Determining ECG characteristics using wavelet transforms

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Abstract

Electro cardiogram by definition means 'the recording of heart electrical activity'. Electrocardiogram (ECGs) represents the electrical signature of the heart activities whose proper working is very important to the human body. An ECG wave is used to predict abnormalities by a careful study of the features. Delay in cardiac re-polarization causes ventricular tachyarrhythmia as well as Tor Sade de pointes (TdP) and irregular heart beat. A feature of TdP is pronounced prolongation of the QT interval in the supraventricular beat preceding the arrhythmia. TdP can degenerate into ventricular fibrillation, leading to sudden death. The RR interval represents the amount of time between heart beats. If a subject's heart rate is over 100 beats per minute they are said to be in sinus tachycardia. And below 100 beats per minute are said to in be sinus Brady cardiac. The present work compares ECG feature extraction system based on the multi-resolution wavelet transform with that of older time plane system. The feature extraction has been done by using Daubechies 4 & 6.

Keywords: ECG, Multi resolution Analysis, Soft or Hard Thresholding, Signal Averaging, five point derivative.

1. Introduction

Electro cardiogram by definition means 'the recording of heart electrical activity'. This is caused by de-polarization and re-polarization of cardio myocytes or otherwise called cardiac cells. This continuous cycle of de-polarization and re-polarization causes the heart rhythm. So by studying the cardiogram one can detect the anomalies in the heart functioning. ECG signal can be sensed by surface electrodes.

To analyze the ECG signal more efficiently we adapt the frequency domain analysis technique using wavelet transform. Wavelet transform allows us to decompose the time-limited signals at various scales, which is going to be essential in case of ECG signals.

Firstly a MATLAB program is created in order to de-noise the ECG signal that is measured by cardiograph. This can be done using 1-D wavelet analysis. Then the signal is decomposed into a no. of different signals at different scales to measure the required parameters of ECG signal. The detailed analysis and algorithms are given further.

2. Electrical signal generation in heart

The electric signal in heart is generated by rhythmic excitation of heart achieved by continuous process of de-polarization and re- polarization of cardiac cells. Initially cardiac cells are negatively polarized inside compared to exterior of the cell. Diffusion of sodium and
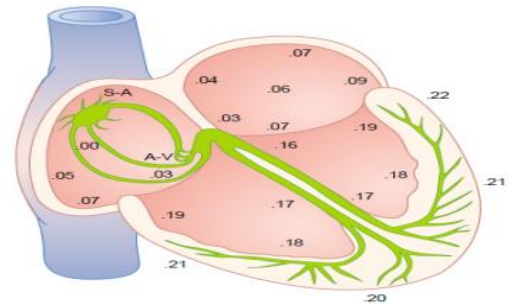

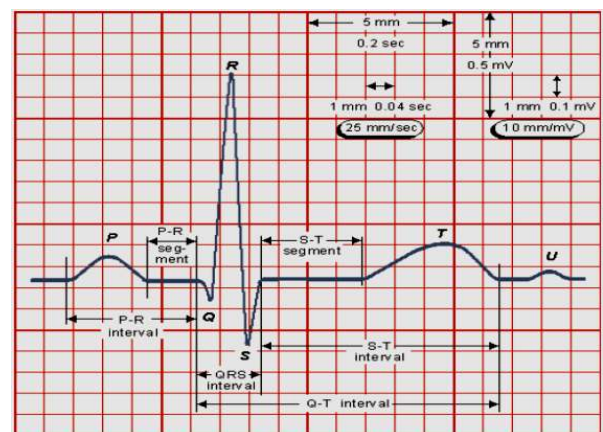Fig.1 Transmission of the cardiac impulse through the heart [1]

Fig.2 Normal ECG waveform [2]

compared to exterior of the cell. Diffusion of sodium and calcium ions into interior of cells causes de-polarization and immediate diffusion of a large no. of potassium ions out of cell causes re-polarization. This

process continues for lifelong producing a rhythmic cardiac excitation.

Fig.2 represents normal ECG signal. P-wave is caused by spread of de-polarization through atria followed by atria contraction. QRS-complex is a result of de-polarization of ventricles which initiates the contraction of ventricles. T-wave represents re-polarization of ventricles, that's when ventricle muscles begin to relax.

