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DEVELOPMENT OF A SYSTEM FOR ASSESSMENT OF HRV

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***Abstract* : Electrocardiogram (ECG) is the most preferably used noninvasive test for diagnosis of cardiac rhythm. Irregular rhythm of heart beats is measured in terms of Heart Rate Variability (HRV). Analysis of HRV plays an important role in automated diagnosis of cardiac status. This paper discusses about the development of an economical, reliable and portable HRV system. A low cost embedded system for monitoring an ECG has been developed using operational amplifiers and a Microchip's microcontroller. Digitized ECG has been transmitted serially to computer for analysis of HRV. The system is built around the principles of short term recording for 5 minutes.**

The system provides time domain measures like heart rate in BPM for every minute of recording, average heart rate over the recording period of 5 minutes, mean NN interval, variance in NN intervals and SDNN. The system also provides frequency domain measures based on short term spectral analysis like total power (0.00 to 0.4 Hz), LF (0.00 to 0.04 Hz), MF (0.04 to 0.15 Hz) and HF (0.15 to 0.4 Hz) power in ms2. The sympatho vagal balance (MF/HF) which indicates the influence of two branches of autonomic nervous system on HRV is finally calculated from the above parameters. The testing is done on a sample of healthy persons RR intervals and RR intervals of persons with different heart related abnormalities. The system clearly identifies the diseased state of heart from the healthy state

Key words: *ECG, HRV, BPM, SDNN, LF, MF, HF*

I. INTRODUCTION TO HRV

Heart rate is a non-stationary signal and provides a powerful interplay between the sympathetic and parasympathetic nervous systems. The heart rate variation may contain indicators of present disease, or warnings about impending or future cardiac diseases. These indicators may be present at all times or may occur at random during certain intervals in the time scale [6]. It is difficult and time consuming to pinpoint these abnormalities in huge cardiac data.

Heart rate variability (HRV) constitutes a tool for assessing the activities of the autonomic nervous system (ANS).

The health of the entire body can be determined by analyzing the length of time between each heartbeat. The difference in time between each heartbeat is referred to as heart rate variability (HRV). Like a fingerprint, each individual's heart rate variability is unique. This "fingerprint" reflects all of the fluctuating neurological, immunological, and hormonal processes that occur in a human body. A decrease in heart rate variability has emerged as the single most common risk factor for many chronic diseases such as diabetes, chronic fatigue, chronic heart failure, neurological disorders, and many other conditions. Two people could have exactly the same average heart rate, yet when the time period between each heartbeat is carefully measured, it can be seen that the variation of time between each beat is different for different individuals.

A key advantage of HRV analysis is the method's ability to detect the early signs of development of pathological processes or the presence of a functional disorder which may not be revealed by the procedures of an ordinary physical examination. Numerous studies have now shown HRV to be an independent prognosticator of mortality[10].

Diminished HRV predicts both death and arrhythmic events with greater sensitivity and specificity than conventional predictors. Also, the reproducibility of HRV measurement is superior to those of other variables that are also known to predict mortality in survivors of myocardial dysfunction.

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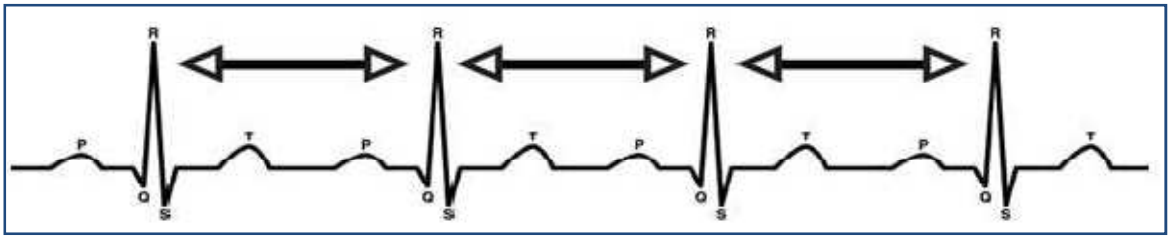

Fig. 1: HRV measurement is done by calculating the time between R spikes on an ECG trace.

II. HRV AS AN INDICATOR OF AUTONOMIC NERVOUS SYSTEM FUNCTIONS

The autonomic nervous system is a major division of peripheral nervous system and differs from the somatic and motor nervous system in that its control is essentially involuntary. It was once thought that the autonomic system is completely involuntary, but recent experimentation indicates that it is possible for a person to learn to control portions of this system to some extent [8].The major divisions of autonomic nervous system are the sympathetic and parasympathetic systems [8].The sympathetic system is primarily involved in mobilizing the body to meet emergencies whereas the parasympathetic nervous system is concerned with the vegetating functions of the body, such as digestion, sexual activities, and waste elimination.

