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HRV Analysis of Arrhythmias Using Linear – Nonlinear Parameters

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ABSTRACT
Heart rate variability (HRV) refers to the beat-to-beat alterations in heart rate. HRV analysis is based on the concept that, fast fluctuations reflect the changes of sympathetic and vagal activity which results in variability of intervals between R waves i.e. "RR intervals". In the current work HRV was assessed by traditional linear time and frequency-domain indexes, in parallel with the non linear Poincare plot analysis.

Initially R peaks are detected from the ECG and RR interval signal is obtained which is further used to get the HRV signal. Spectral analysis of this HRV signal is done to estimate the power content in different frequency bands. Two frequency bands play a vital role in the power spectrum, a low frequency and a high frequency. Simultaneously, for time domain analysis, parameters such as mean of RR interval signal, standard deviation, coefficient of variance, root mean square of standard deviation are evaluated from RR interval signal and analyzed for different arrhythmias. Poincare plot analysis is an emerging quantitative-visual technique whereby the shape of the plot is categorized into functional classes that indicate the different arrhythmia. In this each R-R interval is plotted as a function of the previous one, and the standard deviations of the instantaneous and long-term R-R interval variability are calculated.

It is observed that mean of RR interval signal and coefficient of variance plays an important role and can be used in classification along with the power content in low and high frequency bands. Also position and orientation of RR intervals in Poincare plot play an important role in visual identification of arrhythmias. The method is applied to normal sinus rhythm, ST change, CU Ventricular Tachyarrhythmia, Malignant ventricular arrhythmia signals. In this work, the different linear and non linear parameters evaluated show a particular range for various cardiac arrhythmias.

General Terms
Signal Processing, Biomedical signal processing, ECG Arrhythmia Classification.

Keywords
Coefficient of variance, Heart Rate Time Series (HRTS), Heart Rate Variability (HRV), Poincare plot, Power Spectral Density (PSD), Standard deviation.

1. INTRODUCTION
Heart disease is a broad term that includes several more specific heart conditions which are Coronary Heart Disease, Heart Attack, Acute Coronary Syndrome, Aortic Aneurysm and Dissection, Ischemia, Arrhythmias, Cardiomyopathy, Congenital Heart Disease, Peripheral Arterial Disease (PAD). ECG analysis plays an important role in identifying the disorder. Some of the ECG feature extraction methods implemented in previous research includes Discrete Wavelet Transform, Karhunen-Loeve Transform, Hermitian Basis and other methods ([1]-[3]).In recent years special attention has been given to the analysis of the heart rate variability (HRV) and its relation to the other physiological signals. Methods for quantifying HRV are categorized as: time domain, spectral or frequency domain, geometric and nonlinear ([4],[5]).

In time domain analysis, the intervals between adjacent normal R waves are measured over the period of recordings. A variety of statistical variables can be calculated from the intervals [5].

In frequency domain method ([6],[7]) either fast Fourier transformation or autoregression techniques can be used to quantify cyclic fluctuations of RR intervals. Two peaks are seen in RR interval power spectra a low frequency peak between 0.04 Hz – 0.15 Hz, and high frequency peak between 0.15 Hz – 0.40 Hz. The magnitude of power in LF and HF regions provide quantitative index of the sympatho-vagal dynamic balance in control of the heart rate.

One nonlinear method used is the Poincare plot [8]. It is a graphical representation of the correlation between consecutive RR intervals. It is a graph of each RR interval plotted against the next interval as shown in figure 1. Poincare plot analysis is an emerging quantitative-visual technique whereby the shape of the plot is categorized into functional classes that indicate the degree of heart failure in a subject. Two basic descriptors of the plot are SD1and SD2. The line of identity is the 45^0 imaginary diagonal line on the Poincare plot. SD1 and SD2 are dispersions as shown in figure 1.