3. ECG measurement system [3, 4]

The ECG measurement system comprises of following function blocks.
Transducer - an AgCl electrode converts ECG into electrical voltage (Range ~ 1mV to 5mV).
Instrumentation Amplifier – analogy device, amplifies the differential input (CMRR-90dB, Gain-1000).
Isolator [5] - Opt coupler used to isolate In-amp and output.
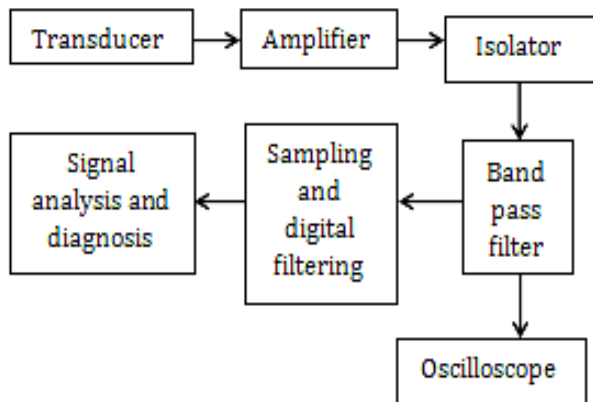Band-pass filter – Used to filter unnecessary data of signal being received (pass band 0.04Hz to 150Hz)

Fig.3 Function block diagram of ECG measuring system

4. Wavelet analysis

The frequency analysis of the ECG signal is done by wavelet transform. The use of Fourier transform will not yield optimum results. the This is because Fourier Transforms domain stretches out to infinity. Since ECG signal contains sharp spikes, trying to limit the frequency interval of its Fourier transform may result in considerable amount of data loss. But this kind of loss in physiological signals is extremely undesirable and

ruinous. Wavelet transform provides all those desirable features required to analyze an ECG signal. Moreover, at each point in time ECG signal contains different amount of frequency contents. It is important to focus on the frequency content at required point of time, in detail. So the time localization of spectral components is needed i.e. time-frequency representation of the signal is needed. By using wavelet transform a signal can be decomposed into a finite set of coefficients that describe the frequency content of a given signal at any particular point of time. In case of ECG signal processing the Daubechies wavelet is used as basis function.

The wavelet transform of a signal in analog domain [6] can be represented as

$$W_s f(x) = f(x)*\psi_s(x) = \frac{1}{\sqrt{s}} \int_{-\infty}^{\infty} f(t).\psi\left(\frac{x-t}{s}\right) dt \quad \ldots (1)$$

'S' represents the scaling factor and dilation of $\psi(t)$ by a factor s can be expressed as

$$\psi_s(t) = \frac{1}{\sqrt{s}}.\psi\left(\frac{t}{s}\right) \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2)$$

Fraction $\frac{1}{\sqrt{s}}$ is used for energy normalization [7].

Like sins and cosines used as basis functions for Fourier transforms, wavelet functions are used as basis functions for wavelet transforms. The equation stating the basis function of wavelet transform is given by [8]
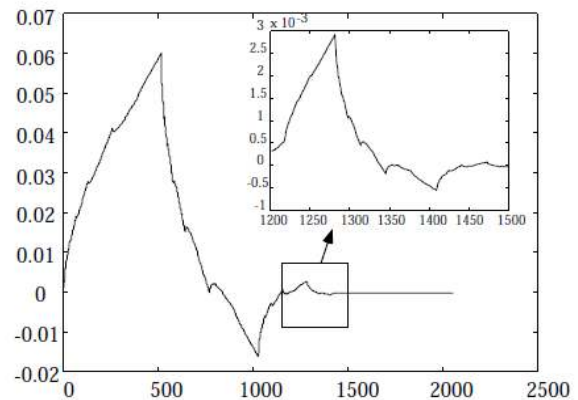

Fig.4 2048-point DAUB4 mother wavelet [9]

$$\Phi_{(s,l)}(x) = (2^{\frac{-s}{2}}).\phi(2^{-s}.x-l) \ldots \ldots (3)$$

Φ is mother function of wavelet family (Daubechies wavelet in case of ECG signals),'s' and 'l' are integers

that scale and dilate the mother wavelet. Scale index's' indicates the width of wavelet and location index 'l' indicates the position. These indices cause self-similarity to the wavelet basis functions that makes them particularly interesting. The fractal self-similarity of the Daubechies mother wavelet is shown in Fig.4.

