Automated ECG Signal Quality Assessment based on Wavelet Decomposition for Baseline Wander Noise Removal

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ABSTRACT **-**Recent advances in telecommunications, microelectronics, sensor manufacturing and data analysis techniques have opened up new possibilities for using wearable technology in the digital health ecosystem to achieve a range of health outcomes. Generally the data obtained from the mobile patients are noisier hence it is very difficult task for the recognition of invalid data in recordings obtained using wearable sensors having great importance. In this paper, we present a Signal Quality Index (SQI), which is planned to assess whether Heart Rates (HRs) were reliable and can obtained from Electrocardiogram (ECG) signals are collected with the help of wearable sensors. These algorithms were nothing but manually labelled data which were validated. The proposed method determines various cardiovascular diseases using reliable Heart Rate signals, which are obtained from the Signal Quality Index algorithm and also removes the Baseline Wander (BW) noise in ECG signals using Wavelet Decomposition. This generic algorithm has been done on diseases which paves us the achievement of better results than the previous techniques.

Keywords: *Electrocardiogram, Signal quality, Wearable sensors.*

INTRODUCTION

ECG signals are used to detect heart rate and heart abnormalities. The ECG signals are mainly corrupted by different types of noises and artifacts such as power line noise, Base line wander (BW), muscle contraction and other external noises which affects the reliability of the heart rate. The Automated Heart rate calculation is usually based on the identification of heart beat signals, which could be taken from the QRS complex or simply the R waves in electrocardiogram (ECG). For extraction of ECG features and detection of QRS complexes it is required to remove baseline wander (BW) and minimize the noise interference. One of the most common problems of ECG recordings is the baseline wandering in the ECG signals during data collection. Baseline wander elimination is considered as a classical problem in ECG signal filtering. A new method is proposed to remove baseline wander in ECG signal based on wavelet decomposition and notch filter.

In this paper we implement Signal Quality Algorithm (SQI) to identify the reliable heart rate signals from ECG signals. The reliable heart rate signals are used to determine the various cardiovascular diseases and abnormalities. The reliability is expressed through a quality index for each Heart rate. The proposed algorithms are carried out in Matlab environment and are tested using specific ECG recordings from the MIT-BIH Arrhythmia Database, taken from a web based resource for free access to study of physiological signals.

Electrocardiography (ECG)

Electrocardiography is the process of recording of electrical activity of heart with limb and chest electrodes. The heart rate in terms of beats per minute (bpm) may be easily estimated by counting the R-R interval. Some of the cardiovascular diseases such as myocardial ischemia and infarction, ventricular hypertrophy, and conduction problems alter the shape of ECG wave. Therefore, clinical diagnosis of the heart functioning is done by ECG analysis. The Cardiac signal in an ECG signal is shown in Figure 1.

"P" represents the initiation of depolarization in the sinus node and subsequent atrial contraction. Whereas, "QRS" complex represents the conductance and sequential depolarization of the ventricals.

"ST" represents the period of time in which the ventricles are isoelectric and "T" represents the repolarization of the ventricles.

"PR" represents the time it takes an impulse to travel from atria through AV node. "QT" represents the time necessary for ventricular depolarization and repolarization.

An electrical activity of heart can be analyzed from 12 lead ECG that gives a tracing from twelve different electrical positions of the heart. Each lead pick up the signal at different position of the heart.