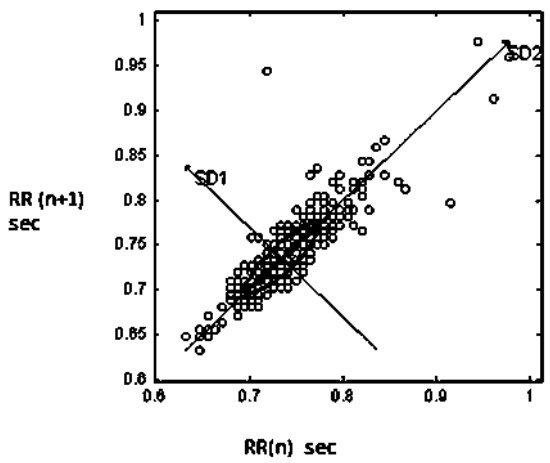

Fig 1: Poincare Plot

2. SYSTEM DESIGN IMPLEMENTATION

The objective of the research is to obtain the range of values of the time and frequency domain parameters in parallel with non linear parameters for identification of different arrhythmias. Figure 2 shows the system block diagram.

The process of ECG analysis is subdivided into a number of processing modules as stated below:

2.1 Data Acquisition and Sampling

The ECG Database from Physio Bank (MIT – BIH database) mostly which are sampled at 250 Hz is being used as a data of ECG input signal for features extraction part and processing.

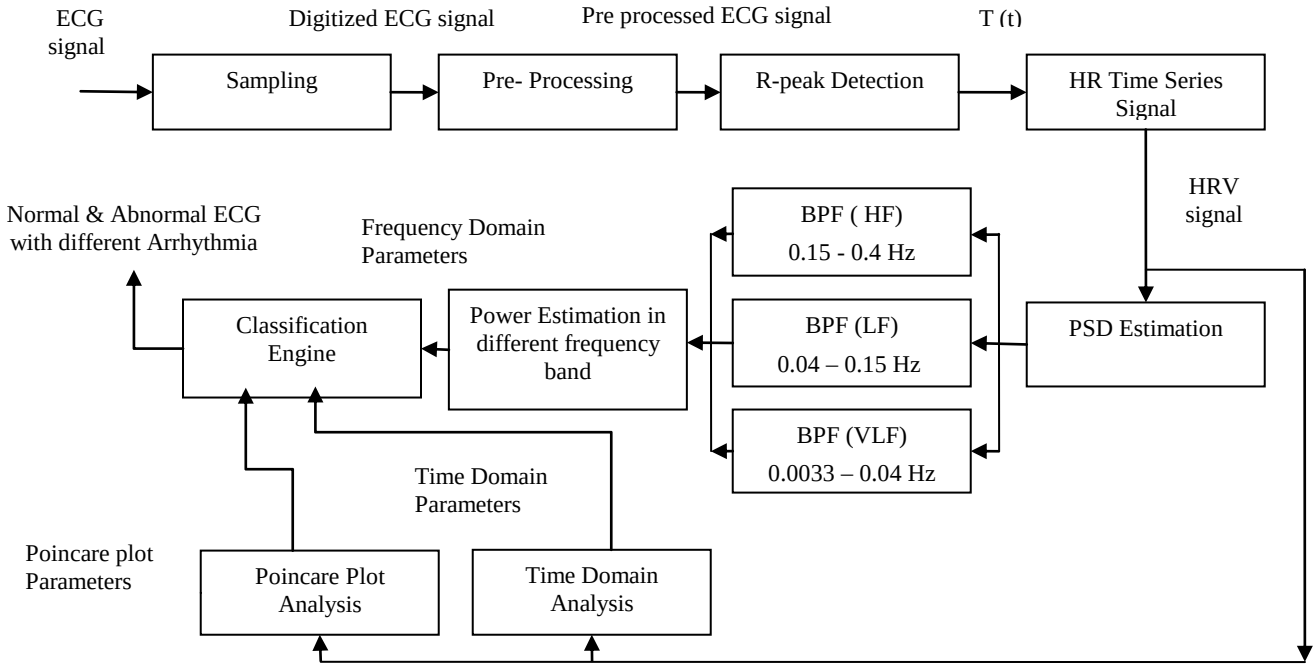

Fig 2: System Block Diagram

2.2 Preprocessing of ECG Signals

Generally, the recorded ECG signal is often contaminated by noise and artifacts that can be within the frequency band of interest and manifest with similar characteristics as the ECG signal itself. Preprocessing ECG signals helps to remove the contaminants from the ECG signal [9]. Among the various noises, the power line interference and the baseline wandering are the most significant and can strongly affect ECG signal analysis. Except for these two noises, other noises may be wideband and usually are a complex stochastic process which also distorts the ECG signal.

