Development of QRS Detection using Short-time Fourier Transform based Technique

Nopadol Uchaipichat
Med-Intelligence and Innovation Lab,
Faculty of Engineering,
Thammasat University, Pathumthani, Thailand

Sakonthawat Inban
Med-Intelligence and Innovation Lab,
Faculty of Engineering,
Thammasat University, Pathumthani, Thailand

ABSTRACT
This paper reports our study in QRS complex detection. The short-time Fourier transform (STFT) was employed in ECG filtering stage. The narrow rectangular window was used to transform ECG signals into time-frequency domain. The temporal information at 45 Hz from spectrogram was analyzed for detecting QRS locations. The automated thresholding combined with local maxima finding method was modified to find the QRS location. The data used in this study is MIT-BIH Arrhythmia database. As the results, our proposed technique achieved the detection rate better than 99% and fail ratio was 1.3%.

Keywords
QRS detection, Electrocardiogram, Shot-time Fourier Transform

1. INTRODUCTION
Currently, the number of victims of sudden cardiac arrest increases every year. The electrocardiogram (ECG) represents electrical activities of heart that is generally used in contemporary medicine. The main morphology of ECG consists of P wave, QRS complex, and T wave for each cycle of cardiovascular. This information of ECG is very useful for cardiologist in diagnosis of abnormalities of the heart [1]. In the measurement of ECG, the signal sometimes includes some unwanted information such as power-line interference, ECG baseline wander, etc. These interferences may effect on the diagnostic. The finding of QRS complex is usually investigated for beat detection since the QRS complex is the dominant component of each normal ECG cycle. Therefore, several research groups have developed many methods to find the location of QRS complex. For instance Chen et al. combined discrete wavelet transform and adaptive thresholding method to detect QRS complexes [2]. Darrington proposed the fast method with minimal pre-process for real time QRS detection [3]. In addition to Mehta et al. applied support vector machine (SVM) and K-means algorithms to detection QRS complexes [4,5]. Therefore, in this study we have proposed novel technique to detect the QRS complex of ECG surface. The normal ECG recordings from MIT-BIH Arrhythmia database were studied in our investigation. The narrow window of short-time Fourier transform (STFT) was employed to remove unwanted information such as P wave, T wave and noises. The adaptive thresholding method was proposed to detect the QRS complex.

2. MATERIALS AND METOHODOLOGY
2.1 Data Study
The datasets used in this study were obtained from MIT-BIH Arrhythmia database available in *Physionet* website [6]. The data contain 48 half-hour ECG recordings obtained from 47 subjects. Each recording was collected at 360 Hz of sampling rate with 11-bit resolution over a 10 mV range. The dataset also includes annotation files evaluated from cardiologist for indicating the information of ECG traces. Most studied ECG signals are from modified limb lead II (MLII) except modified lead V5 was used for record 102 and 104. The dataset totally contains 116,137 beats.

2.2 ECG Filtering and QRS Complex Detection Method
This section describes our proposed technique to remove P wave and T wave. In this paper the short time Fourier transform (STFT) was applied in ECG processing. The STFT is the technique for non-stationary signal analysis that transforms signal information from time domain into time-frequency domain. The main concept of the STFT is to consider a non-stationary signal as a stationary signal over short periods of time within a window function [7,8]. The computation of STFT can be defined as equation (1).

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

where $w(t-\tau)$ is the window function. From equation (1) the STFT maps signal $x(t)$ into two-dimensional function in time, τ, and frequency, f. The energy surface distribution of STFT called spectrogram can be computed from equation (2)

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

The rectangular window was used in this study. The narrow window width of 16-point was used because the high resolution in time is required to detect QRS complex. Figure 1 shows the example of ECG time series and its corresponding STFT spectrogram. For this example the simulated noise was added into original ECG as defined in equation (3).

$$x_n(t) = x(t) + n(t) \qquad (3)$$

where *x(t)* presents original ECG signal and *n(t)* presents function of simulated noise. The adding noise contains both low and high frequency of interference. Equation (4) expresses the function of simulated noise which contains noise of 0.5 Hz and 50 Hz .

$$n(t) = 100\cos(\pi t) + 50\cos(100\pi t) \qquad (4)$$

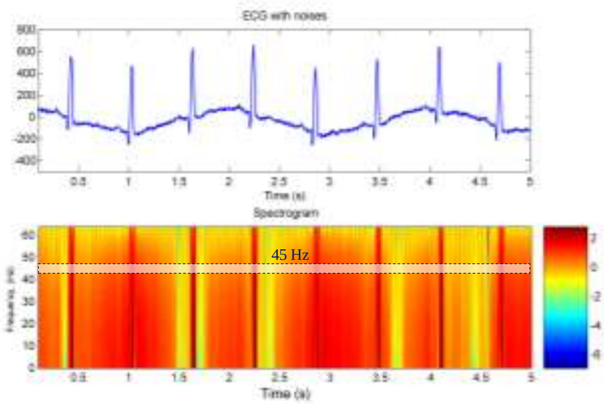

Figure 1. The STFT of example ECG

From spectrogram in figure 1, the highlighted box illustrates the temporal information at 45 Hz that was used for the finding of QRS location. The STFT temporal information at 45 Hz can be defined as equation (5).