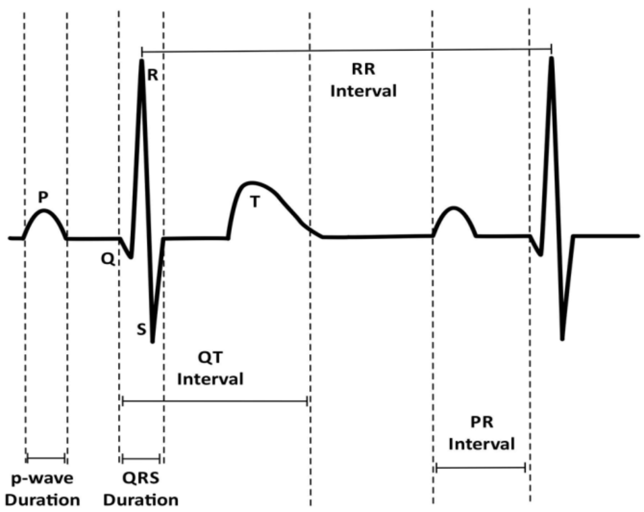


Figure 1: Cardiac cycle in an ECG signal

Standard Databases

In the present work reported in this thesis, we have used several dataset, namely PhysioNet/CinC Challenge 2011 training set-a, PhysioNet/CinC Challenge 2014 training dataset (set p and set p2), PhysioNet/CinC Challenge 2014 hidden test dataset, MIT-BIH Polysomnographic database, MIT-BIH Arrhythmia database, MGH/MF waveform database and MIT-BIH noise stress test database. To validate the performance of our algorithm on noisy cardiovascular signals, a synthetic noise dataset has been generated by adding calibrated amount of different types of noises in clean ECG signals separately. A brief description of the above mentioned dataset/database is given below.

MIT-BIH Arrhythmia database (mitdb)

The MIT-BIH Arrhythmia database contains 48 two-channel ambulatory ECG recordings, each of half-hour duration, obtained from 47 subjects. Twenty-three recordings were chosen at random from a set of 4000, 24-hour ambulatory ECG recordings whereas the remaining 25 selected recordings include less common but clinically significant arrhythmias. The sampling frequency of recordings was 360 samples per second per channel with 11-bit resolution. The digitization rate of 360 samples/second per channel was chosen so that simple digital notch filter can be used to remove 60 Hz interference. The analog signals were filtered to limit saturation in A/D conversion and for anti-aliasing using a pass band of 0.1-100 Hz relative to real time during digitization.

MOTIVATION AND RELATED WORK

ECG signal describes the state of a Human Heart hence; it detects the health conditions of a human being. A proper ECG gives us the information about various diseases related to heart. The irregularities in ECG may not be periodic and may show at different intervals. Various contributions have been made in literature regarding pulse peak detection and classification of ECG. Most of these use time domain or frequency domain representation of ECG signals. But major problem faced is the variations in the morphologies of ECG signals.

This objective has motivated to search and experiment with various techniques. So, we have detected the quality of Heart rate from ECG using SQI algorithm and we have implemented the removal of Base wander noise in ECG signal using Wavelet decomposition. Advancement in signal processing methods has brought significant improvement in artifact detection and removal in the past several years. There had been various techniques proposed for artifact separation and their removal.

PROPOSED ALGORITHM

Although many researchers have done on ECG signals to determine what signals exist for which patients, there is no guarantee of quality, and sometimes the data can be so noisy that no useful clinical information can be extracted from the data. To avoid requesting noisy data, and using this data for further processing, we have developed a set of signal quality indices (SQI's) for electrocardiogram.

In this study, we implement the SQI algorithm to determine the quality of the heart rate from ECG signals. By using this heart heart rate signals we determine the various cardiovascular diseases. The Flowchart of the SQI algorithm is shown in the Figure 2.

The different steps used in the SQI algorithm are discussed as follows:

a) Raw ECG signal: The ECG signals are taken from the MIT-BIH Arrhythmia database taken from a web based resource for free access to study of physiological signals. The ECG signal is collected from 12 patients in whom each patient has 15 different ECG signals with 60000 lengths. But the input ECG signals have different types of noises, to remove these noises we use preprocessing.

b) Preprocessing: The preprocessing of ECG signal (Raw) is required for removal of noises. Preprocessing stage involves wavelet decomposition and filtering. For the extraction of ECG features and QRS complex it is required to remove the baseline wander noise which present in ECG signal. A new method is proposed to remove baseline wander in ECG signal based on wavelet decomposition and notch filter.