2.3 Feature Extraction

In feature extraction initially R wave signal is obtained by marking the R peaks by unit impulses. R-R time series signal is evaluated from R wave signal.

The R-R interval is obtained as,

$$RR(t) = T(t) - T(t-1) \quad (1)$$

Where,

RR(t) = R - R interval at t^{th} sample

R(t - 1) = position of delta function at (t - 1)st R peak.

R(t) = position of delta function at t^{th} R peak

Variability of the RR interval signal is obtained in both time and frequency domain.

For frequency domain analysis HRV is estimated as

$$HRV = RR - mean\ (RR) \quad (2)$$

Where,
HRV= heart rate variability signal
RR= RR time series signal

Error in measurement of HRV is function of sampling frequency [10]. Error is significant when sampling frequency is low and decreases with increase in sampling frequency of ECG.
In time domain method there are several statistical indices used to describe heart rate variability, e.g. average, median, deviation between maximum and minimum values (range), standard deviation (S_x) and root mean square of successive differences (RMSSD).

The statistical properties of a time series $x(t)$ i.e. RR are often described using basic indices such as the mean of x(t), and standard deviation S_x, which can be obtained from the given data as follows:

$$\bar{x} = \sum_{t=1}^{N} x(t)/N \quad (3)$$

$$s_x = \sqrt{\sum_{t=1}^{N} (x(t) - \bar{x})^2/N} \quad (4)$$

The variance is the square of the standard deviation,

$$var\ (x(t)) = s_x^2 \quad (5)$$

The coefficient of variation CV_x and the range d_x, i.e. the deviation between the maximum and minimum values in a time series, are formulated as

$$CV_x = 100.\frac{s_x}{\bar{x}} \quad (6)$$

$$d_x = \max(x(t)) - \min(x(t)) \quad (7)$$

The root mean square of successive differences (RMSSD) is calculated for the purposes of HRV analysis by

$$RMSSD_x = \sqrt{\sum_{t=1}^{N-1} (x(t) - x(t+1))^2/N} \quad (8)$$

In case of spectral analysis, the power of the signal in a given frequency band can be calculated by integrating over required range of frequencies. In this methodology power is estimated in different frequency ranges LF, HF, Plf, Phf and the ratio Rf and PRF is evaluated as shown below.

LF = 0.04 - 0.15 Hz, HF = 0.15 - 0.4 Hz
Plf = 0.15 - 0.25 Hz , Phf = 0.25 - 0.35 Hz

$$Rf = LF/HF \quad (9)$$
$$PRF = Plf/Phf \quad (10)$$

The range of power ratio for spectral analysis is calculated for different arrhythmia by using the ECG signals from MIT- BIH database.

In case of non linear parameters, SD1 and SD2 of Poincare plot is directly related to the basic statistical measures, standard deviation of RR interval (SDRR), and standard deviation of the successive difference of RR interval (SDSD) which is given by the relation shown in equations below.

$$SD1^2 = ½\ SDSD^2 \quad (11)$$
$$SD2^2 = 2\ SDRR^2 – ½\ SDSD^2 \quad (12)$$

The ratio S12= SD1/SD2 is evaluated for further analysis.

2.4 Classification

The range of powers estimated and the values of time domain parameters obtained by using the standard database for different arrhythmias are used for classification. Further the standard descriptors of Poincare plot can be used for verification and plot can be used for visual identification.

3. RESULTS AND DISCUSSIONS

The ECG data from MIT-BIH database of physiobank dataset is used. A set of normal sinus rhythm (NRM) is used as normal subject database and Creighton University Ventricular Tachyarrhythmia (CUVT), Malignant Ventricular Arrhythmia Ectopy Database (MVA) and ST Change (ST) are used for abnormality analysis. The ECG signals selected are of 1 minute duration.

Figure 3, 4, 5 and 6 shows the HRV and PSD of HRV for normal and different arrhythmias. Figure 7 shows Poincare plot of normal subject. The cluster of RR intervals appears in between 0.6 sec to 1.2 sec window without scatter around along the line of identity axis. Figure 8 is Poincare plot of ST Change subject where the cluster of RR intervals appears in between 0.6 sec to 1.5 sec window with some intervals scattered around the cluster. Mostly cluster appears near 1 sec. Figure 9 shows Poincare plot of CUVT subject, the cluster of RR intervals appears in between 0.4 sec to 2.5 sec window with some intervals scattered around the cluster. The SD1 and SD2 are nearly equal. Figure 10 shows Poincare plot of MVA subject. The cluster of RR intervals appears in between 0.3 sec to 2 sec window with mostly all RR intervals scattered around. The SD1 and SD2 are nearly equal.

