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An Algorithm for Detection of Arrhythmia

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Abstract This paper presents an algorithm for Electrocardiogram (ECG) analysis to detect and classify ECG waveform anomalies and abnormalities. This is achieved by extracting various features and durations of the ECG waveform such as RR interval, QRS complex, P wave and PR durations. These durations are then compared with normal values to determine the degree and types of abnormalities. Most of the data used for this study were extracted from the MIT-BIH arrhythmia database while some data was extracted from ECG recordings acquired specifically for the purposes of this study. The paper is concluded with detailed results obtained from testing the algorithm using the ECG data.

Keywords Electrocardiogram, QRS Complex, Arrhythmia, Fiducial Point, Sampling Rate, Peak Valley Checker

1. Introduction

The ECG waveform reflects the electrical activity of the heart. It is widely used as a routine cardiac diagnostic tool. The ECG signal is a repetitive waveform that comprises several waves distinguished each other by frequencies and amplitudes. These waves originate from different parts of the heart and are denoted by letters P, QRS, T and U as shown in Figure 1. Table 1. Shows characteristics of normal ECG. The normal rhythm of the heart is commonly named as normal sins rhythm (NSR). Variations in the time durations of these waves and segments from the NSR parameters indicate a pathological condition called arrhythmia. Arrhythmia can be classified into several types such as tachycardia, bradycardia, premature ventricular contractions, ventricular fibrillation, atrial flutter, sick sinus syndrome and heart blocks[1-2].

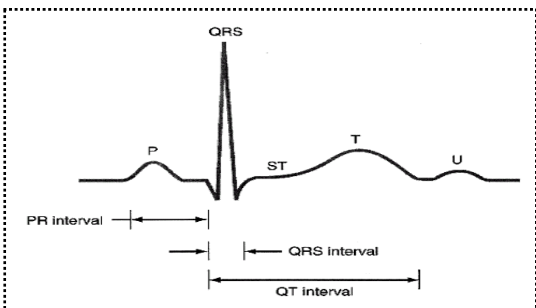

Figure 1. Typical ECG Signal[12]

In conventional methods of ECG diagnosis, physician tries to find whether the ECG signal is different from normal sinus rhythm in terms of the morphology of each component, time intervals and heart rate. Considering the large numbers of critical patients and the need for accurate interpretation of their cardiac status and the limitations of human to observe the fine details in ECG waveform led to the introduction of automated arrhythmia monitoring systems to assist cardiologists in detecting the signs of arrhythmia at early stages which can save patients lives[3-5]

In this paper, a time domain based technique for arrhythmia detection and interpretation is presented. The method involves ECG data processing, QRS detection, determination of QRS complex, P-wave, PR and heart cycle (RR) durations followed by arrhythmia interpretation using a set of decision rules[8-11].

Table 1. Characteristics of normal ECG

Segment	Duration in seconds
P Wave	0.12
QRS	0.06 – 0.1
PR interval	0.12 – 0.2
ST segment	0.08

2. Methodology

2.1. Data Acquisition

Most of ECG signals were downloaded from the MIT-BIH arrhythmia database[6], which are sampled at the rate of 360 samples/sec. Additional ECG signals were acquired from patients suspected to have cardiac problems, by using a bio-amplifier together with data acquisition card (Advantech DAQ). Figure 2 explains the real time ECG data acquisition. Presence of noises were the most difficult threat while recording ECG signal. These noises are base line wandering noise, muscle tremor, power line (50Hz) noise etc. Specially designed filters were used in the bio amplifier module, which include band pass filter, notch filter etc to filter out these potential noises. In addition to this software based filters were also used to filter the acquired signal for better efficiency. Sampling rate of the acquired signal are 250 Hz. All

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ECG data used in this study were standard lead II. MATLAB was used as back end and front software.

