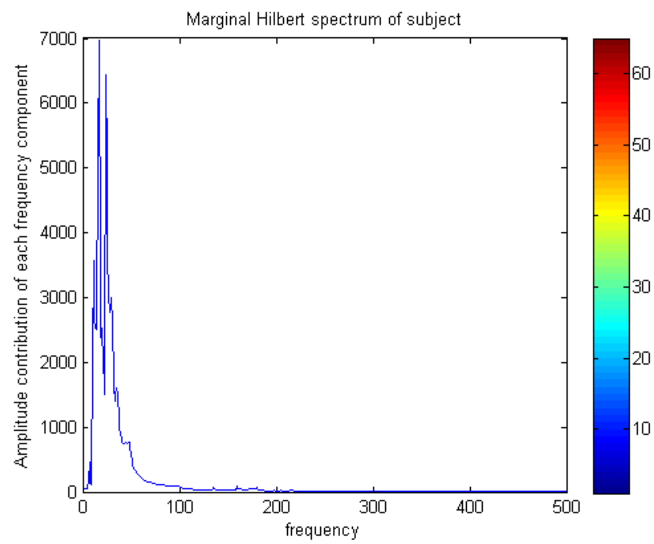


Fig. 9 Hilbert Marginal spectrum of subject 1 without RF exposure

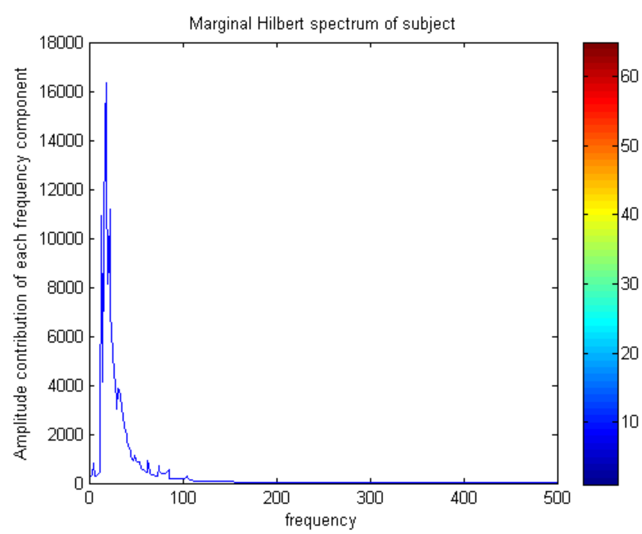


Fig.10 Hilbert Marginal spectrum of subject1 during receiving call.

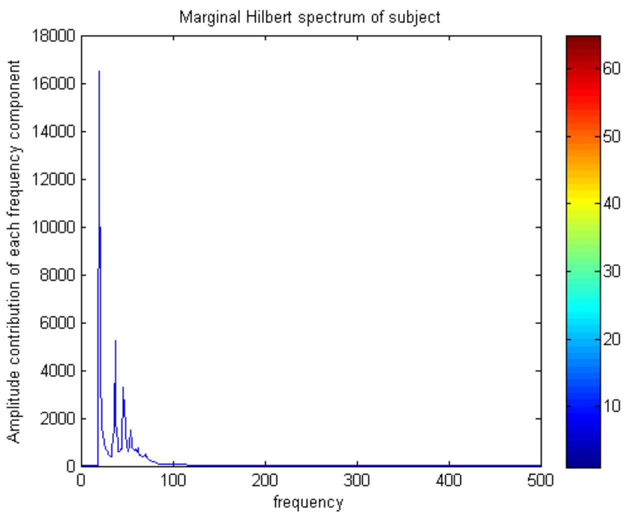


Fig. 11 Hilbert spectrum of subject 1 using 2G MP during transmitting a call

Table 1 shows the LF/HF and HF/AF ratio of all the subjects without using mobile phone and using 2G mobile phone in receiving and transmitting mode. Table suggests that using 2G mobile phone out of ten subjects in seven subjects LF/HF ratio is increasing and corresponding HF/AF ratio is decreasing. In three subjects LF/HF ratio is decreasing and corresponding HF/AF ratio is increasing. It is also observed that in any subject if LF/HF ratio is increasing in transmitting mode then the LF/ HF ratio in receiving mode is also increasing and if LF/HF ratio is decreasing in transmitting mode then the LF/ HF ratio in receiving mode is also decreasing. This shows that effect of RF is same on HRV of the subject irrespective of receiving and transmitting mode. An increase in LF/HF ratio in majority of subjects shows an autonomic imbalance with increase in sympathetic activity and withdrawal of vagal activity and corresponding decrease in ratio HF/AF shows decrease or withdrawal of parasympathetic/vagal activity in nervous system. This shows that RF exposure influences the HRV and change the autonomic balance.

