

Heart Rate and Inter-beat Interval Computation to Diagnose Stress Using ECG Sensor Signal

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Abstract. Problem in diagnosing of stress is an important issue. The variations in beat-to-beat alteration in the heart rate (HR) can provide an identification of stress. HR can be determined from the Electrocardiogram (ECG) signal. However, accurate detection of HR and inter-beat interval (IBI) values from the ECG waveform is important. This report presents a way of measuring the ECG signal together with the ECG component analysis such as QRS peak detection and HR calculation to use it in a computer-based stress diagnosis system.

1. Introduction

Today's increased use of computer-based systems in the medical domain requires computer processing of biomedical signals such as finger temperature [13], [14], [15], skin conductance, heart rate etc. These are often obtaining from sensors, transducers, etc. and such signals contain information about their underlying biological systems [7]. Heart rate variability (HRV) analysis depicts the activity of autonomous nervous system and thereby commonly used as a quantitative indicator of stress [12]. It represents the variations in beat-to-beat alteration in heart rate. The ECG records the electrical activity of the heart. The change in electrical potential over time that is reflected in the ECG signal measurement can be used to diagnose stress-related disorders. Therefore, developing a system to provide accurate measurement of HR and IBI is essential. In this project we are focusing on the following three important issues:

1. How to measure heartbeat by using ECG sensor signal. Develop a computer system capable to receive analogue signal and produce heartbeat in QRS complex wave form.
2. Determine methods that can be used to calculate both the HR and IBI automatically.
3. Design and develop a user interface to display and store the ECG sensor signals and calculated the HR and IBI values.

1.1 Aim and objective

The main goal of this project is to design and develop a computer-based system that can capable to measure human heartbeat and thereafter calculates the rate and variance of the heartbeat. A user interface will also be developed where the measured QRS complex wave form, calculated IBI and HR values over time will be displayed. Moreover, all of these data in time series format can be saved in different files namely .xls, .xml, and .txt format to use them in a computer-based stress diagnosis system.

2. Background and related work

When our brain appraises stress, the sympathetic nervous system (SNS) stimulates the hypothalamus, and prepares the brain to respond to stress. The stress hormones decrease digestions, increase the heart rate, increase metabolic rate, dilates blood vessels in the heart and other muscles. When the brain receives the information that the stress situation is over, the parasympathetic nervous system helps to return the hormones to the baseline levels. Thus, the SNS activates during stress and helps to release the stored energy. On the other hand, the parasympathetic nervous system performs the opposite function i.e. returns the body to its normal state. So, due to a stress response the body releases large amount of energy immediately and this reaction to stress can affect many physiological mechanisms. To diagnose psychophysiological dysfunctions such as stress, clinicians often consider the balance between the activities in the sympathetic and parasympathetic nervous systems. A small amount of stress is good for us. It can prepare us to meet difficult challenges in life. On the other hand, long-term exposure to stress i.e. when the emergency stress response is prolonged i.e. out of its functional context for most of the time, it may in the worst case cause severe mental and physical problems that are often related to psychosomatic disorders, coronary heart disease etc.

2.1 The ECG signal and stress

The four chambers of the heart are called the right atrium, right ventricle, left atrium and left ventricle [1]. The upper chambers: the right and left atriums make the first wave-the 'P wave (depolarization)'. The next flat line shows the electrical impulse goes to the bottom chambers. The bottom chambers: the right and left ventricles make the 'QRS complex wave (depolarization)'. The resting period of the ventricle represents the 'T wave (re-polarization)' as shown in Fig. 1. So, the ECG represents each electrical events of the cardiac signal with a distinct waveform. One example is shown in Fig 1.

