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Energy Efficient QRS Detection Method for Portable and Personal Analysis of ECG Signal Obtained from Wearable Wireless ECG Body Sensors

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Abstract: ***In this research, a novel heart beat signal propagation and heart rate computation model is developed for the patients using body wearable sensors for heart rate monitoring (also known as Holter) connected through Bluetooth Environment with the medical database through smart phone. These environments are usually designed to post-treatment or pre-treatment monitoring of the heart patients on the regular basis to avoid the critical health hazard situations, while they are at work, home, etc (out of the medical facility or controlled environment). In this research project, the aim is to improve the ECG QRS detection process by making the whole process energy efficient to maximize the smart phone battery life. In this research, a novel heart beat signal propagation from holter to smart phone and then towards the medical database. The smart phone is used as a transmission hub. The holter batteries choke more energy when running on the cellular networks than Bluetooth interface. Hence, the first objective was to maximize the holter battery life by making the connectivity of holter using bluetooth interface. Once the ECG data is obtained on the smart phone via Bluetooth connection, the second objective was to transmit the ECG data from smart phone towards medical database using the smart phone as transmission hub which utilizes cellular or wireless LAN network to send the ECG data. The third and the most important objective was to design and improve the heart beat detection using QRS detection algorithm to minimize the energy consumption by QRS detection using various programming methods. The proposed algorithm will take lesser time than usual added with effective energy consumption model to maximize the battery life of smart phone. The QRS algorithm for smart phones can be used to obtain the similar results they are getting from the medical databases. The QRS detection algorithm will generate the heart beat calculation results, which helps the patients to monitor themselves and to detect the emergency as earlier as possible. The medical databases monitor a number of patients at one point of time; hence, there is always a possibility of delay in case of emergency. Also, the medical services are hierarchical, which makes the process little slower which may put an adverse effect on the patient's life. A little delay made while detecting the emergency and the service provided can cause casualty, which can be easily mitigated by using the localized monitoring. The results of the Bluetooth energy consumption has been obtained by using two Bluetooth enabled phones to transmit the data in the controlled environment where all other additional processes were shutdown on the receiver's end. The receiver smart phone is running its essential processes along with the Bluetooth data channel. The smart phone energy computed adds the energy consumed by the initial processes also. The essential applications consist of operating system and other related essential processes. It is not possible to run the smart phone and its bluetooth without its operating and some essential processes. The recorded/computer heart beat is computer by performing QRS-detection algorithm on the medical database server by using the optimized ECG signal as the input signal for QRS-detection algorithm. The energy consumed and elapsed time has also been recorded for QRS detection on each patient dataset. The results have shown that the new algorithm is very quick and consumed less than 1 joule energy for 90 seconds ECG data recorded at 512 samples per second.***

Keywords: QRS detection, Peak analysis, ECG, Energy efficient algorithm

1. Introduction

The cardiac disease is one of the most common in the people among the world so, the management of cardiac disease is Electrocardiogram (ECG) analysis.QRS detection algorithm is essential method in development of real-time ECG analysis system. a step to reach this objective to develop an evolution methodology to compare different QRS detection under combination of noise and QRS morphologies. Limitation of earlier composed method is that an ECG is composed of multiple noise level and verity of beat morphologies. A good example of a is study comparing QRS detector. They compared nine simple QRS detection algorithm with respect to gold standard ECG waveforms the waveform was corrupted with five type of artificial noise, modelling typically clinical noise. The author concluded on the best of nine is QRS detector by comparing their average performance and clearly exhibiting that each detectors performance is related to the noise context.

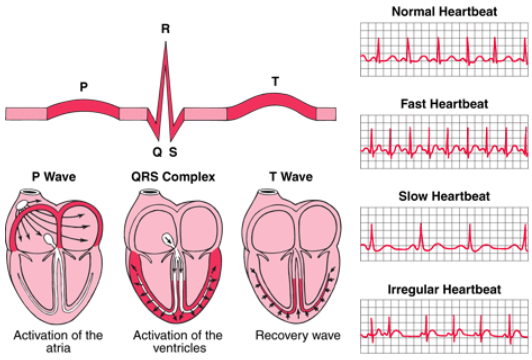

Figure 1: An representation of Electrocardiogram with respect to heart beat

The QRS complex is most striking waveforms within the ECG. Since it reflects the electrical activity within heart during the ventricular contraction, the time of its occurrence as well as its shapes provides much information about the current state of the heart. The QRS detection provides the fundamental for all automated ECG analysis algorithm. In this paper, we are going to develop

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and evaluate a robust single-lead electrocardiogram (ECG).