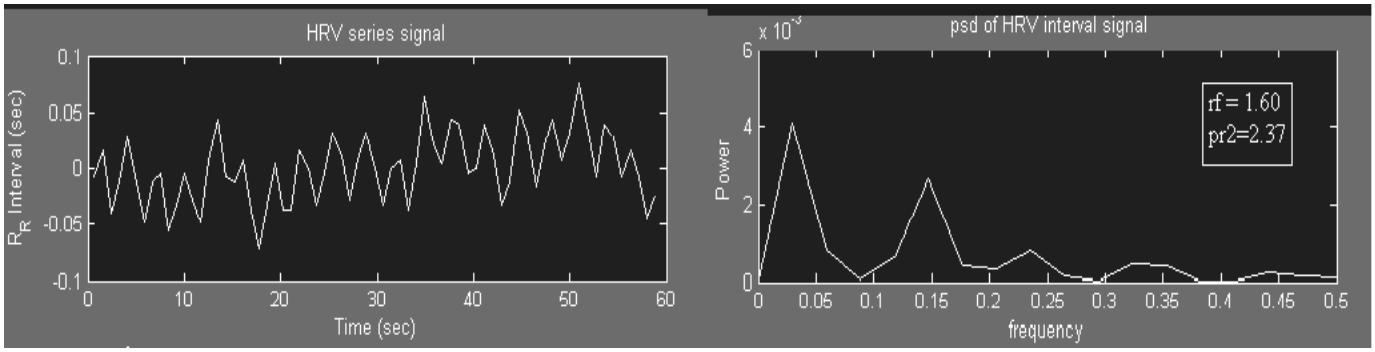

Fig 3: HRV and PSD of normal subject

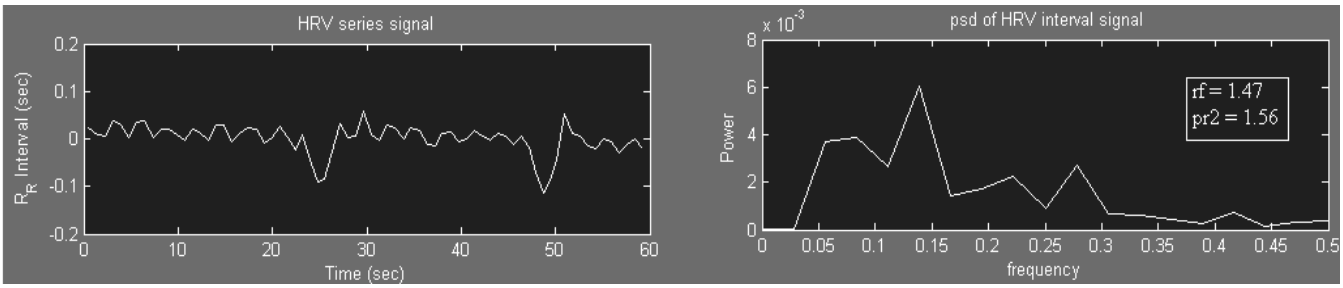

Fig 4: HRV and PSD of ST change subject

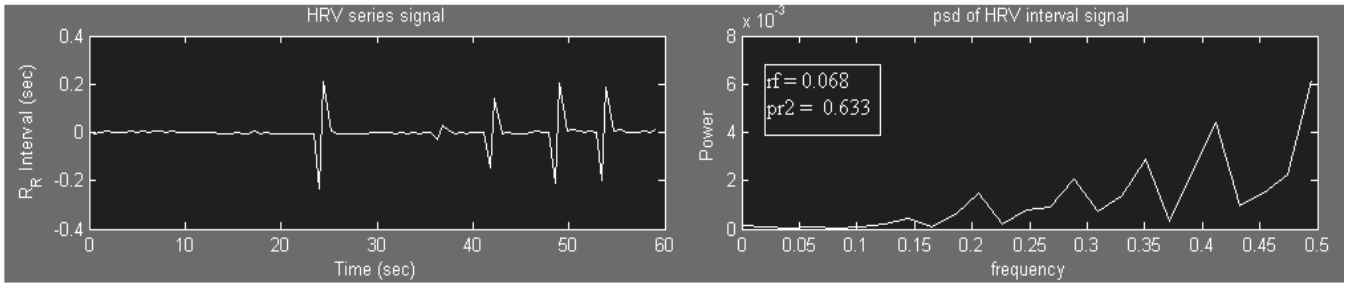

Fig 5: HRV and PSD of CUVT subject

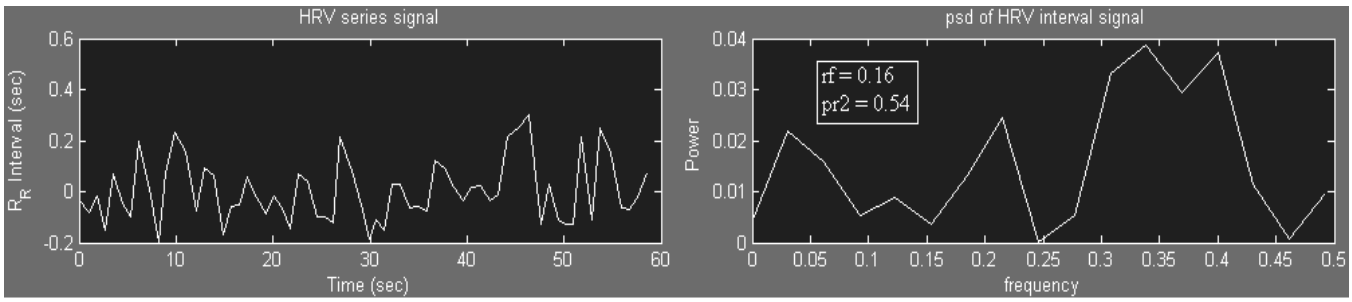

Fig 6: HRV and PSD of MVA subject

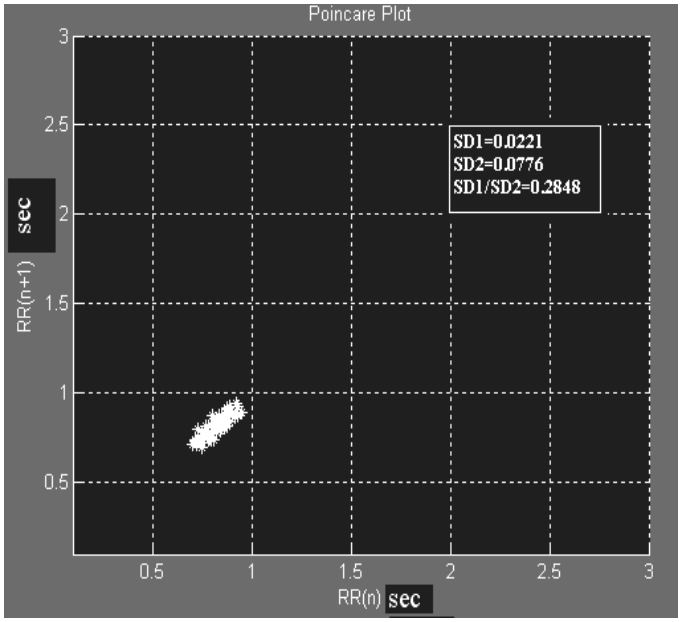

Fig 7: Poincare Plot of normal subject

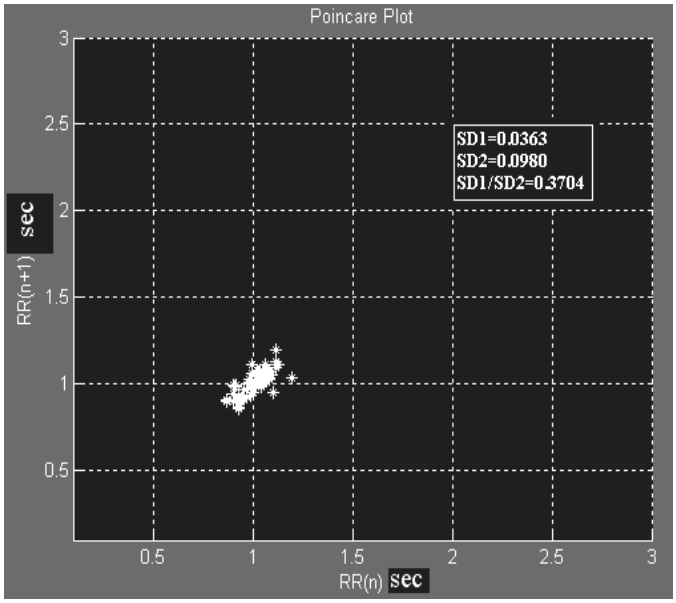