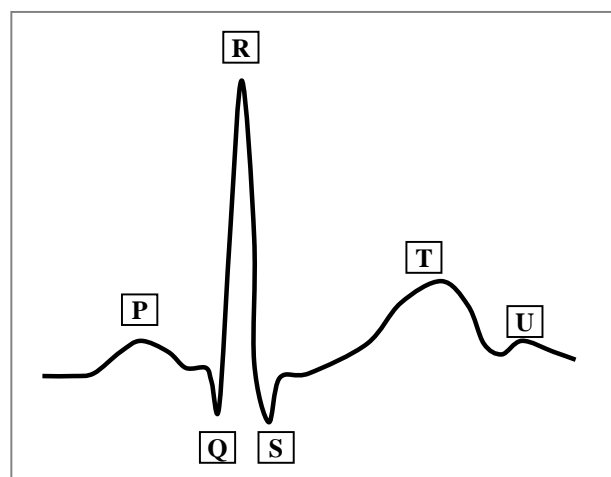


Fig. 1. ECG signal in QRS complex wave form.

A heartbeat is the physical contraction of the heart muscle and the trace of each heartbeat consists of these three complexes i.e. P, R, and T. The heartbeat initiated with the firing of the Sinoatrial (SA) node which is the dominant peacemaker of the heart. When a person is stressed

the sympathetic nervous system increases the SA firing rate and thereby reduces the inter-beat interval [8]. The ECG represents the electrical activity in the heart during the ventricular contraction using the QRS complex. The time period between the consecutive heartbeats (or RR intervals) can be detected from the QRS complex and then the measurement of the heart rate variability (HRV) analysis can be obtained from the RR interval. Therefore, it is important to detect QRS complex, in particular, inter-beat interval as correctly as possible to get reliable stress diagnosis.

2.2 Related work

The authors in [5] use a mobile ECG sensor for diagnosing stress using HRV. McCraty et al. [3] determine the power spectrum density (PSD) of HRV to investigate the relationship between the PSD and human emotional state. They applied Fast Fourier Transformation (FFT) to perform the PSD analysis where the frequencies are divided into three parts viz. low frequency-LF (0.01-0.08 Hz), medium frequency-MF (0.08-0.15 Hz) and high frequency-HF (0.15-0.5 Hz). The LF/HF ratio has been used as a measure of sympathovagal balance. It shows that during anger there is a significant increase in the LF power with no change in the HF power and as a result it provides an increase in the LF/HF ratio. During appreciation there is an increase in both the LF and HF power so the ratio remained approximately unchanged. In [2] Fuzzy c-means clustering algorithm is applied to determine continuous stress curve. They collected data from drivers in a stress recognition test. Different biomedical signals e.g., electrocardiograph, electromyography, skin conductance in feet and hands, heart rate signal and respiration signal of few drivers while they were experiencing driving in various levels are used in this study. The authors in [4] use ECG signal to measure and analyze the HRV and provide a discussion about how it relates to stress. A procedure for diagnosing stress-related disorder is put forward by Nilsson et al. in [6] where stress-related disorders are diagnosed by classifying the heart rate patterns. Stress-related disorders can be diagnose using figure temperature (FT) mentioned in [14], [15] and a biofeedback treatment procedure using FT is also proposed by Ahmed et al in [13]. Moreover, a diagnosis and treatment system using FT, for the individual stress management is also present in [16].

3. Approach and method

There are several ways to measure heartbeat namely pulse oximeter, ECG and photoplethysmographic (PPG). A pulse oximeter is used mainly for measuring the oxygen saturation in the blood and blood volume changes in skin [9]. But most of the monitoring system also provides HR. PPG is a newly developed sensor system that can also be used for measuring the HR by considering pulse [10]. However, ECG is a standard way to measure HR and still it is the best and widely used approach. Willem Einthoven has received his Nobel Prize¹ in Physiology or Medicine for the discovery of the mechanism of the electrocardiogram in 1924. In this project we applied ECG to measure QRS complex wave form.