One other effect that should be mentioned is that of pressoreceptors or baroreceptors situated in the arch of the aorta and in the carotid sinus. Their function is to alter the vagal tone whenever the blood pressure within the aorta or carotid sinus changes. When blood pressure rise, vagal tone increased and the heart rate slows; when blood pressure falls, vagal tone is decreased and the heart rate increased [8].Figure 2 indicates the control of heart rate by the sympathetic and parasympathetic nervous system.

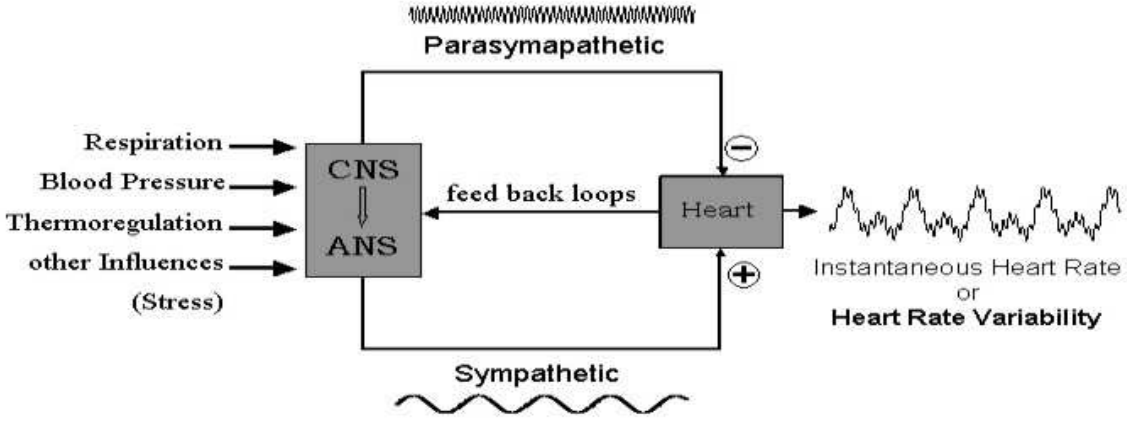

Fig.2: Control of Heart rate by autonomic nervous system

III. MEASUREMENT OF HEART RATE VARIABILITY (HRV)

From the electrocardiogram (ECG), the R-R waves are determined (in terms of the interval lengths between consecutive R-waves), and are used to generate HRV signal. A clean ECG signal, with preferred low level of ectopic activity, is used to acquire the HRV signal. Filters are utilized to filter ectopic activity prior to generation of an R-R interval file [6]. The R-R interval file contains information in both the time and frequency domain, and hence both time and frequency domain analyses can be used to evaluate heart rate variability.

A) Time Domain Methods: The variations in heart rate may be evaluated by a number of methods. Perhaps the simplest to perform are the time domain measures. In these methods, either the heart rate at any point in time or the

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intervals between successive normal complexes are determined. In a continuous ECG record, each QRS complex is detected, and the so-called normal-to-normal (NN) intervals (that is, all intervals between adjacent QRS complexes resulting from sinus node depolarization) or the instantaneous heart rate is determined. Simple time domain variables that can be calculated include the mean NN interval, the mean heart rate, the difference between the longest and shortest NN interval, the difference between night and day heart rate, and so forth. Other time domain measurements that can be used are variations in instantaneous heart rate secondary to respiration, tilt, Valsalva maneuver, or phenylephrine infusion. These differences can be described as either differences in heart rate or cycle length.

B) Frequency Domain Methods: Various spectral methods for the analysis of the tachogram have been applied since the late 1960s. Power spectral density (PSD) analysis provides the basic information of how power (variance) distributes as a function of frequency. Independent of the method used, only an estimate of the true PSD of the signal can be obtained by proper mathematical algorithms. Methods for the calculation of PSD may be generally classified as nonparametric and parametric [7]. In mos instances, both methods provide comparable results.

Spectral Components in Short-term recordings: Three main spectral components are distinguished in a spectrum calculated from short-term recordings of 2 to 5 minutes LF, MF, and HF components. The boundaries of the bands are defined differently by different authors. The bands with most commonly employed boundaries are the following [3,4,5,6].

a. HRVPS Low Frequency (LF) Band (0.00-0.04 Hz): In this band, variations are related to temperature regulation of the body, the vasomotor control and the rennin-angiotensin system, with the center-of-frequency at 0.04 Hz. This is an ill-defined band, modulated by the influence of both parasympathetic and sympathetic systems. A very low frequency band (VLF) 0.01 to 0.04 Hz is associated with the influence of mainly the sympathetic system.

b. HRVPS Mid Frequency (MF) Band (0.04-0.15Hz*):* This band consists of variations related to the arterial blood pressure control system, with the center-of-frequency at 0.1 Hz. It is influenced by parasympathetic and sympathetic systems. Increase in vagal activity augments peak power, or energy content of the HRV wave for in this frequency range [6, 7]. Conversely, parasympathetic blockade diminishes power, especially in the supine position.

c. HRVPS High Frequency (HF) Band (0.15-0.4 Hz): Variations related to respiration are associated with parasympathetic activity, with the center-of –frequency at 0.25 Hz, which varies with the respiratory rate. This band is mediated solely by the parasympathetic system. The magnitude of the power in this band is more in the supine than the standing position. There is a linear decline in the power of this band up to the age of 30 years, and does not change thereafter [7].