$$E(\tau) = \log(E(45,\tau)) \qquad (5)$$

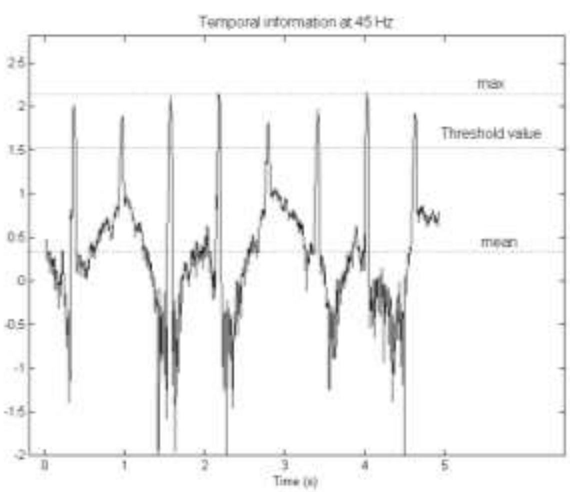

Figure 2. The temporal information of 45 Hz

Figure 2 shows the STFT temporal information of ECG at 45 HZ. In thresholding stage, the threshold value was determined by using simple adaptive thresholding method that can be defined as equation (6)

$$Th\_val = Mean + \frac{2}{3}(Max - Mean) \qquad (6)$$

where *Mean* and *Max* presents the average value and maximum value of *E(τ)* in equation (5) respectively. The thresholding condition can be described in equation (7). Figure 3 shows the result of thresholding stage.

$$E(\tau) = \begin{cases} E(\tau) & ; E(\tau) \geq Th\_val \\ Mean & ; E(\tau) < Th\_val \end{cases} \qquad (7)$$

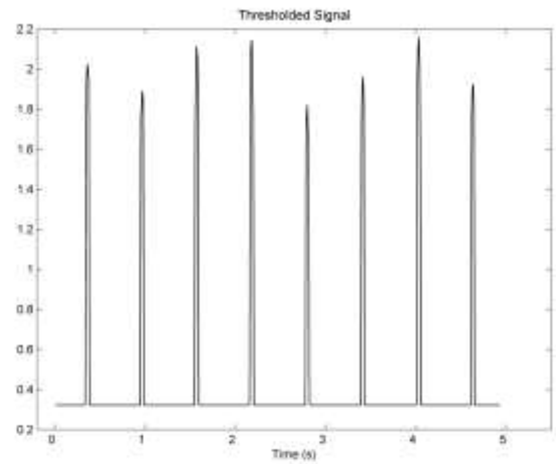

Figure 3. The thresholded information

The locations of QRS complexes were then evaluated from the position of local maxima. In this binarization stage the value of thresholded signal at position of local maxima were set to one and others were set to zero. The binary signal can be illustrated in figure 4. It can be seen that eight positions of QRS complexes were detected for this example. Comparing to ECG trace this method can detect the position of QRS complexes correctly.