ECG is an approach that records the electrical activity of the heartbeat and presents it in a continuous time period captured by attached electrodes in the skin. Since no single point provides the complete view the ECG is constructed to measure the electric activity of the heart from

¹ Nobel Prize, http://nobelprize.org/nobel_prizes/medicine/laureates/1924/

various points of the body. The leads are electrodes which measure the difference in electrical potential between either two different points on the body i.e. bipolar leads or one point on the body and a virtual reference point with zero electrical potential (located in the center of the heart) i.e. unipolar leads. The standard ECG signal has 12 leads: three standard limb leads, augmented limb leads and precordial leads. Table 1 shows the leads summary for the ECG [11].

Approaches	Limb leads	Precordial leads
Bipolar	I, II, III (standard limb leads)	-
Unipolar	aVR, aVL, aVF (augmented limb leads)	V1-V6

Table. 1. The ECG leads

3.1 The R peak, IBI and HR calculation

Recalling Fig 1 and observing the R wave, we find that the highest amplitude is the peak. If we plot the ECG signal against time, i.e. X axis will represent the time in milliseconds and Y axis will represent the amplitude, as shown in Fig 2. Then the R peak which is the highest amplitude value is above 2.6 in this example. Each R wave comes after a certain amount of time and the time difference between two R waves is the rate of an RR interval or inter-beat interval. So the time difference in R to R wave from Fig 2 is around 750 milliseconds. The unit of this IBI can be used both in millisecond (ms) and in second (s) format. The number of R wave occurs in a minute is used to calculate HR and the standard unit is beats per minute (bpm). To compute the HR in real time, the time required to produce a total ECG signal is considered, which is further calculated in minute to find the number of beats per minute. For example, if one beat (from R to R) requires 750 ms then in one minute ($60 \times 1000 = 60000 \text{ms}$), there are ($60000/750 = 80 \text{bpm}$) 80 beats can be achieved. This 80bpm is the heart rate against the time.

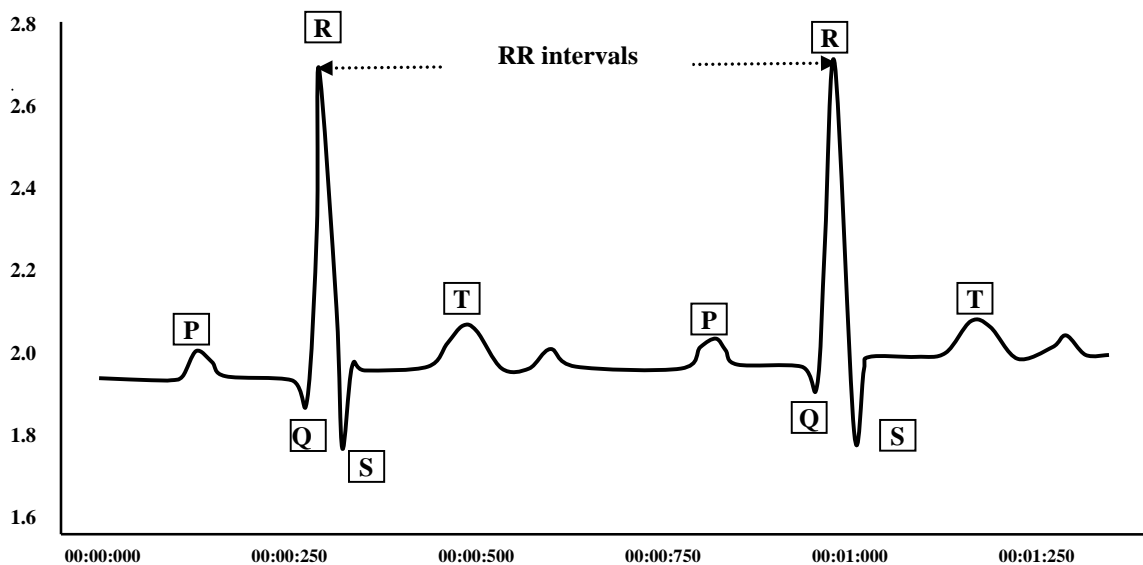


Fig. 2. R peaks of an ECG signal and corresponding RR Interval

4. Implementation

The ECG sensor system implemented mainly in Java programming language but the framework depends on third party solutions. Fig 3 illustrates the block diagram of different parts in the ECG sensor system.