To span data domain at different resolutions, wavelet function is used in a scaling equation.

$$W(x) = \sum_{k=-1}^{N-2}(-1)^k c_{k+1}.\phi(2x+k).... (4)$$

Here W(x) is scaling function for Φ and c_k are the wavelet coefficients, satisfying the linear and quadratic constrains of the form

$$\sum_{k=0}^{N-1} c_k = 2 \quad \text{and} \quad \sum_{k=0}^{N-1} c_k.c_{k+2l} = 2\delta_{l,0}$$

Here δ is unit impulse function.

5. Concept of de-noising

For ECG signal, wavelets can not only help with the decomposition but also help obtaining the de-noised dataset. This is done through the technique called wavelet shrinkage and thresholding [10] methods. Since wavelet transform decomposes the signal with basis functions at different resolutions both gross features and local details are preserved. The idea of thresholding to omit those coefficients corresponding to local details in the dataset, less than a particular threshold. By this localized smoothing is done without effecting the sharp changes.

6. Algorithm and program

According to following algorithm [11] shown in fig.5 programming. Those programs R-R interval, P-R interval, QRS interval are calculated. These parameters are required in the EKG interpretation chart [12] to diagnose the functioning of heart. For the EKG prediction chart, Heart rate, P-R interval and QRS interval are calculated using the Mat lab programming. Regularity of beats, nature of P-wave and marriage of P&QRS complex waves are determined by observing the ECG signal through cardiograph.
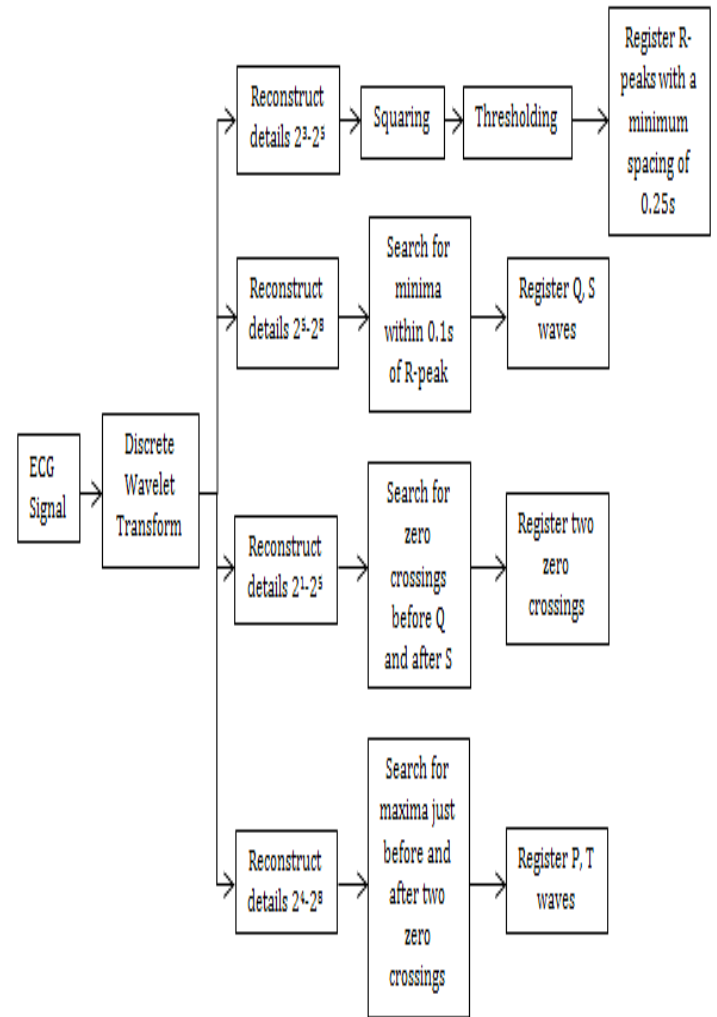

Fig.5 Block diagram of algorithm to determine the ECG characteristic points[11]

7. Results

ECG sample data is downloaded from PTB-DB in *.mat format and loaded into workspace using load ecg function (user defined). In wavelet toolbox 1-D wavelet analysis is selected. Sample data in workspace is imported to wavelet toolbox and is analyzed using 8-level db2 wavelets. Then the signal is de-noised using fixed form soft is done in Mat lab. By executing threshold method assuming the scaled white noise structure. The de-noised signal is exported to workspace.