Table1 [7] indicates the normal values for time domain and frequency domain analysis of HRV.

Table 1: Normal Values of Standard Measures of HRV

Variable	Units	Normal Values (mean ±SD)
Time Domain Analysis of Nominal 24 hours		
SDNN	ms	141±39
SDANN	ms	127±35
RMSSD	ms	27±12
HRV triangular index		37±15
Spectral Analysis of Stationary Supine 5-min Recording		
Total power	ms^2	3466 ±1018
MF	ms^2	1170±416
HF	ms^2	975±203
MF	nu	54±4
HF	nu	29±3
MF/HF ratio		1.5-2.0

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IV SYSTEM BLOCK DIAGRAM

This section discusses about reliable office system useful for many purposes: assessment of risk in cardiovascular disorders; assessment of physical fitness; documentation of benefit for cardiac, chiropractic, or orthopaedic rehabilitation; and quantification of drug effects on the autonomic nervous system. Figure 3 shows the block diagram of the developed portable system for HRV analysis. It consists of four sections.

A. ECG Acquisition *:* This is the analog front end of the system and consists of an ECG Recorder built by making use of Op-Amp circuits. The clamp electrodes are used to obtain the patient ECG as they provide secure connections to the patient extremities. Here we have used lead L1 configuration which provides high amplitude of the QRS complex.

B. ***Signal conditioning***: The AD 620 and AD 705 ICs are used to develop the ECG preamplifier circuit with a gain of 7.At the output of the ECG preamplifier we get ECG signal of approximately 5mv amplitude. This signal is further amplified and filtered by making use of signal conditioning circuit which consists of a low pass filter with a cut off frequency of 16 Hz and a two stage inverting amplifier to provide the overall gain of 1000.The amplified ECG signal available at the output of the ECG Recorder is as shown in figure 4. This signal is connected to the analog input of microcontroller PIC 18F2550 and sends it to the computer through serial port. The ECG signal is also connected to non inverting input of the comparator whose inverting input is connected to a variable reference generated by making use of potentiometer. We have kept the reference voltage to be 1 volt and therefore the comparator acts as R wave detector producing a pulse corresponding to each QRS complex of the applied ECG signal. These pulses are connected to the trigger input of the monostable multivibrator which produces a pulse of width 429 ms corresponding to each R wave pulse. These pulses are used to drive an LED which acts as a beat indicator. These R wave pulses are then connected to optocoupler (MCT2E) which is used to isolate the patient from the high voltage supply used for computer. The R wave pulses are then connected to the CCP pin of the microcontroller PIC18F2550

C .ADC and Serial Transmission*:* It is the interface between the analog front end and the digital computer used for signal analysis. It consists of microcontroller PIC 18F2550 with built in ADC and timer. It has10 bits/10 channel ADC which provides the necessary resolution. The ADC is used for ECG signal output and the timer is used for counting the duration between R-R intervals.

D. Signal Reconstruction : After the RR interval information has been acquired by the microcontroller, it is sent to a PC through a serial port. The PC consists of VB software which performs time domain and the spectral analysis of the data for short term recording of 5 minutes and displays the results on GUI. It also displays the ECG waveform on the basis of the samples coming from the ADC in microcontroller and the instantaneous HRV plot on the basis of the RR interval count coming from Timer1 in the CCP module of PIC.