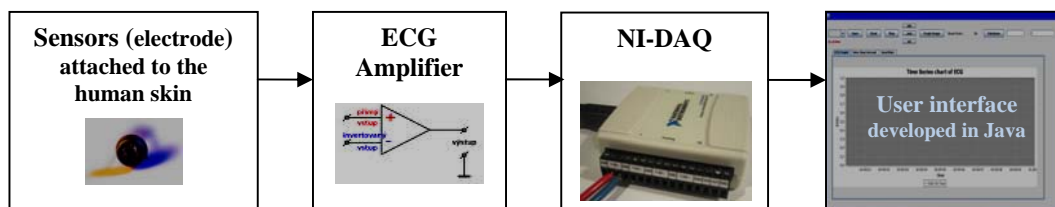


Fig. 3. Block diagram of different parts in the ECG sensor system

Sensors: the 1st part of the system is the sensors attached to the human skin. There are three electrodes works together as the sensors. Two electrodes place in left arm with some distance and one in right arm. The electrodes transform a physical signal from the body into an electrical signal and the signal is then transmitted to the amplifier.

ECG amplifier: the amplifier that takes analog signal (voltage) as an input and produces a meaningful signal by amplifying it. The amplification of the signal could be changed/tuned manually in the hardware device and the amplifier also removes noise from the signal. The device is internally made by the ISS research group at Mälardalen University, Sweden². The amplified output from the amplifier is then sent to the National instruments- data acquisition (NI-DAQ) device.

*NI-DAQ*³: the data acquisition device from national instruments mainly takes the amplified analog signal from the ECG amplifier as an input signal and sends it to the computer through USB. It has 8 analog inputs as single-ended channels in 14 bits resolution which can work also as 4 differential channels and 2 analog outputs in 12 bits resolution. The national instruments also provide the driver of the device for Windows XP and a C programming code that can read data from USB. The C code is editable where it is possible to change the sampling frequency rate.

User interface: the user interface is developed in Java language and the design is done using Netbeans editor. Raw data are captured using the C programming code provided by the national instruments, the code is further edited and formed as a .dll file. This .dll file is then used in Java using the Java Native Interface (JNI). The JNI integrates the code written in different programming language. Here, we have made the integration with the code written in C language. In Java, user interface is developed using multithread programming, one thread is only for receiving data and other for the calculation, logic and display information.

² A research profile in Mälardalen University, <http://www.iss.mdh.se/>

³ NI-DAQ, <http://sine.ni.com/nips/cds/view/p/lang/en/nid/14605>

4.1 The R peak, IBI and HR implementation

As soon as the computer receives the raw signal, our program starts to execute the logics and presents the ECG signal, IBI and HR values. The working steps are illustrated in Fig 4. First step is to acquiring raw ECG signal which is further transmitted into the 2nd step. The 2nd step i.e. extraction identifies the R peaks, IBI and HR and then display the information.

