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QRS Complex and T Wave Detection using STFT

Akash Kumar Bhoi[1*] , Karma Sonam Sherpa[1] and Bidita Khandelwal[2]

[1]Department of Electricaland Electronics Engineering, Sikkim Manipal Institute of Technology (SMIT), SMU, Gangtok - 737102, Sikkim, India; akash730@gmail.com, karmasherpa23@gmail.com
[2]Department General Medicine, Central Referral Hospital and SMIMS, SMU, Gangtok - 737102, Sikkim, India; drbidita@gmail.com

Abstract

Objective: Precisely localize QRS complex and T wave of Electrocardiogram (ECG). Severe cardiovascular abnormalities like Ventricular Arrhythmias, Ventricular Hypertrophy, and Myocardial Infarction may occur due to the ventricular tissue dysfunctioning. The morphological changes in QRS and T wave of ECG represent the depolarization and repolarization disturbances and analysis of these segments alone may lead to identifying certain acute cardiac condition. **Methodology:** Presented algorithm comprises of three stages; 1. Pre-processing of input ECG signal (High-pass filter and Kalman filter), 2. Elimination of P wave (Difference Operation Method and Wavelet Transform), 3. Detection of QRS and T wave using Short Term Fourier Transform (STFT). **Findings:** The algorithm efficiency is evaluated with standard MIT-BIH Arrhythmia database. The Sensitivity (Se) and the Specificity (Sp) for QRS complex is found to be 99.59% and 99.53%, whereas for T wave it is of 99.50% and 99.44% respectively. **Application/Scope:** This algorithm could be implemented in real-time ECG analyzer for possible detection of ventricular chronic heart disease and may reduce the risk of sudden cardiac death.

Keywords: MIT-BIH Arrhythmia Database, Pre-Processing, QRS Complex, STFT, T Wave

1. Introduction

A reliable real-time algorithm for QRS Complex detection was developed by efficiently identified the QRS Complexes by analyzing its slope, amplitude and width[1]. Various methods have already being discussed in recent past, based on spectral domain and nonlinear approaches to detect, estimate and analyze T Wave Alternant (TWA)[2-4]. Few other popular methods which were implemented for detection and analysis of ECG signals e.g. wavelet transform[5], quadratic spline wavelet[6,7], digital fractional order differentiation[8], singularity detector (multi-scale derivative)[9], hidden Markov model[10], support vector machine[11], improvised first-derivative squaring function and Hilbert transform[12]. It proposed deconvolution (time-frequency representation) methods for parameter estimation and bio-signals analysis[13]. Have presented arrhythmia detection approach by evaluating changes in Q-R-S duration[14].

STFT can be an immediate tool for detection of QRS complex and T wave[15] and also proposed this STFT for detection of QRS complex[16], but the problem lies in its strength only, which is precision in time-frequency analysis is not optimal. Moreover, these techniques are not tested over larger database and limited to STFT strength only. To overcome this problem we have adopted to include preprocessing (noise and baseline wander removal) and thresholding techniques.

2. Methodologies

Figure 1 shows the distinctive sections that are implemented to meet the whole objective of this research work. These independent objectives are addressed in the subsequent below subsections.

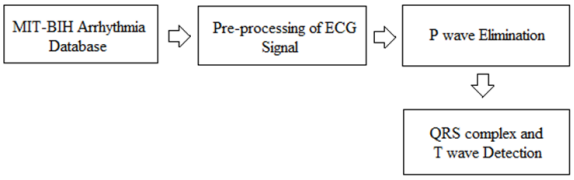

Figure 1. Block Diagram of Proposed Methodology.

* Author for correspondence

2.1 Baseline Drift and Noise Cancellations

The input ECG signal is passed through filtering process to eliminate baseline drift and noise components. The high pass filter[17] is implemented for baseline drift removal, where the specified parameters (keeping in mind the diagnostic frequency range of ECG) of this filter are: 2141 filter length, 0.1 dB maximum pass band ripple, 44.8 dB minimum stop band attenuation, 0.3 Hz stop band-edge frequency and 0.9 Hz pass band-edge frequency. The subsequent output from the high pass filter (i.e. baseline drift free) processed through Kalman–based filtration algorithm[18] for noise cancellation. Figure 2 shows the preprocessed input ECG signal after basleine drift and noise cancellations.