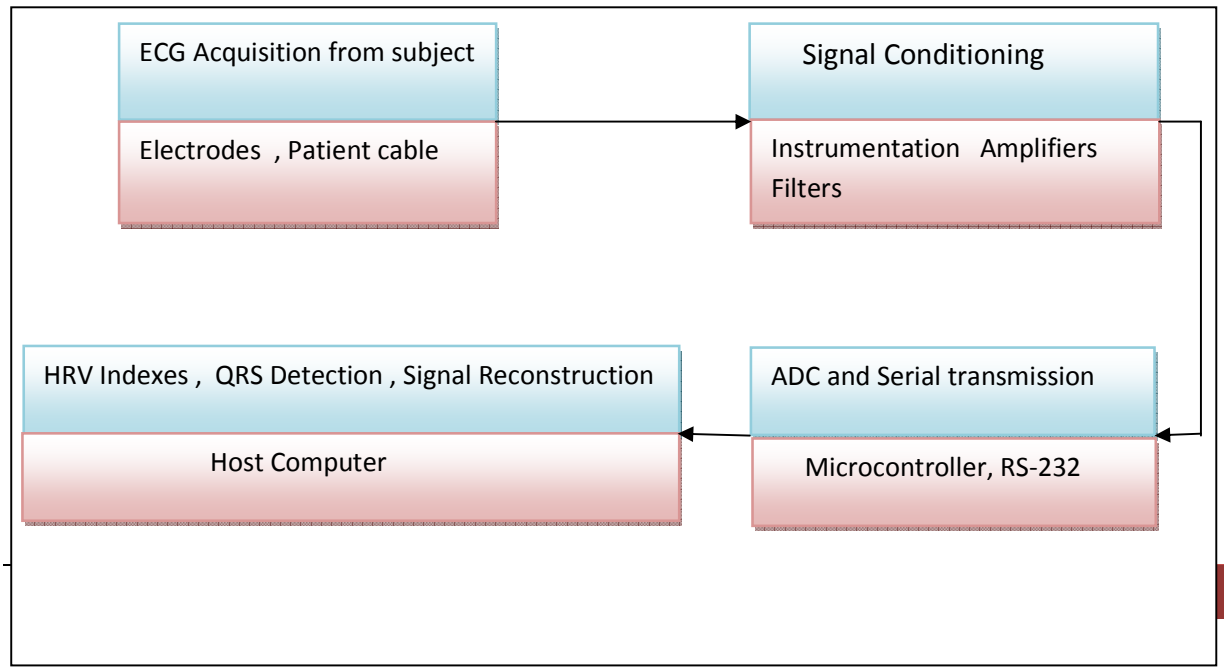

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Fig.3: System block diagram

V. HRV ANALYSIS

The R-R waves coming from the R peak detector will be recorded for 5 minutes for each patient and then sent to the computer by ***Data acquisition system***. The analog ECG signal coming from ECG recorder is sampled at the rate of 8 Hz by the microcontroller and then sent to the computer using serial communication port For serial transmission of data to the host computer, its level must be changed because RS232 needs +3 to +12 volt for logic 0 and -3 to -12 volt for logic1. This is achieved using IC MAX232.The front end GUI is provided using Visual Basic programs to display both the ECG signal and HRV signal The software then makes use of MATLAB to calculate the time domain measures like heart rate in BPM, average heart rate for 5 minutes, mean NN, variance of NN and SDNN.The power spectrum will be then plotted using FFT. The power spectrum plots depict power in (ms)2 versus Frequency in (Hertz). From the power spectrum following parameters are calculated:

Power under Low frequency range: frequency range from 0.00 to 0.04Hz
Power under Mid frequency range: frequency range from 0.04 to 0.15Hz
Power under High frequency range: frequency range from 0.15 to 0.40Hz
Sympatho/Vagal balance ratio: ratio of mid to high frequency powers

The software developed for this application will display the information in various screens. The Startup Screen will appear as soon as the user starts the application. This screen shows up the Various Tabs which the user of the HRV[9]. Analysis Software can access. The four main tabs supported are as below:

A) Setup: This Tab has a Port setting frame which allows basic port access with Port selection by means of the list box which presents a list of available ports. Open & Close Port functionality is supported; when the port is open there is a GREEN LED symbol which turns RED when the port is closed. The selected port is also listed on screen. The status of Sampling is also presented is it stopped? or currently active. If active then the time passed after start of sampling is listed. A Simulate signal check box is provided which allows the ECG microcontroller Hardware to simulate some Waveforms so that the communication between PC and the ECG Hardware and the Graph presentation of the Data Received can be tested/ Verified. The Next frame in this Tab is the Serial Data Frame which shows the Data communication by presenting the packet exchanged between the PC and ECG Hardware. The outgoing Data from the PC is presented in blue colour and
Incoming responses or Data Packets are presented in Red.

Note that most Command buttons except the Stop sampling and Exit Application are Disabled, this ensures that User cannot open or close port while sampling is in progress. The Test Hardware button provided in the software allows the user to test the ECG recorder for the connection. The Next button provided in this tab allows the user to go to the next tab in the software which is the patient interaction tab with graph frame to display the incoming ECG or HRV signal.