1. **Threshold detection:** the computer receives 1000 samples in one second, but not all the samples contain the highest amplitude. To save the computational time we have generated a threshold. So, the system will start to scan when it receives the threshold value in order to find the highest amplitude. The procedure to detect the threshold is as follows:
 - a. First it receives samples for 3 seconds and identifies Maximum and Mean amplitudes.
 - b. If the Maximum amplitude is greater than the Mean amplitude, then from this range (Mean to Maximum), 2nd Mean amplitude is calculated. Otherwise 1st Mean is considered as the threshold.
 - c. Again, if the Maximum amplitude is still greater than the 2nd Mean, then 3rd Mean amplitude is calculated from the range between the 2nd Mean and the Maximum amplitudes. This 3rd mean value is treated as a threshold otherwise 2nd Mean is considered as the threshold.
2. **R peak detection:** when a sample value is higher than the threshold then it is considered temporarily as a peak and peak detection starts. The temporary peak is being replaced as long as the next sample value is higher than it. When the sample value becomes lower than the peak, the system determines the amplitude value as the R peak. The next peak detection again starts when the sample value becomes less than threshold.
3. **IBI calculation:** each time the system detects the R peak, it saves the time accordingly. Let assume that the system saves the time according to the R peak (t_0, t_1, \dots, t_n), so the IBI value for t_1 will be the time difference from t_1 to t_0 . i.e. $t_1 \text{ IBI} = t_1 - t_0$
4. **HR value:** similarly, HR value for t_1 will be 60000 ms divided by the value of $t_1 \text{ IBI}$

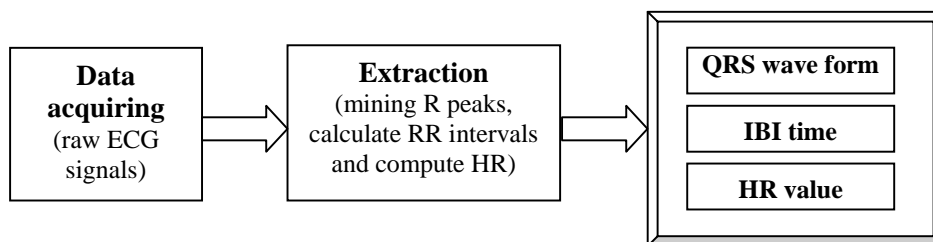


Fig. 4. Working steps for the ECG sensor system

The 3rd step is to display the ECG signals and calculate the IBI and HR values. In the presentation of the IBI and HR values we have skipped the value for the 1st beat (t_0), since it is the initial value used for the calculation.

5. Result and Evaluation



Fig. 5. User interface that displays the ECG signal

Recalling the aim and objective mentioned in the introduction and after the implementation, it is now time to see how far we have succeeded to solve the problem and in what level in terms of accuracy. Fig. 5 and Fig. 6 show the user interface, where the system printed the ECG signal in QRS complex wave form in time series and also the IBI value against the time.