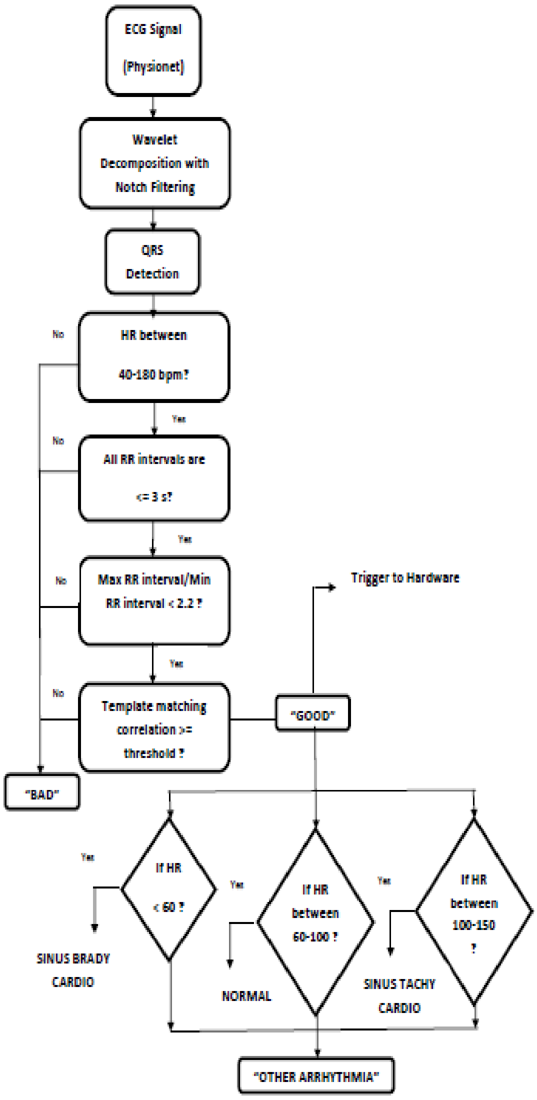


Figure 2: Flowchart of SQI Algorithm.

Notch Filter:

In practical electrocardiogram (ECG) measurements, the primary signal is often contaminated by strong disturbances, which must be removed before the signal is registered for further analysis. The varying ECG contact potentials and breathing artifacts (below 0.5 Hz) cause unwanted base line drift. For stress ECG recordings, this drift may sometimes make the recording impossible. Such unwanted signals are effectively removed by using appropriate linear phase notch filters. Elimination of dc component of an ECG is another use of notch filters. Notch filters are also used to suppress the secondary artefacts that arise due to electrical interference, as well as cross coupling from frontal EEG while analyzing ECG signal.

Wavelet Decomposition:

Unlike Fourier transform, Wavelet transform (WT) provides more information in its domain, which includes both frequency and time representation. A very efficient and reliable algorithm is used to compute the DWT decompositions using consecutive filters and decimators as shown in the Figure 3. The HPFs and LPFs determine the corresponding details and approximations coefficients of the applied signal.

The down samplers are used to remove the redundant samples from the output of the filters and it keeps the total number of samples the same. According to the characteristics of the applied signal and the required degree of processing we can reapply the approximation to the most recent decomposition segment several times.

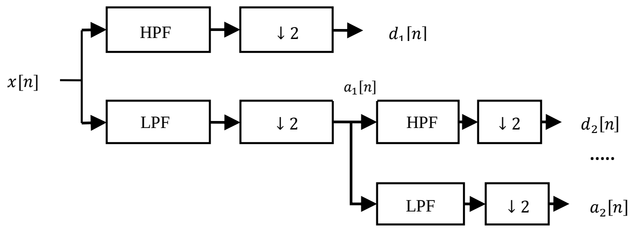


Figure 3: Two levels of Mallar's algorithm for decomposition.

The approximation coefficients are related to the low frequency part of the signal, which contains the main features and information. The detail coefficients are used to preserve the perfect shape when reconstruction is invoked. It is noticeable that detail coefficients at higher levels of noiseless signals are sparse. So, in these high levels, larger coefficients can be assumed to be actual ones plus noise; the remaining are considered as pure noise. The denoising signals using wavelet thresholding methods of detail coefficients is shown in the Figure 4. The two famous thresholding methods in the use of wavelets for estimation of unknown signals in the presence of noise are: 'SureShrink' and 'NeighBlock'. These methods are developed by Donoho et.al. and cai et.al.

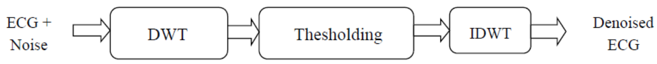


Figure 4 Denoising steps using Wavelet.

This algorithm removes the noise by thresholding most the detail coefficients according to the value of the threshold (λ),which depends on the level of decomposition.