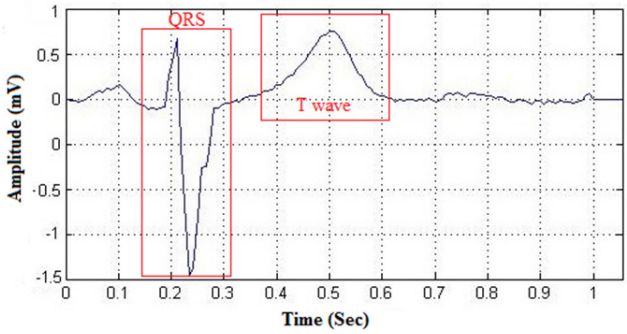

Figure 2. Preprocessed (Baseline Drift & Noise Eliminated) ECG Signal.

2.2 P Wave Elimination

At first R peak is detected using difference equation operation of the preprocessed ECG signal[19]. Normally the QRS complex duration is of 80-120 ms[20], so to locate P wave a search interval is performed. The search length was decided by assuming the Q inflection location 60 ms before the R peak (i.e. [R+60]+x, where x= 200 ms). This means that the search interval took place for 200ms from the onset of QRS complex (i.e. excluding first 60ms before the R peak). To locate the exact position of P wave, the onset and offset points of P wave also need to be localized, which can be of modulus maxima with opposite signs. Wavelet tarnsform[21] is applied with 2^3 scale to find out T max which lies between the zero crossing and same windowed search on left and right of T amx is applied to findout the onset and offset points. Once the P wave is localized, then this is segmented out from the non-stationary ECG waveform.

2.3 QRS Complex and T Wave Detection

The Short Time Fourier Transform (STFT) is thetechnique best suited for for non-stationary signal like ECG analysis. Implementaing STFT, the time doiman information of ECG signal is transformed into time-frequencydomain, which enhance the analysis part. This performs by considering ECG signal as a stationary signal of the defined window function for a short period of time. The

$$T(f,\tau) = \int_{-\infty}^{\infty} [u(t)w(t-\tau)]e^{-j2\pi ft}dt \qquad (1)$$

where, $u(t)$ is the ECG signal, $w(t-\tau) = window\ functio$,
$\tau = 2D\ function\ of\ time\ \&\ f = frequency$

Moreover, the STFT energy surface distribution (Spectrogram) is computed using follwing equation;

$$E(f,\tau) = |T(f,\tau)|^2$$

Here, rectangular window with 16 points width was choosen. The QRS complex and T wave requires high resolution in time, so different sacle with width was implemeted and finally 16 ponts narrow window width was selected for the operations. The contour plot Figure 3 shows the detected QRS and T waves.

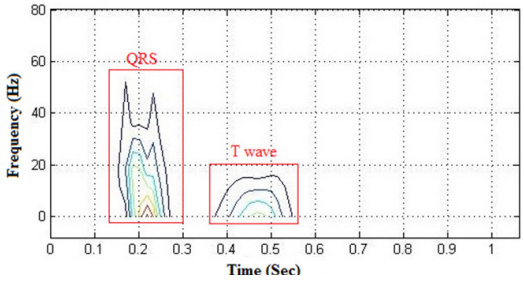

Figure 3. QRS and T wave detection using STFT

3. Result Analysis

1 hour tape of MIT-BIH Arrhythmia (MITDB)[22] is selected for the results evaluation and validation. ECG recordings from MITDB are of 360 Hz (sampling frequency) with 0.0027 sec (sampling interval).

The detection performance may also be concluded from the Failed Detection percentage (FD%), Sensitivity (Se) and the Specificity (Sp)[19] for both QRS complex and T wave. The Se and Sp for both QRS complex and Twave are calculated as follows [equation (1)–(4);

$$Se_{QRS} = \frac{TP}{TP + FN} \times 100 = \frac{4449}{4449 + 18} = 99.59\% \quad (1)$$

$$Sp_{QRS} = \frac{TP}{TP + FP} = \frac{4449}{4449 + 21} = 99.53\% \quad (2)$$

$$Se_T = \frac{TP}{TP + FN} \times 100 = \frac{4449}{4449 + 22} = 99.50\% \quad (3)$$

$$Sp_T = \frac{TP}{TP + FP} \times 100 = \frac{4449}{4449 + 25} = 99.44\% \quad (4)$$

4. Discussion

Failed Detected beats found in #105, #106, #108, #112, #114, #116, #121, #200, #201, #203, #208, #215, #222, #228 tape of MITDB, the details results are tabulated in Table 1. The over all FD% for QRS complex is found to be 0.87% and 1.05% for T wave. The detection performance for both QRS and T wave is indivisually calculated based on the True positive beats, False positive beats and False negative beats Table 1. The Sensitivity and the Specificity for QRS complex are found to be 99.59% and 99.53% respectively.