B) Patient Interaction: This Tab has a Graph frame which is used to display HRV or ECG waveform while it is being sampled by the Microcontroller hardware system. The Show ECG and Show HRV buttons are provided to select the waveform to be displayed. The default waveform displayed is HRV waveform. The name of the waveform displayed is also shown in this tab along with the corresponding waveform. The microcontroller sends the data to the PC in three channel format. The first channel indicates ECG units, the second channel indicates Whether RR interval is detected or not? When RR interval is detected it sends 1 else 0. The third channel indicates the value of detected RR interval. Since we have used 8 Hz sampling rate for ECG signal there will be eight values consecutively displayed in the ECG channel corresponding to one value in RR interval. All these three channel values are also displayed in this tab along with the graph. This Tab also has the Sampling time section indicating the current sampling time lapsed or sampling stopped status. Using the Setup and Patient Interaction tab the user can Setup the Port and interact with the Patient by Starting or Stopping sampling. Also Testing Hardware connectivity or Quitting

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Application Command Buttons are available. There are Previous and Next Navigation keys available for moving between the four Tabs, when the user is on First (Setup) Tab the Prev key is disabled and when the user reached the Last tab the Next key is disabled.
In case of Clicking the Test / Start /Stop /Start with Simulate selected Command buttons the corresponding packets are sent by the PC over serial port hardware and the incoming packets are populated in to the Serial Data Frame in RED colour. Also the data from packets is decoded and saved in a data File name HRV_file.text.
C) Analysis: This Tab has a Save file button which allow the User to Save Patients Data and Calculations for the purpose of later use. Also the Load file button can be used to reload a saved file back into HRV software. This tab supports the Analysis based on Time and frequency domain, which allows the user to Select and evaluate specific HRV parameters for Analysis. The Process HRV button in this tab calls the MATLAB program named processPSD.m to calculate the time and frequency domain parameters based on the acquired or loaded RR interval file. This Tab also has a Graph frame which displays HRV power spectrum for the patient.
The next frame in this tab is Time domain measures which displays the time of recording, the number of NN samples in the loaded RR interval file, heart rate in BPM for every minute of recording, average heart rate over a recording period of 5 minutes, mean NN value in ms, variance of NN values in ms and SDNN value in ms.
It also has frequency domain measures frame which displays the values of various components obtained from short term spectral analysis of HRV for 5 minutes. The values displayed are total power in ms2, LF power, MF power and HF power in ms2, along with the peak power in each band and the corresponding peak power frequency. The MF and HF powers are also displayed in normalised units which reduce the effect of changes in total power on these components. The sympatho vagal balance which is the ratio of MF to HF power and indicates the influence of the two branches of autonomic nervous system on HRV is also displayed in this frame[11,12,13].
D) Storage: This Tab again has a Save file button which allow the User to Save Patients Data and Calculations for the purpose of later use. Similarly the Load file button can be used to reload a saved file back into HRV software. The Clear record button is used to delete the previous saved record of the patient. This tab supports the Patient Information like Name, Address and Other Contact details etc. to be feed in or reviewed along with Doctors Contact Information. The file is saved in text format which contains the RR interval information over a recording period. The path for saving of file can also be selected from this tab. The figure 5 indicates the Analysis tab displaying time domain and frequency domain measures along with the power spectrum for the patient.

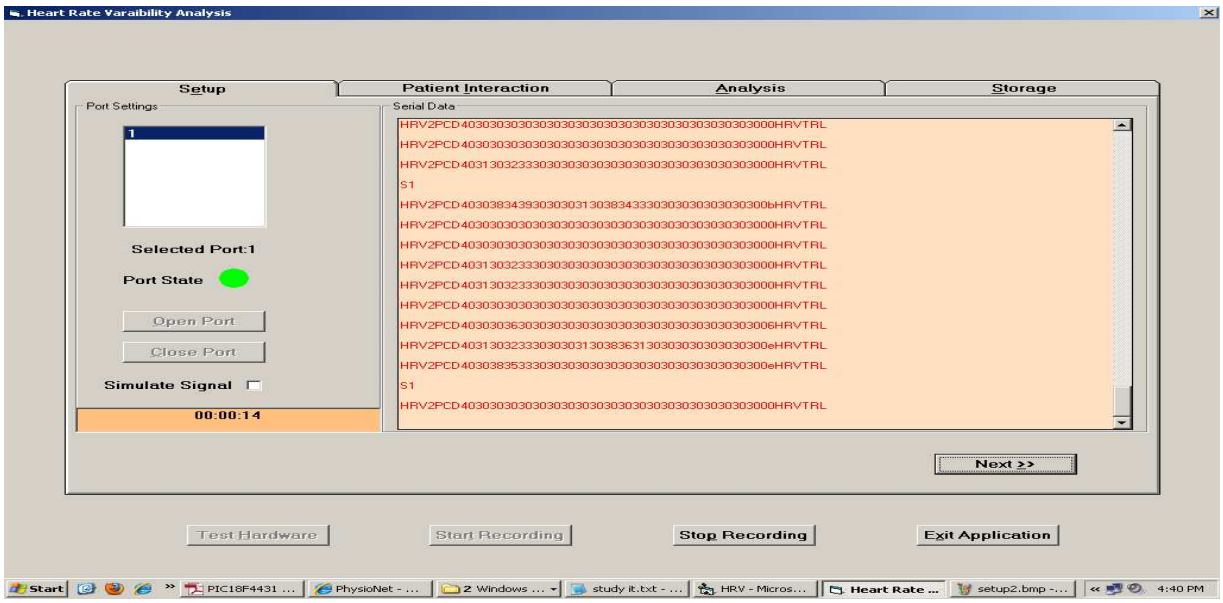

Fig. 4: The Setup tab with com 1 port open and sampling started.