The remaining program written on the basis of algorithm illustrated in Fig.5 is executed on the de-noised signal and the required Heart rate, P-R interval and QRS interval are obtained along with P, Q, R, S

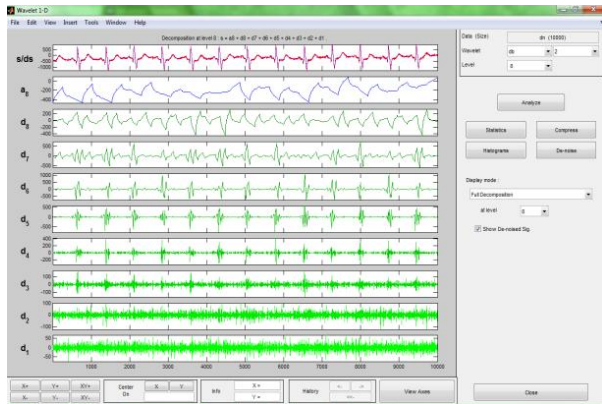and T points. X-axis is in ms and Y-axis is in mV.Forpatient001/s0010_rem.mat
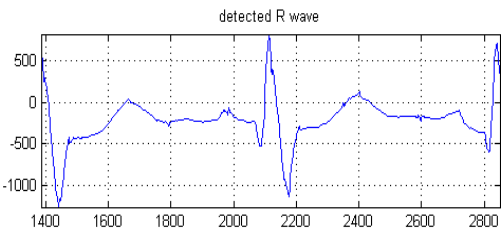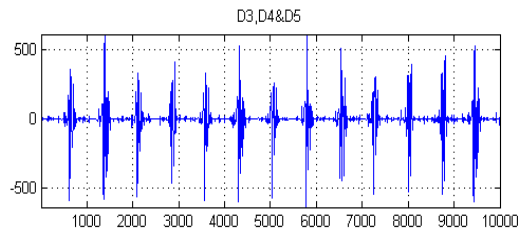

Fig.6 8-level decomposition using db2 wavelet

Fig.7Denoising signal using thresholding technique

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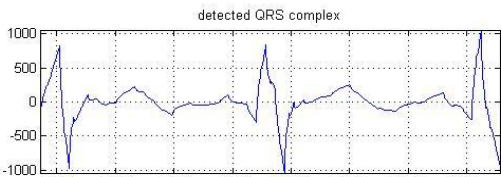Fig.8 Original signal and de-noised signal
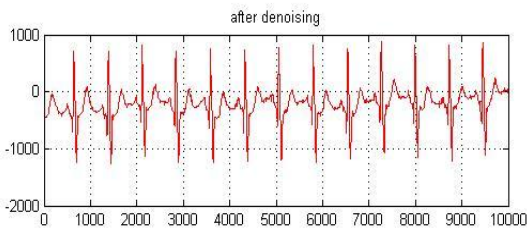

Fig.9 Detecting R-wave and R-peak
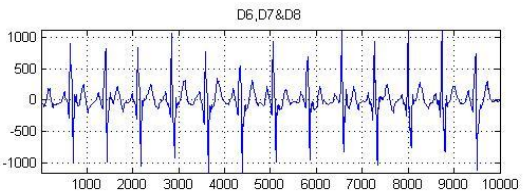
Fig.10 Detecting the QRS complex and Q, S points
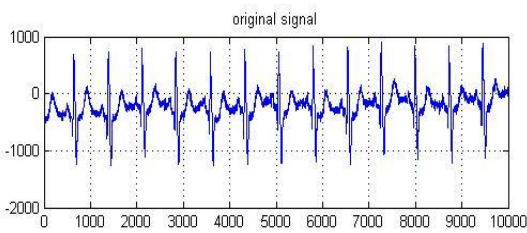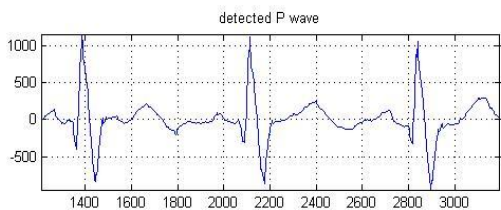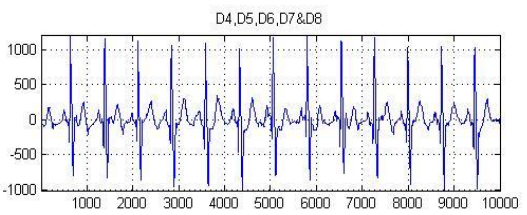