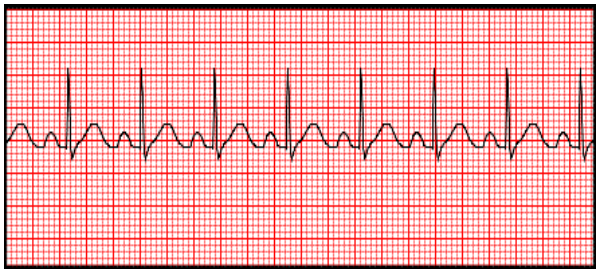

Figure 2: Representation of simple ECG print of sinus in ECG signal obtained by ordinary ECG monitoring device

Firstly, QRS complexes are detected than each QRS is de-linerated by detecting and identifying the peaks of individual waves as well as the complex onset ends. Finally determination of P and T wave's peaks onsets and ends is performed To create different context signals, typical clinical noise and QRS morphologies were extracted from actual ECG records. Since the filtering stage is taken into account in every real application of QRS detection, the ECG waveform was filtered in order to reduce noise. The tested detectors were chosen considering both complexity and efficiency but prioritising the low complexity against the efficiency, since the paper is devoted d real-time.

2. Literature Review

Nehla DEBBABI, Sadok EL ASMI have proposed Algebraic Approach for R-peak Detection in the ElectroCardioGram (ECG) Signal. In this paper, authors have presented a novel method for R-peaks detection in ECG signal in real time environment with noisy ECG data. They have interpreted R-peaks occurrence as an regular process to find the peaks in the signal to count the heart beat. Therefore, the authors have transformed the problem of R-peaks detection into irregularity instants estimation. To check these irregularities, authors have used an mathematical approach based on differential algebra and operational calculus. To increase the accuracy of R-peak detection algorithm, authors have proposed new decision rule permitting the accurate distinction between R-peaks and false alarms. The numerical simulations are performed on the signals obtained from the MIT-BIH arrhythmias database. These are performed to yield out the performance of the proposed method. The results obtained have shown the effectiveness of the algebraic method in the context of complicated pathologies as well as to various types of noises. Won-Jae Yi and Jafar Saniie have proposed Smart Mobile System for Body Sensor Network. This paper is based on the smart mobile application for wearable body sensor network that is used to collect, display, analyze and stream the ECG sensor data to a centralized database server. There are multiple wireless techniques like Bluetooth, cellular data network, Wi-Fi and Near Field Communication (NFC) for the ECG data propagation. The Intelligent Personal Communication systems (iPCS) can use smart phones connected to the data collection sensor. The other processes like pre-processing, analysis and transmission are done by the smart phones. ECG data collected by body wearable wireless sensor data is processed and the results can be generated by the smart phone, which are represented in the simple human readable form for the patient. The ECG data undergoes the QRS detection method for the calculation of heart beat rate, which is performed by smart phone's computation feasibility for real-time signal processing. The major benefit of using smart phones is their ability to communicate with sensor nodes on-demand and to acquire realtime multiple sensor data simultaneously. The proposed smart sensing system is not restricted to body sensor network, but also can have other applications for other critical health monitoring environment that requires instantaneous and remotely accessible monitoring system. Xiangdong Peng et. al. have developed an ECG Compressed Sensing Method of Low Power Body Area Network. Aimed at low power problem in body area network, an ECG compressed sensing method of low power body area network based on the compressed sensing theory was proposed. Random binary matrices were used as the sensing matrix to measure ECG signals on the sensor nodes.

3. Experimental Design

Patients may have undergone the check up as per the above said systems, still demands more attention as they feel uncomfortable in their daily live, their busy world demands a system on a go. Portability is the one factor that needs attention to squeeze the size of the traditional system, which is not possible. Marking the portability factor a new system is designed named as Holter, working same as traditional system but remotely. Time limit is the another factor that demands a system with large operating time usual time for Holter**[8]** is 24-48 hours, this gives a large view of analysis for the doctor on the go or sitting at the seat in the hospital.

The detection of QRS complex is the first step towards automated computer-based ECG signal analysis. To detect the QRS complex more accurately it is necessary to identify the exact R-peak location from the recorded data. Morphological differences in the ECG waveform increase the complexity of QRS detection, due to the high degree of heterogeneity in the QRS waveform and the difficulty in differentiating the QRS complex from tall peaked P or T waves [1].