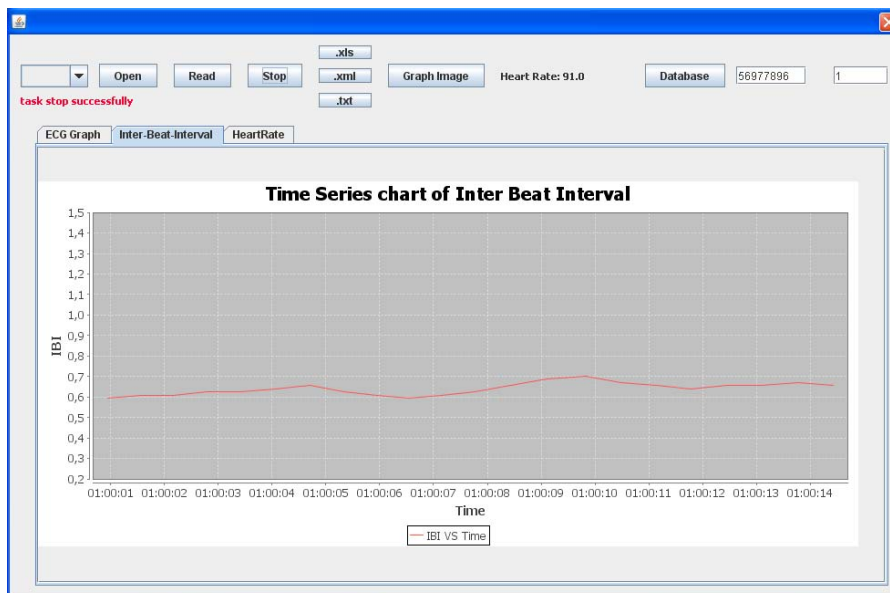


Fig. 6. User interface that displays the calculated IBI values

	A	B	C	D	E	F	G
1	Time	ECG	Time	IBI	Time	HR	
2	0.0	2.06	1360.0	0.672	1360.0	89.0	
3	0.0	2.03	2031.0	0.671	2031.0	89.0	
4	16.0	2.03	2719.0	0.688	2719.0	87.0	
5	16.0	2.01	3422.0	0.703	3422.0	85.0	
6	16.0	2.0	4141.0	0.719	4141.0	83.0	
7	16.0	2.01	4875.0	0.734	4875.0	81.0	
8	16.0	2.02	5610.0	0.735	5610.0	81.0	
9	31.0	2.01	6297.0	0.687	6297.0	87.0	
10	31.0	2.05	7000.0	0.703	7000.0	85.0	
11	31.0	2.04	7719.0	0.719	7719.0	83.0	
12	31.0	2.06	8469.0	0.75	8469.0	80.0	
13	31.0	2.04	9203.0	0.734	9203.0	81.0	
14	31.0	2.06	9953.0	0.75	9953.0	80.0	
15	47.0	2.06	10688.0	0.735	10688.0	81.0	
16	47.0	2.02	11391.0	0.703	11391.0	85.0	
17	47.0	2.02	12078.0	0.687	12078.0	87.0	
18	47.0	2.04	12782.0	0.704	12782.0	85.0	
19	47.0	2.03	13469.0	0.687	13469.0	87.0	

Fig. 7. Data stored in a file (.xls format)

The implemented system also has the opportunity to store both the raw signal as well as the calculated IBI and HR values against time. User could use different file format, namely .xls, .txt and .xml, these exported data could be used for further analysis using other tools (e.g. MathLab). Fig. 7 present an .xls file as an example how the data are stored where the 1st row presents the name of the parameters and rest of the rows shows the corresponding values.

An evaluation is also performed in a very small scale, where we compared the calculated HR value of the developed system with a reference system. Four subjects were involved in this test procedure where the HR measurement was taken for 1 (one) minute using both the system. The HR measurements of each subject (taken from the both system) were saved in excel files. Using excel, we have calculated some statistical methods i.e. maximum, minimum, median, standard deviation, and mean. Finally, the Goodness-of-fit (R^2) was calculated among the statistical methods and the comparison results are presented in Table 2.

Table. 2. Comparison between the reference system and the developed system

Comparison on 1 minute HR value using both the developed system and the reference system								
Statistical Methods	Subject1		Subject2		Subject3		Subject4	
	Developed System	Reference System	Developed System	Reference System	Developed System	Reference System	Developed System	Reference System
Maximum	103	101	91	85	80	85	91	91
Minimum	89	90	50	55	60	54	70	78
Median	96	96	80	71	71	68	81	83

Standard deviation	2.84	2.35	8.66	7.21	2.21	2.65	3.83	2.90
Mean	95.6	96	78	71	72	68	82	83
Goodness-of-fit(R^2)	0.99		0.98		0.98		0.99	

It can be seen from Table 2, the 1st column represents the statistical methods and 2nd to 5th column represents the values for the four subjects. The values are representing by using both the developed system and as well as the reference system. The last row presents the R^2 value for each subject. For example, the R^2 value for the HR measurements (using the developed system) of subject1 is 99% which shows that the developed system performed very close to the reference system. From the evaluation result, it is observed that the developed system is quite close as the reference system at least in calculating the HR.

6. Conclusion

We have in this report presents a computer-based system capable to measure the heart rate and inter-beat interval in real time. The system is developed with the intention to use it in a computer-based stress diagnosis using physiological parameters e.g. heart rate and heart rate variability. The developed interface takes the ECG signal as input and computes the heart rate and IBI from the measured QRS complex wave form. The reliability of the system is examined in a very short scale study and it shows a performance close to a reference system.

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