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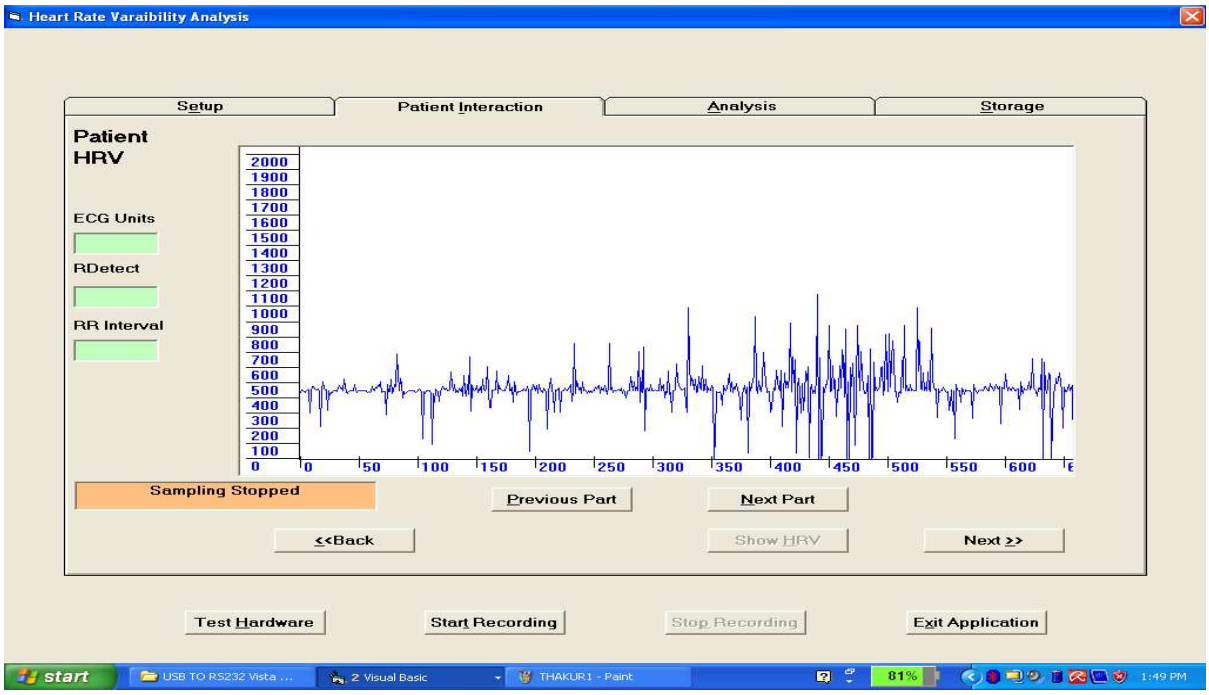

Fig. 5: Patient interaction tab with patient HRV displayed.