Table 1. Results of beats detections for the signals in MIT-BIH Arrhythmia database

Tape No.	Total Beats	QRS Complex Detection				T wave Detection			
		FP	FN	Total FD	% FD	FP	FN	Total FD	% FD
100	95	0	0	0	0	0	0	0	0
101	78	0	0	0	0	0	0	0	0
102	92	0	0	0	0	0	0	0	0
103	88	0	0	0	0	0	0	0	0
104	93	0	0	0	0	0	0	0	0
105	107	2	1	3	2.80	3	1	4	3.73
106	84	1	0	1	1.19	2	0	2	2.38
107	89	0	0	0	0	0	0	0	0
108	75	7	1	8	10.66	8	2	10	13.33
109	105	0	0	0	0	0	0	0	0
111	88	0	0	0	0	0	0	0	0
112	106	0	1	1	0.94	0	2	2	1.88
113	75	0	0	0	0	0	0	0	0
114	78	1	2	3	3.84	0	2	2	2.56
115	81	0	0	0	0	0	0	0	0
116	101	0	3	3	2.97	1	3	4	3.96
117	64	0	0	0	0	0	0	0	0
118	95	0	0	0	0	0	0	0	0
119	83	0	0	0	0	0	0	0	0
121	78	0	1	1	1.28	0	2	2	2.56
122	103	0	0	0	0	0	0	0	0
123	63	0	0	0	0	0	0	0	0
124	67	0	0	0	0	0	0	0	0
200	108	1	0	1	0.92	1	0	1	0.92
201	82	0	1	1	1.21	0	1	1	1.21
202	89	0	0	0	0	0	0	0	0
203	124	3	2	5	4.03	4	2	6	4.83
205	111	0	0	0	0	0	0	0	0
207	78	0	0	0	0	0	0	0	0
208	123	0	1	1	0.81	0	2	2	1.62
209	125	0	0	0	0	0	0	0	0
210	110	0	0	0	0	0	0	0	0
212	114	0	0	0	0	0	0	0	0
213	135	0	0	0	0	0	0	0	0
214	94	0	0	0	0	0	0	0	0
215	140	0	2	2	1.42	0	1	1	0.71
217	92	0	0	0	0	0	0	0	0
219	90	0	0	0	0	0	0	0	0
220	85	0	0	0	0	0	0	0	0
221	101	0	0	0	0	0	0	0	0
222	104	4	3	7	6.73	5	3	8	7.69
223	108	0	0	0	0	0	0	0	0
228	86	2	0	2	2.32	1	1	2	2.32
230	94	0	0	0	0	0	0	0	0
231	79	0	0	0	0	0	0	0	0
232	74	0	0	0	0	0	0	0	0
234	115	0	0	0	0	0	0	0	0
Total: 48 patients	**Σ4449**	**Σ21**	**Σ18**	**Σ39**	**0.87%**	**Σ25**	**Σ22**	**Σ27**	**1.05%**

*Note: FP = False Positive beats, FN = False Negative beats and Total FD= Total Failed Detection Beats.

The evaluated Sensitivity and the Specificity for T wave is 99.50% and 99.44% respectively. These findings shows better results as compared to earlier discussed techniques. STFT further explore the relationship between time and frequency content of the signal and any deviation or shift in any particular segments will be easily highlighted. Moreover, it helps in choosing the best methods fit for preprocessing of ECG signal, where any shifting in time-frequency distinguish clearly. However this method is distinguish from othersby introducing preprocessing techniques, P wave elimination and thresholding technique. This helps in incresing the Sensitivity and Specificity for QRS complex and T wave detctions.

5. Conclusions and Future Work

The earlier discussed and implemented methods are distinctively focoused on either QRS complex and T wave detection or analysis, where they conclude their findings. In this proposed approach, both QRS complex and T wave concurrently detected and explore the possiblity of futher investigation for precise and conclusive findings for such complex coronary heart diseases. The overall detection performance is found to be 99.5% or above in MITDB. Moreover, we have attempted real-time interfacing using NI ELVIS-II DAQ with Matlab R2013a for healthy subjects in our lab. 1000 samples data (ECG) are imported to workspace of Matlab and the algorithm efficiency was successfully evaluated. Our future work lies in real-time implementation of this algorithm and validation with larger datasets. This work may be furter extended by analyzing QRS complex and T wave both in time and frequency domains.

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