Several techniques are reported to improve the accuracy of QRS complex detection from ECG signal because the exact detection of QRS complex is difficult, as the ECG signal is added with different types of noise like electrode motion, power-line interferences, baseline wander, muscles noise etc. [2]. Pan and Tompkins [3] reported a technique where, the detection of QRS complex was achieved by linear filtering, non-linear transformation and decision rule algorithm. In another method [4] the QRS complex of ECG signal was found out using multi rate signal processing and filter banks. As reported in [3] the QRS complex can be found after finding the R-peak by differential operation in ECG signal. The first differentiation of ECG signal and its Hilbert transform is used to find the location of R-peak in the ECG signal [5].

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Baseline noise is the short time variation of the baseline from a straight line caused by electric signal fluctuations, lamp instability, temperature fluctuations and other factors. Noise usually has much higher frequency than actual chromatographic peak. Noise is normally measured "peak-to-peak": i.e., the distance from the top of one such small peak to the bottom of the next. Sometimes, noise is averaged over a specified period of time. Noise is the factor which limits detector sensitivity. In trace analysis, the operator must be able to distinguish between noise spikes and component peaks. A practical limit for this is a 3 x signal-to-noise ratio, but only for qualitative purposes. Practical quantitative detection limit better be chosen as 10x signal-to-noise ratio. This ensures correct quantification of the trace amounts with less than 2% variance. Figure below illustrates this, indicating the noise level of a baseline (measured at highest detector sensitivity) and the smallest peak which can be unequivocally detected.

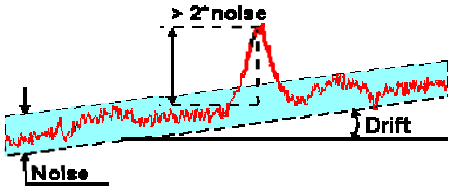

Figure 3: Definition of noise, drift, and smallest detectable peak.

Electrocardiogram (ECG)**[2]** basically checks the rhythm of the Patient's Heart, the electrical activity of patient's heart is plotted on a graph paper. Willem Einthoven designed a machine that could record an electrical activity of heart; this traditional system is still in use. Graph shows the area swiped on a graph paper as in the form of P,Q,R,S,T,U waves**[4].** Firstly, Each peak has its on specific amplitude and time for which it must appear and any fluctuation in the amplitude or timing for the time the peak has to appear but not coming or it appearance cannot be detected on the graph paper can be further examined. Secondly the time slot between the P(1^{st} wave)- P(2^{nd} wave), R(1^{st} wave)- R(2^{nd} wave),PR-interval , QRS-complex and ST-interval ,QT-interval, ST-segment, have been defined with measured values of each one of them. Einthoven designed the machine to have his own ECG and laid down the results over a paper.

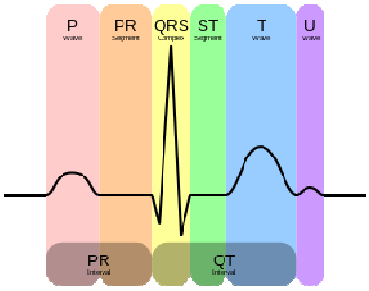

Figure 4: Normal ECG data representation

Traditional ECG systems **[1]** demand the patient to be present at the nearby hospital for the ECG check up, normal ECG constitute a 10-Electrode placed at various sensitive areas of patient's body for monitoring the electrical activity of heart **[2].** System's output is drawn onto a graph paper, which gives a transparent look for the doctor. Sometime considering the data being provided by ECG machine leads to no defect data. Traditional System gives short time input, this cannot be used for analyzing the activity of heart over a large interval.

Algorithm 1: Complete Proposed Method

1. *Read the patient signal dataset*
2. *Remove the baseline drift*
3. *De-noise signal using Sgolay Filter*
4. *De-noise signal using Median Filter*
5. *Compute QRS detection*

Once the ECG data is obtained for the Holter it undergoes the noise removal process at very first step of the proposed signal processing algorithm. Three basic types of noises will be eliminated which can be probably caused during the signal recording, signal propagation, etc. The first step is to eliminate the baseline drift [26] which is a type of noise got generated during the signal recording process. Baseline drift will be eliminated using a moving average filter. The next step is to remove the signal burst using Savitzky-Golay Filtering. After removing the signal burst, the next objective is to remove the salt and pepper noise or spikes from the ECG data that arises because of any voltage fluctuation using Median Filter.