Fig 8: Poincare Plot of ST Change subject

Table 1 specifies the range of Power ratio for PRF and Rf along with the time domain parameters Coefficient of Variation (CVx) and Mean of RR interval signal (Mean_x) for normal ECG and different arrhythmias obtained from ECG signal analysis. By using the values of table 1, system is designed to classify the ECGs and is evaluated as shown below.

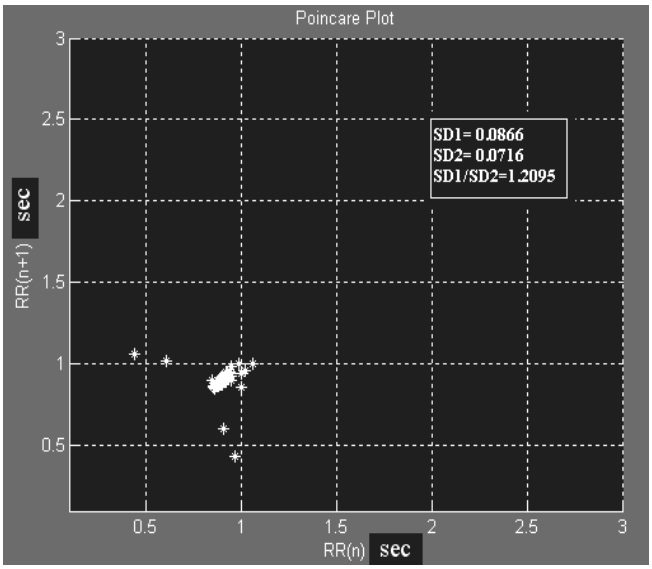