TABLE1. LF/HF and HF/AF ratio using 2G mobile phone

Status Subjects		Without using Mobile phone	2G Mobile Phone	
			Receiving mode	Transmitting mode
01	LF/HF	4.3386	9.0090	15.1754
	HF/AF	3.8328%	1.9565%	2.7217%
02	LF/HF	2.9037	2.9037	42.3423
	HF/AF	6.0161%	6.0116%	0.9884%
03	LF/HF	12.3107	2.9785	9.7553
	HF/AF	3.9118%	12.7654%	4.0499%
04	LF/HF	4.3337	5.8055	8.6790
	HF/AF	3.4432%	3.2417%	2.2700%
05	LF/HF	5.5117	10.0887	5.5506
	HF/AF	5.9137%	3.9007%	4.0999%
06	LF/HF	8.2688	15.6490	9.9179
	HF/AF	3.7495%	2.1505%	3.2933%
07	LF/HF	6.3967	42.5666	16.9545
	HF/AF	2.1019%	0.1263%	1.7577%
08	LF/HF	5.5456	3.2238	3.6385
	HF/AF	4.1142%	5.0345%	6.4696%
09	LF/HF	13.1570	5.9412	7.0056
	HF/AF	4.0027%	4.3236%	4.4562%
10	LF/HF	2.8990	13.2476	9.3797
	HF/AF	5.4427%	4.8830%	5.3646%

IV. CONCLUSION & DISCUSSION

This paper is concerned with the analysis of the RF exposed ECG signal using Hilbert-Huang transform. Empirical mode decomposition (EMD) and Hilbert spectral analysis is performed on the recorded ECG signal. Results of our study demonstrate that RF exposure may influence HRV and change the autonomic balance. The increase in the sympathetic tone with a concomitant decrease in the parasympathetic tone is measured by analysis of Hilbert spectrum and Hilbert marginal spectrum of HRV during RF exposure in majority of the subjects. The LF (Low Frequency, 0.04 Hz to 0.15 Hz) in the HRV complex is believed to be account for both the sympathetic and parasympathetic nervous influence, and HF (High Frequency, 0.15 Hz to 0.4 Hz) component is believed to be dominated by parasympathetic nervous system. This means that LF/HF ratio reflects the balance of sympathetic and parasympathetic (vagal) system. An increase in LF/HF ratio thus, shows an autonomic imbalance with increase in sympathetic activity and withdrawal of vagal activity. This imbalance is verified by another parameter i.e. HF/AF ratio. As stated above that HF component accounts for the parasympathetic nervous system, so a decrease in ratio HF/AF shows decrease or withdrawal of parasympathetic/vagal activity in nervous system.

Since, there are many other parameters to consider while analyzing the sympathetic and parasympathetic activities in nervous system, so it would be so early to comment on positive or negative impact of Radio frequencies on the autonomic nervous system activities. The more accurate results can be obtained by increasing the number of subjects and exposure time. HHT is a powerful tool for analyzing non-linear and non-stationary data. All real world applications are non-stationary and non-linear. ECG signals are typically non stationary signals so, HHT method in ECG signal processing has broad application prospectus. RF exposed ECG signals are much more nonlinear and non-stationary. Mobile phones are now extensively used by us. The effect of radio frequencies on the heart is a topic of research. Hence use of HHT shall be an accurate approach for analysis of RF exposed signal.

V. ACKNOWLEDGEMENT

The authors thank Dr. S.S Pattnaik, Vice chancellor, Biju Patnaik University of technology (BPUT), Odisha and National Institute of Technical Teachers Training and Research (N.I.T.T.T.R), Chandigarh laboratory for their technical assistance and taking recordings of the E.C.G

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Suman was born in Chandigarh, INDIA, in 1973. She received the AMIE and M.E. degrees in Electronics & Communications Engineering from the Institutions of Engineers and Punjab University in 1996 and 2011 respectively. She is pursuing Ph.D. degree in electronics engineering from Punjab Technical University.

From 1996 to 2002, she was a Senior Group Engineer in Punjab Communications Limited and has a good industrial and practical exposure also. Since 2010, he has been an Assistant Professor with the Electronics & Communication Engineering Department in a PTU College. She has published in National and International Journals and conferences and has won best papers awards. Her research interests include biomedical engineering, neural networks, soft computing techniques and also has good hand on Sci-lab.