Fig.11 Detecting P-wave and P,T points

In command window we get the results as
RR-interval= 0.732 sec.
Heart rate=82 beats per minute,
PR-interval= 0.1153 sec. And
QRS- interval= 0.096 sec.
Complete results are shown in appendix-I

8. GUI design

A graphic user interface is designed in MATLAB to perform above operations. In mat lab 'start/MATLAB/GUIDE (GUI builder)/create new GUI/ Blank GUI (default)' is selected to create a blank GUI. A list box and six pushbuttons were added to the figure. The GUI layout is as follows
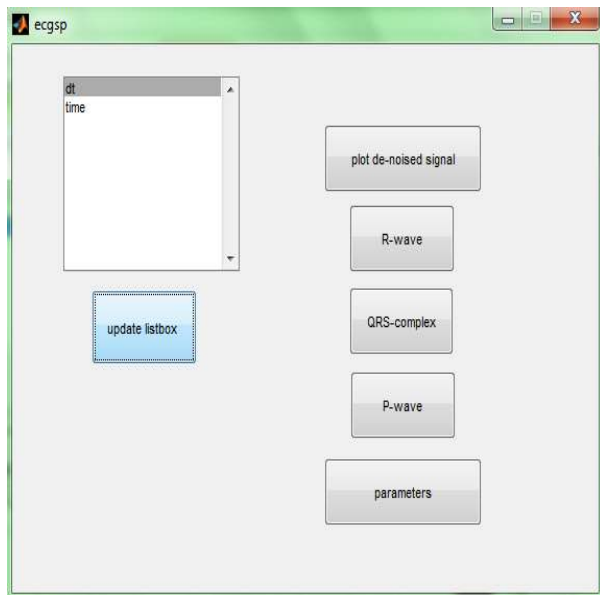

Fig.12 GUI layout

Call back function for each pushbutton is nothing but the programs those are used obtain respective parameters.

9. Observations

Since we are basing our algorithm based upon normal ECG signal characteristics, there exist some limitations on using program. The algorithm can give accurate results only if the heart rate is between 34 to 160 beats per minute. This is a limitation due to programming. If required, by adding more loops and decreasing the interval that check for R-peaks, wider range of heart rates can be analysed.
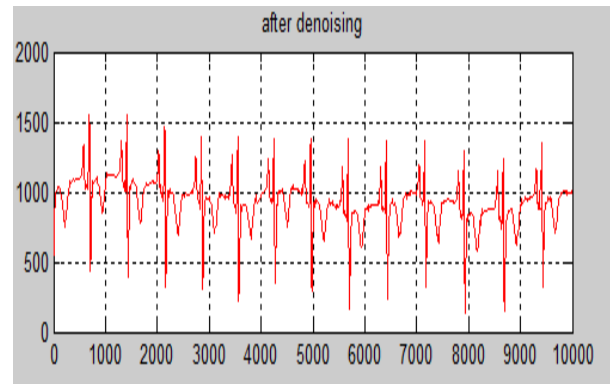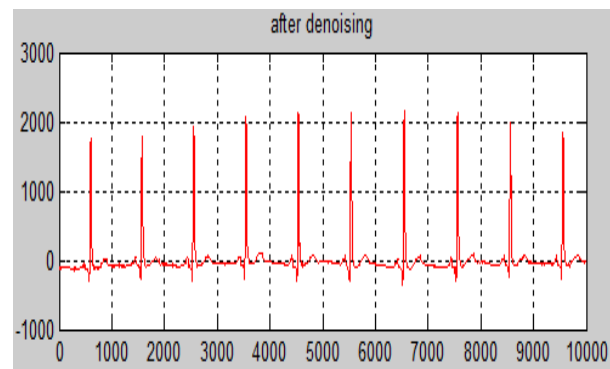

Fig.13 Error due to abnormally low S-point

Fig.14 Error due to abnormally low P-wave

The minima after R- point, S, is much less than zero level than R-peak. Due to this after squaring the 2^3-2^5 details of the signal, the peak value shifts from R to S. So S will identify as point R. Since remaining characteristic points are dependent upon detection of 'R', results couldn't be obtained. In some patients the occurred errors are due to error in zero crossing detection. Since the zero level of ECG signal is fluctuating a small error probability exists.