Fig 9: Poincare Plot of CUVT subject

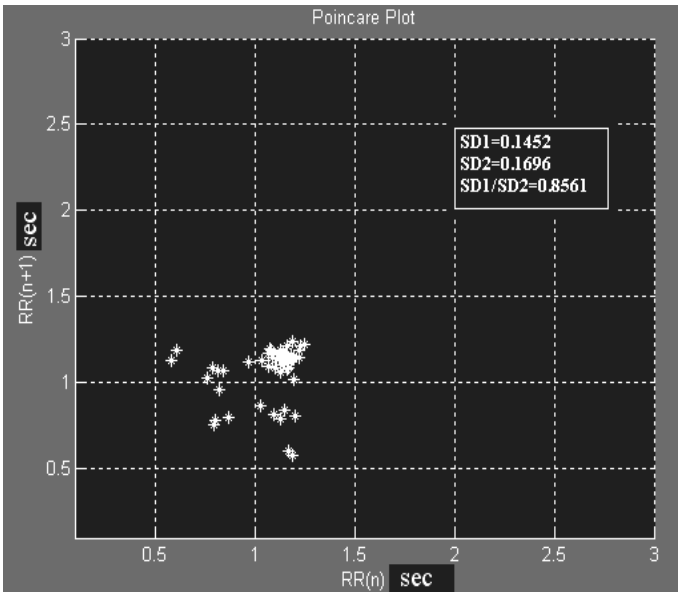

Fig 10: Poincare Plot of MVA subject

Table 2 presents the performance of the classification by the system.

Table 3 specifies the Poincare plot indexes of the HRV measured from the Poincare plots of normal and different arrhythmia subjects. Using these values and visually analyzing the plot the classification can be further enhanced.