There are two approaches to decide whether d_t pure noise or an actual coefficient plus noise: soft and hard decisions as given in the following equations.

$$Hard: d_1 = \begin{cases} d_1 \; if \; |d_1| > \lambda \\ 0 \; else \end{cases}, \qquad Soft: d_1 = \begin{cases} d_1 - \lambda \;\; if \; d_1 > \lambda \\ d_1 + \lambda \;\; if \; d_1 < -\lambda \\ 0 \; else \end{cases}$$

In the hard decision, coefficients are set to zero if they are less than λ or preserved otherwise. This type of decision is modified by the soft decision as all considered with noise, so deducting λ from the coefficients which are considered as non-pure noise values. Denoising using the soft decision method performs better han the hard decision approach.Thus in this project the soft decision is considered among the wavelet denoising methods.

c) QRS/Pulse peak detection: Detection of peaks often forms an essential part of time domain analysis of biomedical signals and patient monitoring. Peak detection is the process of finding the locations and amplitudes of local maxima in a signal that satisfies certain properties. Generally a signal sample is considered as a peak when it is greater than its previous sample and next sample. Most of the algorithms for detection of QRS complexes in ECG combine a Filter with a Transformation, such as the signal derivative or the wavelet transform, to exploit the large slope and high frequency content of the QRS complex (10 to 25 Hz). This transformation generates a feature signal in which QRS complexes can be detected easily by a threshold.

d) SQI Rules: The SQI algorithm is carried out with three rules.namely,

Rule-1: In this the heart rate must be inbetween 40-180 bpm which is the probable range of an adult population. If the signal satisfy this rule it is send for next condition otherwise it is considered as bad signal.

Rule-2: The R-R interval of the signal must be less than or equal to 3sec which is the maximum acceptable gap. Not morethan one beat should be missed. The R-R interval is nothing but the difference between two consecutive R-peaks of ECG signal.

Rule-3: The proportion of max R-interval to min R-interval must be less than 2.2sec. The heart rate should not be more than 10% of the sample.

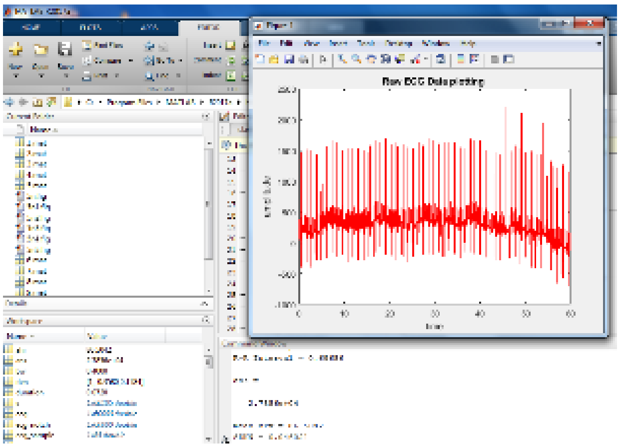
e) Template matching: In this we compare the obtained ECG signal to the basic reference signal. This approach calculates the median beat to beat interval of the signal by using all the detected R-peaks.

Matching is the generic algorithm in pattern recognition which is used to determine the similarity between two entities of specified type. The test sample which is an effort to recognize indications of diseases is compared with template. The comparison is making with respect to the metrics and is calculated the similarity. It is necessary to make the normalizing changes of sample, inorder to achieve the best similarity.

f) Correlation: The average correlation coefficient is finally obtained by averaging all correlation coefficients over the whole ECG sample lower than the determined threshold, it was classified as “bad,” and if it was higher than the determined threshold, it was classified as “good.” In the Existed method the Signal quality index algorithm is used only to monitor the quality of heart rate. In addition, we proposed a technique which determines the various cardio vascular diseases like Sinus Bradycardia, Wolf Parkinson white syndrome, Sinus Trachycardia and etc based on the parameters like QRS peak duration, heart beat which are obtained from Reliable Heart Rate of ECG signal.

TESTING AND DISCUSSION

The proposed algorithms are carried out in Matlab environment and are tested using specific ECG recordings from the MIT-BIH Arrhythmia Database, taken from a web based resource for free access to study of physiological signals.



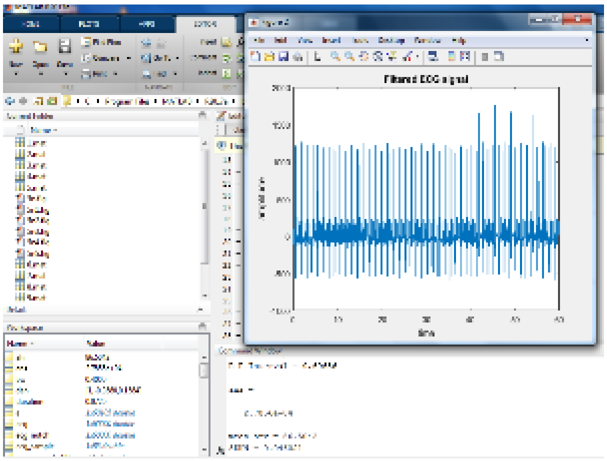


Figure 5: Raw ECG signals. Figure 6: Filtered ECG signal after pre-processing.