10. Conclusion

Normal ECG signal characteristics are learnt by familiarizing the generation and propagation of ECG signal. Different types of ECG leads are observed and one of them is chosen to be analyzed. According to processing of that signal referred algorithms been designed and programs are written according to that algorithm. Behavior of wavelets is understood and suitable wavelet for ECG signal processing is chosen to be Daubechies wavelet. 'Concept of de-noising is by

thresholding the coefficients', is understood by time-frequency localization plane. The parameters to extract from program have been learnt by understanding EKG prediction chart. The downloaded signals are successfully analyzed and possible errors have been noted.

Though all points are determined successfully, from a number of observations it is revealed that seldom there is a significant error in determining the zero crossing points. Adjusting threshold points in de-noising, using different scales and/or basis functions might be possible solutions.

11. References

[1] 'Text book of medical physiology (eleventh edition)' by Guyton andHall;   ch.10Rhythmic excitation of heart and ch.11 Normal electro cardiogram. .

[2] 'Comprehensive lectrocardiology: Theory and Practice in Health and Disease' (1st ed., Vol. 1, 2, and 3), 1785 pp. Pergamon Press, New York.

[3]http://www.cisl.columbia.edu/kinget_group/student_projects/ECG%20Report/E6001%20ECG%20final%20report.htm

[4] 'A Smart ECG Measurement System Based on Web-Service-Oriented Architecture for Telemedicine Applications' by Claudio De Capua (Member, IEEE), AntonellaMeduri, and Rosario Morello (Student Member, IEEE); IEEE Transactions on instrumentation and measurement, vol. 59, no. 10, October 2010.

[5]http://www.analog.com/library/analogDialogue/archives/37-11/ecg.html

[6] 'Detection of ECG Characteristic Points Using Wavelet Transforms' by Cuiwei Li, ChongxunZheng, and ChangfengTai; IEEE transactions on biomedical engineering, vol.42, no.1, 1995.

[7] 'Using Wavelet Transforms for ECG Characterization – an online digital signal processing system' by J.S. Sahambi & R.K.P. Bhatt(Electrical Engineering Department),S.N. Tandon (Centre for Biomedical Engineering), Indian Institute of Technology Delhi; IEEE engineering in medicine and biology(0739-5175/97), January/February 2007.

[8] Numerical Recipes in Fortran, Cambridge University Press, New York, 1992, pp. 498-499,584-602.

[9] 'An introduction to wavelets' by Amara Graps ; IEEE Computational Science and Engineering, Summer 1995,vol. 2, num. 2, published by the IEEE Computer Society, 10662 Los Vaqueros Circle, Los Alamitos, CA 90720, USA.

[10] 'An introduction to wavelets or The wavelet transform: what's in it for you?' by Andrew E. Yagle and Byung-Jae Kwak (Dept. of Electrical Engineering and Computer Science, The University of Michigan, Ann Arbor, MI); Presentation to Ford Motor Co.May 21, 1996.

[11] ECG feature extraction using daubechies wavelets by S.Z.Mahmoodabadi (MSc), A. Ahmadian (PhD), M.D. Abolhasani (PhD) (TUMS, Tehran, Iran & RCSTIM, Tehran, Iran); Proceedings of fifth IASTED international conference, Visualization, Imaging and Image processing, sept.7-9, 2005, Benidorm, Spain.

[12] 'Basic Dysrhythmias, Interpretation and Management' (3rd Edition) by Robert J. Huszar, Mosby.

Appendix-i

Following Table shows the results obtained for 55 sample signals from 20 patients. Source is http://www.physionet.org/cgi-bin/atm/ATM.(**e:** indeterminable parameter or possible error).