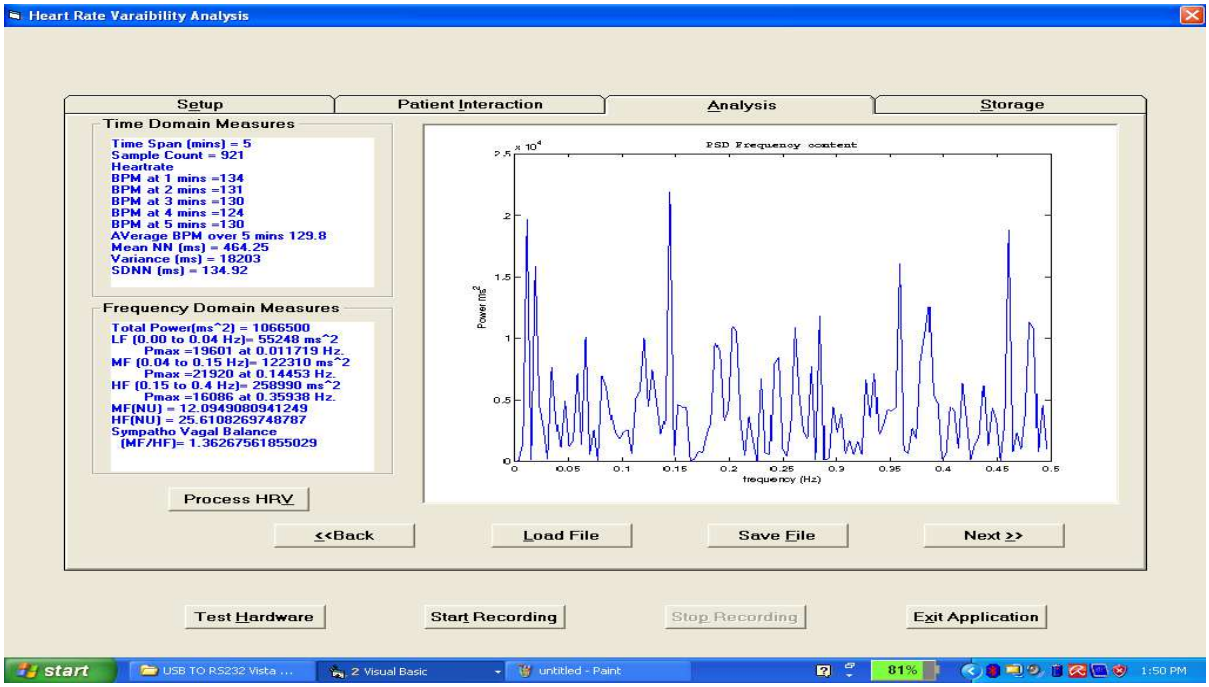

Fig. 6: Analysis tab with HRVPS, Time & Frequency domain measures.

VI. RESULTS:

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The fig.7 (a) and 7(b) presented below indicates the HRV graph and HRV power spectrum obtained for patient with MIT_BIH Arrhythmia. While fig. 9(a) and 9(b) indicates the HRV and HRVPS obtained for patient with normal heart rate variations. Both the results are obtained from the RR interval samples recorded over a period of 5 minutes. Looking at the very nature of the HRV graph the doctor can very easily and primarily differentiate between the normal and abnormal heart rate variations. The software also provides HRVPS and various time domain and frequency domain parameters calculated from HRV which further helps the doctor for detail diagnosis.

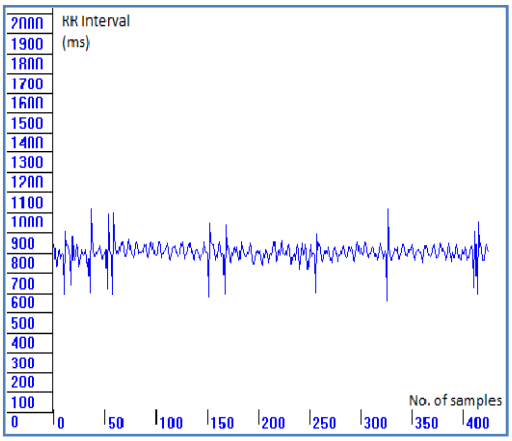

Fig. 7 (a): HRV for patient with MIT_BIH Arrhythmia

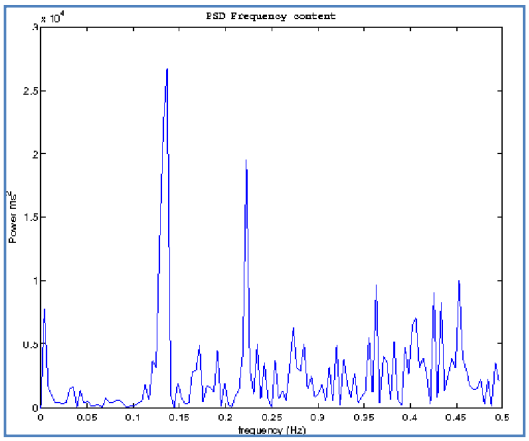

Fig.7 (b): HRVPS for patient with MIT_BIH Arrhythmia.