Table 1. Variation of Parameters in Time and Frequency Domain

ECG signal	Rf = lf/hf	PRF	Coefficient of variation (CVx)	Mean_x
Normal	<1 or >1	> 2	2<CVx<10	0.5<M<0.9
STchange	< 1 or >1	1 – 2	>1	0.6 < M
CUVT	<1	<1	0<CVx<10	M<1 or M>1
MVA	<1	< 1 or >1	>10	M<1 or M>1

Table 2. Accuracy of System Designed

Input ECG signal		Classified as					% of Evalu - ation
	Total	Normal	ST Change	CUVT	MVA	Unidentified	
Normal	13	11	1		--	1	84.61
ST Change	19	2	16	1	-	--	84.21
CUVT	18	1	2	9	4	2	50
MVA	16	--	2	3	10	1	62.5

Table 3. Poincare Plot Indexes of HRV

ECG Signal	Poincare Plot Indexes		
	*SD1(sec)	*SD2(sec)	*SD1/SD2
Normal	0.0189 ± 0.0150	0.0529 ± 0.0330	0.3556 ± 0.2600
ST Change	0.0916 ± 0.0820	0.0979 ± 0.0741	0.6620 ± 0.5100
CUVT	0.0674 ± 0.0580	0.0778 ± 0.0650	0.9120 ± 0.7011
MVA	0.1493 ± 0.1100	0.1828 ± 0.1250	1.1735 ± 0.5674

* Indexes are expressed as mean ±deviation

4. CONCLUSIONS

Quantifying the variability in cardiovascular signals provides information about autonomic neural regulation of the heart and the circulatory system. RR interval recording, which is used to describe heart rate variability (HRV), involves a noninvasive and easy approach to gain information on cardiovascular function.

Frequency domain analysis plays a vital role in analysis and identification of different arrhythmias. But along with the time domain the identification can be done more efficiently. From the percentage of evaluation, it is concluded that the methodology proves good to detect Normal and ST Change arrhythmia whose accuracy is greater than 80 % where as it is not good to detect the CUVT and MVA arrhythmias. But in order to identify CUVT and MVA Poincare plot can be used as an important tool and enhance the performance.

The classification can be further improved by analyzing the HRV in combination with all the different methods.

5. REFERENCES

[1] Costas Papaloukas, Dimitrios I. Fotiadis, Aristidis Likas, Lampros K. Michalis, "Automated Methods for Ischemia Detection in Long Duration ECGs", 2003.

[2] Moraes, J.C.T.B., Seixas, M.O., Vilani, F.N., Costa, E.V., "A Real Time QRS Complex Classification Method Using Mahalanobis Distance" Comput. Cardiol., 2002.

[3] Davi[d Cuesta-Frau, Juan C, Perez-Cortes, Gabriela Andrea Garcia, Daniel Navak, " Feature Extraction Methods Applied to the Clustering of Electrocardiographic Signals. A Comparative Stucy", Czech Technical University In IEEE Proceeding, 2002.

[4] Rajendra Charta U., Kannathal N., g Wai Sing, Luk Yi Ping and Tjileng Chua, "Heart Rate Analysis in normal subjects of various age groups", Biomedical Engg. Online 2004.

[5] Robert E. Kleiger, Phyllis K. Stein, J. Thomos Bigger, "Heart Rate Variability: Measurement and Clinical Utility", A.N.E. 2005.

[6] S. Akselrod, D. Gordon, F. A. Ubel, D.C. Shannon, A. C. Barger and R. J. Cohen, "Power spectrum analysis of heart rate fluctuations : A quantitative probe of beat-to-beat cardiovascular control", Science vol. 213, pp220 – 222, 1981.

[7] V. P. S. Naidu "Frequency domain analysis of heart rate time series signal", Department of medical electronics, M. S. R. Technology, Bangalore, Journal of the Institution of Engineers (India), 2002.

[8] Brennan M, Palaniswami M, Kamen P, "Do existing measures of poincare plot geometry reflect nonlinear features of heart rate variability", IEEE Trans on Biomed Engg. 2001.

[9] S. R. Seydngad R. I. Kiteny, "Real time Heart rate variability Extraction using Kaiser Window", IEEE transactions on Biomedical Engg., 1997.

[10] M. Merri, David C. Farden, J.G. Mottley, E. L. Titlebaum, "Sampling Frequency of the Electrocardiogram for Spectral Analysis of the Heart Rate Variability", IEEE trans. On Biomedical Engg., 1990.