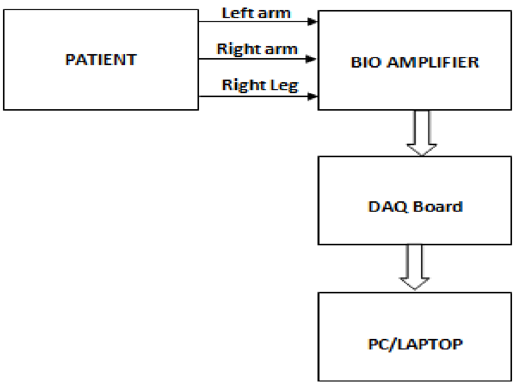

Figure 2. Block diagram for real time ECG data acquisition

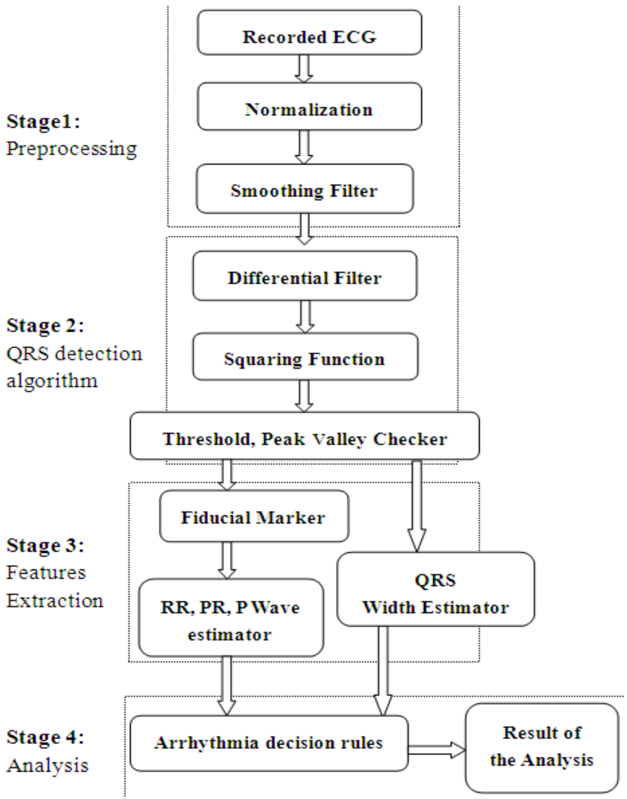

Figure 3. Block diagram of ECG processing and arrhythmia interpretation

2.2. ECG Data Processing and Arrhythmia Detection Algorithm

The flowchart in Figure 3. explains the algorithm used for ECG data pre processing, features extraction, arrhythmia detection and interpretation. The waveform diagrams given in Figure 4 are the results of the various stages of the ECG pre processing.

2.2.1. ECG Preprocessing

The ECG waveform was first normalized to remove the DC offset. After that the ECG signal was passed through squaring and smoothing filters[3]. Stage 1 in figure 3 show various steps during ECG pre processing.

Filtered signal y[n] is obtained using the formula:

$$y[n] = (x[n] + 2x[n-1] + x[n-2])/4 \qquad (1)$$

where x(n) are the ECG samples.

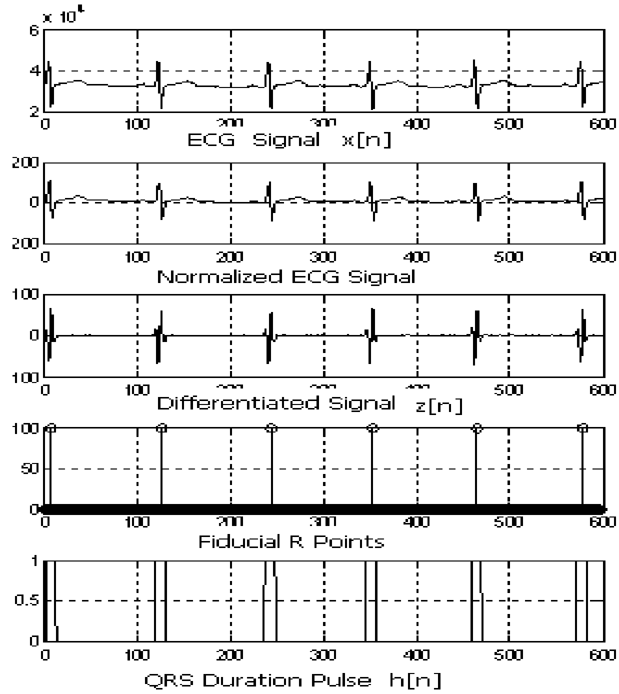

Figure 4. ECG signal at various stages of the algorithm

2.2.2. QRS Detection Algorithm

Stage 2 in the figure 3 shows the various steps in QRS detection algorithm. The signal y[n] from (1) was then differentiated twice to give z[n] using the following equations:

$$u[n] = y[n] - y[n-1] \qquad (2)$$

$$z[n] = u[n] - u[n-1] \qquad (3)$$

The differentiated signal was then squared to give w[n] using

$$w[n] = (z[n])^2 \qquad (4)$$

Signal (4) shows the squared QRS complex, from which the start point and end points of the QRS complex is determined. In order to confirm he detected signal is a QRS complex, this signal need to pass through threshold and peak and valley checker[7]. This was followed by the following threshold operation:

$$h[n] = 100 \; for \; w[n] \geq threshold, else \; h[n] = 0 \qquad (5)$$

This threshold operation generated series of pulses h[n] with durations equivalent to the width of the QRS complexes.

Peak and valley checker confirm the presence of the peak and valley points of the QRS complex, which is a distinguished feature of QRS complex.

2.2.3. Features Extraction

After the determination of the QRS durations the fiducial points which show the location of R points were determined. The cardiac cycle (RR) intervals were obtained and hence the heart rate (HR) for each beat was calculated using the relationship:

$$HR = (60/RR) * (\text{Sampling Rate}) \qquad (6)$$

The P-wave duration and the PR interval for each beat were also determined by scanning each beat waveform using a time window prior to each R point.

2.2.4. Arrhythmia Interpretation

Sixteen arrhythmia decision rules were developed after consultation with a group of cardiology specialists. The rules were applied to the features extracted from each ECG data files. There were two types analysis applied, one is the beat analysis and second is the beat to bat analysis. In beat analysis, each beat was examined against standard values, where as in the beat to beat analysis the similarities in the beat morphology between adjacent beats were examined.