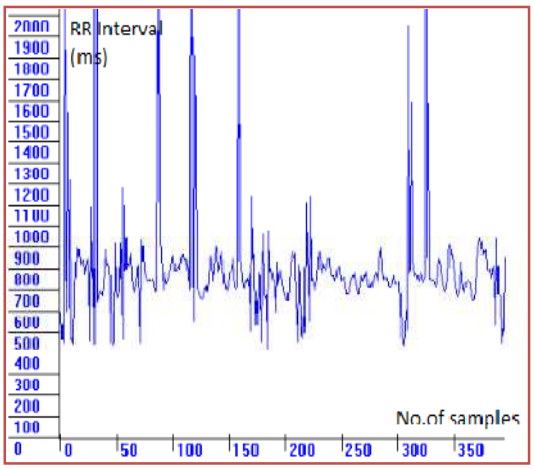

Fig. 8(a): HRV for patient with normal Heart

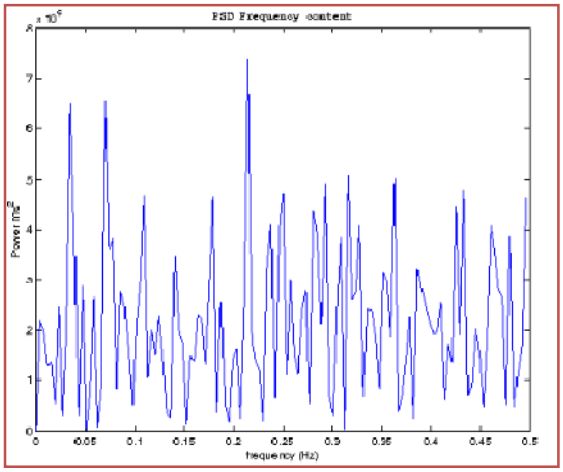

Fig. 8(b): HRVPS for patient with normal Heart

VII. CONCLUSION

Heart rate variability analysis is increasingly becoming an important tool in cardiology, because it constitutes a non-invasive and convenient method to diagnose cardiac patients. It can provide measures of sympathetic and parasympathetic function of the autonomic nervous system. HRV has considerable potential to assess the role of autonomic nervous system fluctuations in normal healthy individuals and in patients with various cardiovascular and noncardiovascular disorders. HRV studies enhance our understanding of physiological phenomena, the actions of

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medications, and disease mechanisms. The developed software for HRV system is user friendly and would provide an economical and efficient solution to the doctors for the assessment of risk in cardiovascular disorders; assessment of physical fitness; documentation of benefit for cardiac, chiropractic, or orthopedic rehabilitation

REFERENCES

[1] Pomeranz M, Macaulay RJB, Caudill MA, Kutz I, Adam D, Gordon D, Kilborn KM, Barger AC, Shannon DC, Cohen RJ, Benson M. Assessment of autonomic function in humans by heart rate spectral analysis. *Am J Physiol*. 1985;248:H151-H153.
[2] Pagani M, Lombardi F, Guzzetti S, Rimoldi O, Furlan R, Pizzinelli P, Sandrone G, Malfatto G, Dell'Orto S, Piccaluga E, Turiel M, Baselli G, Cerutti S, Malliani A. Power spectral analysis of heart rate and arterial pressure variabilities as a marker of sympathovagal interaction in man and conscious dog. *Circ Res*. 1986; 59:178-193.
[3] Issam El Mugamar, K.D. Desai, Sulatan Abdul Ali, Mohammed Saeed, Amin Fikree, S.D. Bhagwat: "Computerized Reliable Detection of Diabetic Autonomic Neuropathy", Proc. Of International Conference on Recent Advances in Biomedical Engineering – 94, Hyderabad, India (1994)321-325.
[4] Fallen, E.L., D. Nandogopal, S. Connonlly and D.N. Ghista, "How reproducible is the power spectrum of heart rate variability in health subjects?" Proceedings of International Symposium on Neural and Cardiovascular Mechanisms, Bologna, Italy (May, 1985)41-45.
[5] Kamath, D.N. Ghista, E.L. Fallen, D. Fitchett, D. Miller and R. McKelvie, "Heart rate variability power spectrogram as potential noninvasive signature of cardiac regulatory system response, mechanisms, and disorders", in Heart and Vessels, 3, 33-41 (1987).
[6] Kamalakar Desai, Dhanjoo N. Ghista,Issam Jaha El Mugamex,Rajendra Acharya U Michael Towsey, Sultan Abdul Ali,Mohammed Saeed, M. Amin Fikri,"DAN detection by HRV power spectral analysis",3-14 (2010).
[7] "Heart rate variability. Standards of measurement, physiological interpretation, and clinical use." Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology.1996 Mar; 17(3):354-81.
[8] Leslie Cromwell, Fred J. Weibell, Erich A. Pfeiffer, "Biomedical Instrumentation and Measurements", Prentice –Hall of India Private ltd.Second edition, 92,292 (1980).
[9] Noel Jerke, "The complete reference Visual Basic 6".First edition 22nd reprint 2005, 187-24
[10] Schwartz PJ, Priori SG. Sympathetic nervous system and cardiac arrhythmias. In: Zipes DP, Jalife J, eds. *Cardiac Electrophysiology: FromCell to Bedside.* Philadelphia, Pa: WB Saunders Co; 1990:330-343.
[11] Hon EH, Lee ST. Electronic evaluations of the fetal heart rate patterns preceding fetal death: further observations. *Am J Obstet Gynecol*.1965;87:814-826.
[12] Sayers BM. Analysis of heart rate variability. *Ergonomics*. 1973;16:17-32.
[13] Penaz J, Roukenz J, Van der Waal HJ. In: Drischel H, Tiedt N, eds. *Spectral Analysis of Some Spontaneous Rhythms in the Circulation.* Leipzig, Germany: Biokybernetik, Karl Marx University; 1968:233-241.