Algorithm 2: Baseline Drift removal

1. Load ECG data file corresponding to the first lead of a particular case and compute overall median for the entire waveform.
2. Shift each sample of the entire waveform by this median value, which is a constant value for all the samples.
3. Fit a fourth degree polynomial to the shifted waveform, with least squares method and compute the polynomial value, with Matlab function, at each sample of the waveform, using the coefficients of this fitted polynomial.
4. Shift each sample of the waveform by this computed value; this is a variable value for the sample range (shown by contour in part (a) of figures 2-6).
5. Detect and demarcate wave complexes by threshold method. Detect peaky R-waves out of these demarcated wave complexes by segregating them on the basis of their relative gradient.
6. After marking R-waves, RR intervals are determined. The base line drift is further removed by applying median correction, one-by-one, in each RR interval. The samples outside RR intervals, i. e., those before the first R-wave and after the last R-wave are covered using decision rules.
7. The cases in which QRS complexes are false negative, with the method of step 5, are detected and delineated by employing the strategy of rate of change of slope, enhancement of signal and elimination of false positive detections.
8. The median correction, in RR-interval, is applied once again and the removal of base line drift achieved is near total.

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4. Result Analysis

In this research, a novel heart beat signal propagation and heart rate computation model is developed for the patients using body wearable sensors for heart rate monitoring (also known as Holter) connected through Bluetooth Environment with the medical database through smart phone. These environments are usually designed to post-treatment or pre-treatment monitoring of the heart patients on the regular basis to avoid the critical health hazard situations, while they are at work, home, etc (out of the medical facility or controlled environment). In this research project, the aim is to improve the ECG QRS detection process by making the whole process energy efficient to maximize the smart phone battery life. In this research, a novel heart beat signal propagation from holter to smart phone and then towards the medical database. The smart phone is used as a transmission hub.

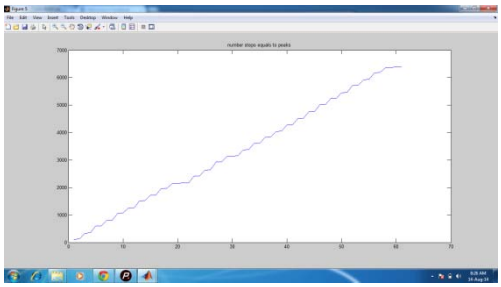

Figure 1: Number steps equal to peaks

The holter batteries choke more energy when running on the cellular networks than Bluetooth interface. Hence, the first objective was to maximize the holter battery life by making the connectivity of holter using bluetooth interface. Once the ECG data is obtained on the smart phone via Bluetooth connection, the second objective was to transmit the ECG data from smart phone towards medical database using the smart phone as transmission hub which utilizes cellular or wireless LAN network to send the ECG data. The third and the most important objective was to design and improve the heart beat detection using QRS detection algorithm to minimize the energy consumption by QRS detection using various programming methods. The proposed algorithm will take lesser time than usual added with effective energy consumption model to maximize the battery life of smart phone. The QRS algorithm for smart phones can be used to obtain the similar results they are getting from the medical databases. The QRS detection algorithm will generate the heart beat calculation results, which helps the patients to monitor themselves and to detect the emergency as earlier as possible. The medical databases monitor a number of patients at one point of time; hence, there is always a possibility of delay in case of emergency. Also, the medical services are hierarchical, which makes the process little slower which may put an adverse effect on the patient's life. A little delay made while detecting the emergency and the service provided can cause casualty, which can be easily mitigated by using the localized monitoring.

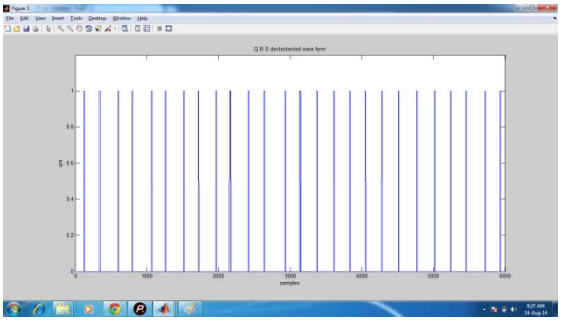

Figure 2: QRS detection wave form

The database contains 25 records from 25 subjects (aged between 27 to 70, mean 48.5; 17 men, mean age 38.5, and 8 women, mean age 42.6; ages were not recorded for 2 female and 3 male subjects). Each subject is represented by one ECG record. Each record includes the continuously measured signals. Each signal is digitized at 356 samples per second, with 16 bit resolution over a range of ± 16.384 mV. On special request to the contributors of the database, recordings may be available at sampling rates up to 10 KHz. The energy recorded for Bluetooth Environment has been recorded and displayed under this research project. The recorded/computer heart beat is computer by performing QRS-detection algorithm on the medical database server by using the optimized ECG signal as the input signal for QRS-detection algorithm. The ECGs in this collection were obtained using a non-commercial, PTB prototype recorder with the following specifications:

- 16 input channels, (14 for ECGs, 1 for respiration, 1 for line voltage)
- Input voltage: ±16 mV, compensated offset voltage up to ± 300 mV
- Input resistance: 100 Ω (DC)
- Resolution: 16 bit with 0.5 µV/LSB (2000 A/D units per mV)
- Bandwidth: 0 - 1 kHz (synchronous sampling of all channels)
- Noise voltage: max. 10 µV (pp), respectively 3 µV (RMS) with input short circuit
- Online recording of skin resistance
- Noise level recording during signal collection

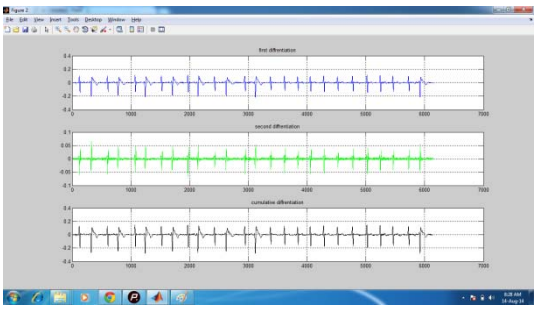

Figure 4: Signal plotting after two level differentiation and cumulative difference

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Table 1: Energy Consumption by smart phone while receiving the data on Bluetooth interface

Patient ID	*Bluetooth Energy Consumption on smart phone*
Pat 1	23. 86
Pat 2	15. 63
Pat 3	40. 22
Pat 4	26. 79
Pat 5	34. 29
Pat 6	18.44
Pat 7	21.48

The results of the Bluetooth energy consumption has been obtained by using two Bluetooth enabled phones to transmit the data in the controlled environment where all other additional processes were shutdown on the receiver's end. The receiver smart phone is running its essential processes along with the Bluetooth data channel. The smart phone energy computed adds the energy consumed by the initial processes also. The essential applications consist of operating system and other related essential processes. It is not possible to run the smart phone and its bluetooth without its operating and some essential processes.

Table 2: Heart Rate Computation and Energy Consumption calculation after QRS detection

Patient ID	*Heart Beat*	*Energy Consumption*	*Elapsed Time*
1	127	0.649115	0.021123
2	132	0.731722	0.020373
3	157	0.647746	0.019857
4	168	0.450924	0.019831
5	158	0.547009	0.01958
6	170	0.296321	0.020239
7	258	0.744693	0.020242
8	223	0.188955	0.020299
9	159	0.183511	0.021009
10	167	0.368485	0.020092
11	265	0.625619	0.019779
12	171	0.081126	0.019885
13	152	0.929386	0.019921
14	253	0.775713	0.019807
15	217	0.486792	0.020083
16	125	0.446784	0.021197
17	107	0.508509	0.021361
18	135	0.817628	0.020186
19	218	0.794831	0.020479
20	218	0.644318	0.020307
21	117	0.81158	0.02015
22	138	0.350727	0.020012
23	243	0.939002	0.02057
24	270	0.875943	0.019837
25	160	0.550156	0.020182
26	217	0.622475	0.02003
27	217	0.587045	0.020061
28	94	0.301246	0.019933
29	129	0.230488	0.019989
30	179	0.194764	0.020286

The recorded/computer heart beat is computer by performing QRS-detection algorithm on the medical database server by using the optimized ECG signal as the input signal for QRS-detection algorithm. The energy consumed and elapsed time has also been recorded for QRS detection on each patient dataset. The results have shown that the new algorithm is very quick and consumed less than 1 joule energy for 90 seconds ECG data recorded at 512 samples per second.

5. Conclusion

The results of the Bluetooth energy consumption has been obtained by using two Bluetooth enabled phones to transmit the data in the controlled environment where all other additional processes were shutdown on the receiver's end. The receiver smart phone is running its essential processes along with the Bluetooth data channel. The smart phone energy computed adds the energy consumed by the initial processes also. The essential applications consist of operating system and other related essential processes. It is not possible to run the smart phone and its bluetooth without its operating and some essential processes.

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