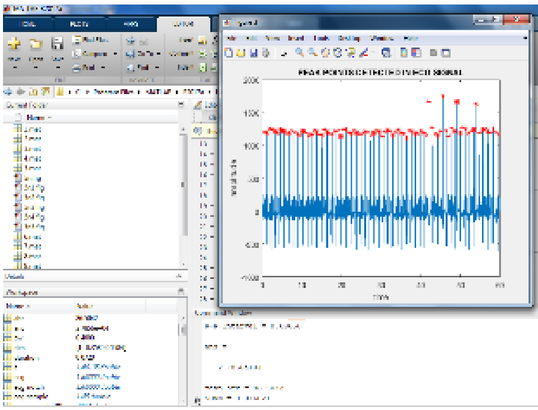


Figure 7: ECG signal after peak detection

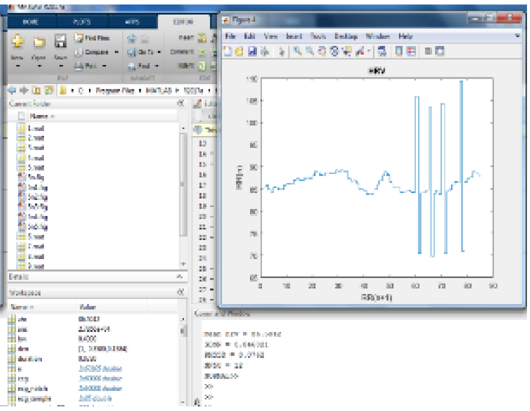


Figure 8: Heart rate variability.

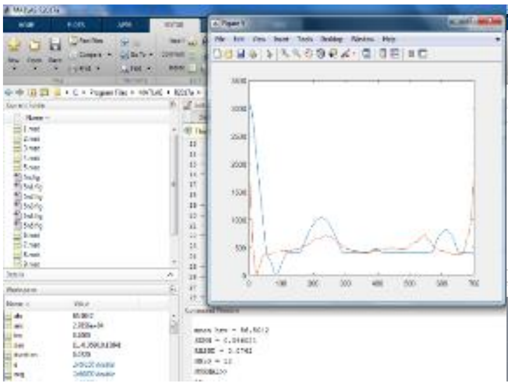


Figure 9: Comparison of obtained ECG signal with reference signal

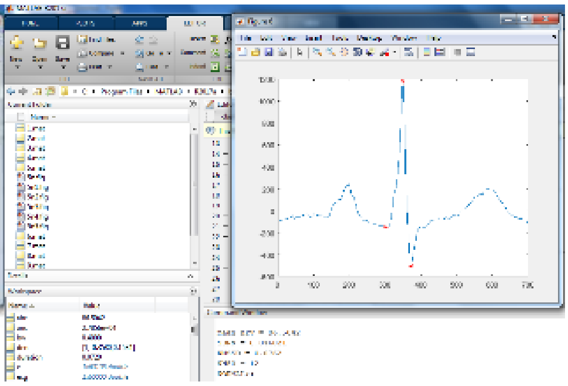


Figure 10: Reliable heart rate pulse.

CONCLUSION AND FUTURE SCOPE

Here we have presented an SQI for the ECG signals on different diseases, which is intended to offer real-time assessment of the correctness of ECG signals for obtaining dependable HR values. The proposed approach is based on the assumption that a single reliable HR measurement every 1 min is sufficient. While this frequency of HR measurement is far in excess of the current standard of care, there is still the danger of patient deterioration being missed because of intermittent recording. Our proposed SQI shows promising results in differentiating between "good" and "bad" segments of data obtained from ambulatory hospital patients using a range of wearable monitoring systems. Our approach concerns clinical settings where a single ECG signal would be available. In settings where multiple ECG signals are present, it is possible to further improve estimation of vital signs by fusing information from the different sources based on their respective quality indices as much recent research has verified.

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