Table showing ECG parameters of a random sample group
(Source: physionet.org/PTB-DB)

Patient	File name (*.mat)	RR-int. calculated (in sec)	RR-int. observed(in sec)	Rate (beats/minute)	PR-int. (in sec.)	RS in. (in sec.)	Accuracy(RR-int.)
Patient001	s0010_rem	0.732	0.728	82	0.116	0.096	99.45%
	s0014lrem	0.716	0.7	84	0.125	0.096	97.71%
	s0016lrem	0.748	0.746	80	0.125	0.096	99.73%
Patient002	s0015lrem	0.718	0.718	83	e	e	100%
Patient003	s0017lrem	0.8	0.804	75	0.156	0.107	99.5%
Pateint004	s0020arem	0.736	0.738	82	0.156	0.096	99.73%
	s0020brem	0.744	0.746	81	0.182	0.085	99.73%
Patient005	s0021arem	0.64	0.639	94	0.099	0.096	99.84%
	s0021brem	0.63	0.631	95	0.082	0.075	99.84%
	s0025lrem	0.582	0.584	103	0.079	0.075	99.66%
	s0031lrem	0.656	0.66	91	0.065	0.032	99.39%
	s0101lrem	0.938	0.938	64	e	e	100%
Patient006	s0022lrem	0.684	0.668	88	0.131	0.096	97.6%
	s0027lrem	0.77	0.772	78	0.095	0.096	99.74%
	s0064lrem	0.802	0.793	75	0.067	0.096	98.86%
Patient007	s0026lrem	0.816	0.826	74	0.087	0.085	98.79%
	s0029lrem	0.834	0.827	72	0.107	0.085	99.15%
	s0038lrem	0.844	0.845	71	0.101	0.075	99.88%
	s0078lrem	1.172	1.172	51	0.127	0.096	100%
Patient008	s0028lrem	1.012	1.024	69	0.072	0.107	98.83%
	s0037lrem	0.984	0.992	61	0.207	0.096	99.19%
	s0068lrem	0.872	0.872	69	0.075	0.096	100%

Patient009	s0035_rem	0.704	0.696	85	0.095	0.085	98.85%
Patient010	s0051lrem	0.728	0.728	82	0.069	0.085	100%
Patient011	s0039lrem	0.68	0.676	88	0.086	0.096	99.41%
	s0044lrem	0.718	0.718	84	0.08	0.075	100%
	s0049lrem	0.68	0.67	88	0.075	0.085	98.51%
	s0067lrem	0.918	0.916	65	0.073	0.085	99.78%
Patient012	s0043lrem	1.138	1.128	53	0.134	0.116	99.11%
	s0050lrem	0.958	0.96	63	0.22	0.096	99.79%
Patient013	s0045lrem	0.698	0.701	86	0.072	0.075	99.57%
	s0051lrem	0.728	0.728	82	0.069	0.085	100%
	s0072lrem	0.694	0.704	86	0.059	0.085	98.58%
Patient014	s0046lrem	0.732	0.714	82	0.188	0.085	97.48%
	s0056lrem	0.814	0.81	74	0.129	0.085	99.51%
	s0071lrem	0.75	0.753	80	0.124	0.075	99.6%
Patient015	s0047lrem	0.526	0.524	116	0.151	0.075	99.78%
	s0057lrem	0.734	0.732	82	0.133	0.096	99.73%
	s0152lrem	0.894	0.886	67	0.145	0.096	98.42%
Patient016	s0052lrem	0.982	0.988	61	e	0.075	99.39%
	s0060lrem	0.8	0.802	75	0.104	0.096	99.75%
	s0076lrem	1.088	1.079	55	e	0.085	99.16%
Patient017	s0053lrem	0.612	0.632	98	0.124	0.085	96.83%
	s0055lrem	0.968	0.959	62	0.207	0.085	99.06%
	s0063lrem	0.774	0.77	78	0.146	0.085	99.48%
	s0075lrem	0.976	0.974	61	0.173	0.085	99.79%
Patient018	s0054lrem	0.704	0.695	85	0.127	0.075	98.7%
	s0059lrem	0.768	0.767	78	0.132	0.107	99.87%
	s0082lrem	0.876	0.873	68	0.173	0.085	99.66%
Patient019	s0058lrem	0.662	0.67	91	0.081	0.096	98.8%
	s0070lrem	0.672	0.672	89	0.082	0.064	100%
	s0077lrem	0.834	0.840	72	0.262	0.096	99.28%
Patient020	s0062lrem	0.862	0.852	70	0.099	0.096	98.83%
	s0069lrem	1.088	1.086	55	0.211	0.096	99.82%
	s0079lrem	0.77	0.778	78	0.143	0.096	98.97%