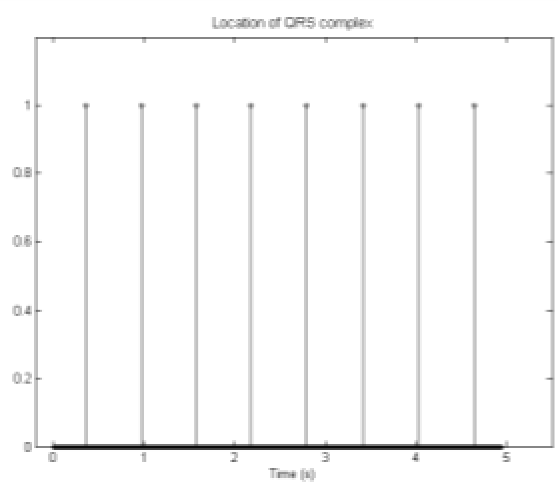

Figure 4. The signal after binarization stage

Table 1. The experimental results

File	Beats	TP	FP	FN	Sens	Spec	Fail Ratio
100	2273	2273	0	0	1.000	1.000	0.000
101	1865	1863	8	2	0.999	0.996	0.005
102	2187	2186	0	1	1.000	1.000	0.000
103	2084	2084	0	0	1.000	1.000	0.000
104	2229	2205	21	24	0.989	0.991	0.020
105	2572	2526	35	46	0.982	0.986	0.031
106	2027	2016	1	11	0.995	1.000	0.006
107	2137	2131	1	6	0.997	1.000	0.003
108	1763	1722	53	41	0.977	0.970	0.053
109	2532	2531	0	1	1.000	1.000	0.000
111	2124	2121	6	3	0.999	0.997	0.004
112	2539	2538	0	1	1.000	1.000	0.000
113	1795	1795	0	0	1.000	1.000	0.000
114	1880	1871	4	8	0.996	0.998	0.006
115	1953	1953	0	0	1.000	1.000	0.000
116	2412	2397	6	15	0.994	0.998	0.009
117	1535	1534	54	1	0.999	0.966	0.036
118	2278	2277	3	1	1.000	0.999	0.002
119	1987	1987	1	0	1.000	0.999	0.001
121	1863	1862	3	1	0.999	0.998	0.002
122	2476	2476	0	0	1.000	1.000	0.000
123	1518	1518	3	0	1.000	0.998	0.002
124	1619	1618	1	1	0.999	0.999	0.001
200	2601	2580	25	21	0.992	0.990	0.018
201	1963	1961	112	2	0.999	0.946	0.058
202	2136	2135	1	1	1.000	1.000	0.001
203	2980	2698	29	282	0.905	0.989	0.104
205	2656	1639	0	17	0.990	1.000	0.006
207	2344	2022	11	322	0.863	0.995	0.142
208	2955	2929	3	26	0.991	0.999	0.010
209	3005	3004	1	1	1.000	1.000	0.001
210	2650	2634	5	16	0.994	0.998	0.008
212	2748	2748	1	0	1.000	1.000	0.000
213	3251	3248	0	3	0.999	1.000	0.001
214	2262	2258	4	4	0.998	0.998	0.004
215	3363	3272	1	91	0.973	1.000	0.027
217	2208	2204	1	4	0.998	1.000	0.002
219	2154	2154	0	0	1.000	1.000	0.000
220	2048	2048	0	0	1.000	1.000	0.000
221	2427	2426	1	1	1.000	1.000	0.001
222	2483	2481	2	2	0.999	0.999	0.002
223	2605	2604	0	1	1.000	1.000	0.000
228	2056	1996	28	57	0.972	0.986	0.041
230	2256	2255	2	1	1.000	0.999	0.001
231	1571	1571	0	0	1.000	1.000	0.000
232	1780	1779	0	1	0.999	1.000	0.001
233	3079	3071	0	8	0.997	1.000	0.003
234	2753	2753	1	0	1.000	1.000	0.000
			Average		0.991	0.996	0.013

3. EXPERIMENTAL RESULTS

From our experiment, each position of QRS complex obtained from our proposed method was compared to the given annotation available in MIT-BIH Arrhythmia database. The accepted tolerance was set to 200 ms. The performance of QRS detection can be measured from sensitivity and specificity [3]. The sensitivity and specificity can be defined as equation (8) and (9) in respectively.

$$Sens = \frac{TP}{TP + FN} \quad (8)$$

$$Spec = \frac{TP}{TP + FP} \quad (9)$$

The true positive (TP) presents number of detected beats from actual beats. The false negative (FN) presents number of undetected beats from actual beats. The false positive (FP) presents number of detected beat from non beats. Table 1 presents our experimental results in QRS detection with 48 studied ECG files. The proposed technique achieved the performance in beat detection at 99.1% sensitivity and 99.6% specificity. There are 107,953 beats that can be detected from 109,982 actual beats. The number of wrong detection is 1,452 beats that equals to 1.3% of fail ratio.

Table 2. Comparison of results with other methods

	Sens	Spec	Detection rate	Fail Ratio
Proposed Method	99.10%	99.60%	99.10%	1.30%
Darrington [3]	99.00%	99.20%	99.00%	1.70%
Chen et al. [2]	99.55%	99.49%	99.49%	0.96%
Mehta et al. [4]	n/a	n/a	98.63%	n/a
Mehta et al. [5]	n/a	n/a	99.30%	n/a

4. DISCUSSION AND CONCLUSION

This paper proposed the STFT technique for beat detection. The temporal information at 45 Hz combined with adaptive thresholding method was employed for finding the R peak. The 48 cases with 109,982 beats were tested in our experiment. The result is comparable to other works which investigated the same topic. The comparison can be presented in table 2. It can be seen that the detection rate is general used to measure the detection performance. The detection rate can be determined from minimum value among sensitivity and specificity [2]. As the result the proposed method achieved detection rate at 99.10% that is nearly on par with other popular methods. However, the results done by Mehta et al were obtained from different database [4,5]. This paper shows that the STFT technique has potential to improve the performance in QRS complex detection. The advanced methods, such as artificial neural networks and fuzzy logic, are suggested to be employed in the stage of decision making. The limitation of this investigation is that time complexity has not been studied in this paper.

5. ACKOWLEDGEMENT
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