Some of the arrhythmia decision rules are explained in the equations (7) and (8).

If ((beat[i] > = 60 & beat[i] = < 90)
& (pr[i] > = 0.12 & pr[i] < = 0.2)
& (qrs[i] > = 0.06 & qrs[i] < = 0.12)) (7)

If (beat[i] > 90 & (pr[i] > = 0.12 & pr[i] < = 0.2)
& (qrs[i] > = 0.06 & qrs[i] < = 0.12)) (8)

Based on the decision rules the arrhythmias were classified as Tachycardia (TA), Bradycardia (BR), Premature Ventricular contraction (PVC), Sick Sinus Syndrome (SSS), Premature Atrial Contraction (PAC), Wandering Pacemaker (WP), Complete Heart Block (CHB), First Degree Heart Block (FDHB), Bigeminy (BI) and Quadrigeminy (Q).

Table 2. Extracted values of ECG signal features from one ECG recording

HR	QRS Duration(s)	PR Interval(s)	P- wave Duration (s)
60	0.091603	0.183206	0.1374
59	0.083969	0.167939	0.0992
58	0.068702	0.183206	0.1374
56	0.091603	0.175573	0.1221
58	0.099237	0.183206	0.1374
56	0.091603	0.190840	0.1450
56	0.106870	0.183206	0.1145
55	0.091603	0.190840	0.1298
56	0.067502	0.185206	0.1450
57	0.096603	0.178573	0.1450
58	0.068702	0.435115	0.1450
57	0.091603	0.190840	0.1145
57	0.092606	0.185573	0.1450
59	0.106870	0.427481	0.1450
57	0.091603	0.183206	0.0916
59	0.091603	0.183206	0.1374
61	0.068702	0.167939	0.1298
58	0.091603	0.190840	0.1221
60	0.091603	0.419847	0.1526

3. Results and Discussion

An algorithm for the detection of arrhythmia were developed. The algorithm was tested for twenty four recorded ECG data files. The values of the features extracted for one of the ECG files are given in Table 2. Table 3. shows the classification of arrhythmias based on features given in Table 2. Table 4 shows arrhythmia classifications of all data files using the algorithm compared with cardiologist interpretation of the same recording based on visual inspection only.

These results show that the algorithm was able to give accurate interpretation of the various types of arrhythmias. The interesting finding was that the algorithm was able to detect additional arrhythmias in the beats which cannot be visually observed by cardiologists.

Table 3. Arrhythmia classification using features given in Table 1

ECG file	Arrhythmia Classification
1	Normal (N)
2	Bradycardia (BR)
3	Bradycardia (BR)
4	Bradycardia (BR)
5	Bradycardia (BR)
6	Bradycardia (BR)
7	Bradycardia (BR)
8	Bradycardia (BR)
9	Bradycardia (BR)
10	Bradycardia (BR)
11	Wandering Pacemaker (WP)
12	Bradycardia (BR)
13	Bradycardia (BR)
14	Wandering Pacemaker (BR)
15	Bradycardia (BR)
16	Bradycardia (BR)
17	Normal (N)
18	Bradycardia (BR)
19	Wandering Pacemaker

Table 4. Comparison of arrhythmia interpretations using the algorithm with cardiologist interpretation for all ECG recordings

ECG No.	Algorithm Interpretation	Cardiologist Interpretation
1	WP, CHB	Heart Block
2	N, PVC, BR, TA	Nomal, Brady, Tachy
3	N, PVC, TA	Normal, Tachy, PVC
4	WP, PAC, CHB	Heart Block
5	PVC, BR, TA, BI, SSS	Brady, Tachy, Bigeminy, PVC
6	N, PVC, TA	Normal, tachy, PVC
7	N, PVC, TA, BI, Q	Normal, PVC, Tachy, Bigeminy
8	N, WP, PVC, PAC, TA, FDHB	Normal, PVC, Tachy
9	N, PVC, Tachy	Normal, Tachy
10	N, WP, PAC, TA	Normal, Tachy
11	PAC, TA	Tachy
12	N, T	Normal, Tachy.
13	N	Normal
14	N, WP, PAC, BR	Normal, Brady
15	N, WP, BR	Normal, Brady
16	TA	Tachy
17	N, TA	Normal, Tachy
18	N, BR	Normal, Brady
19	N, TA	Normal, Tachy
20	N, BR	Normal, Brady
21	N, PVC, TA, BI	Normal, PVC, Tachy
22	N, PVC, TA	Normal, PVC, tachy
23	N	Normal
24	N, PVC, BR, TA	Normal, Brady, Tachy

4. Conclusions

An algorithm for the detection and interpretation of ECG arrhythmia was successfully developed and tested. The algorithm were tested for ECG data from MIT-BIH database and locally acquired ECG data files. Tests results indicate that the algorithm can help cardiologists in the diagnosis of various types of arrhythmia. This algorithm can be used to support diagnosis decisions made using other clinical tests and investigations.

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