FREQUNCY BANDS EFFECTS ON QRS DETECTION

Mohamed Elgendi, Mirjam Jonkman,and Friso DeBoer
School of Enigneering and Information Technology,
Charles Darwin University,Australia
mohamed.elgendi@cdu.edu.au, mirjam.jonkamn@cdu.edu.au, friso.deboer@cdu.edu.au

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Abstract: In this paper, we investigate the QRS frequency bands in ECG signals. Any QRS detection algorithm accuracy depends on the frequency range of ECG being processed. The QRS complex has different morphology and frequency band for different arrhythmias and noises in ECG signals. A standard bandpass range that maximizes the signal (QRS complex)-to-noise (T-waves, 60 Hz, EMG, etc.) ratio will be useful in ECG monitoring and diagnostic tools. A sensitive QRS detection algorithm has been introduced to compare the performance of using different frequency bands. The results shows that the recommended bandpass frequency range for detecting QRS complexes is 8-20Hz which the best signal-to-noise ratio.

1 INTRODUCTION

The electrocardiogram (ECG) is a graphical representation of the electrical activity of the heart. ECG signals are obtained by connecting specially designed electrodes to the surface of the body. It has been in use as a non-invasive cardiac diagnostic tool for over a century. The QRS complex is the dominant feature of the ECG signal. QRS detection is vitally important in many clinical instruments such as simple cardio-tachometers, arrhythmia monitors, and implantable pacemakers. Therefore, reliable detection of the QRS complex remains an important area of research. The problem is complex in that the morphologies of many normal as well as abnormal QRS complexes differ widely.

The ECG signal is often corrupted by noise from many sources: 50/60 Hz from power line interference, EMG from muscles, motion artefacts and changes in the electrode-skin interface. Moreover, large and wide P- and T-waves can act as sources of interference when detecting the QRS complexes.

Band pass filtering is an essential first step of nearly all QRS detection algorithms. The purpose of band pass filtering is to remove the baseline wander and high frequencies which do not contribute to QRS complexes detection. In this research we investigate which pass bands are optimal for QRS detection.

In literature, the QRS frequency band has been used without actually identifying the optimum QRS frequency range for the detection of the QRS complexes.

Thakor et al. (1983) proposed an estimate of QRS complex spectra and suggested that the passband which maximizes the QRS energy is approximately 5-15 Hz. Pan and Tompkins (1985) used cascaded the low-pass and high-pass filters to achieve a 3 dB passband from about 5-11 Hz, Cuiwei et al., (1995) used a quadratic spline wavelet with compact support and one vanishing moment. Their conclusion was that most of the QRS complex energies are at the scales of 2^3 and 2^4. This corresponds to a frequency range between 8 and 58.5Hz. Sahambi et al. (1997) used the first derivative of a Gaussian smoothing wavelet and found that the most of the QRS complex energies are at the scales of 2^3 and 2^4. They claim that most of the energy of the QRS complex lies between 3 Hz and 40 Hz. Benitez et al. (2000) developed a QRS detection algorithm using the properties of the Hilbert transform with band stop frequencies at 8 and 20 Hz in order to remove muscular noise and maximize the QRS complex respectively, Moraes et al. (2002) combined two improved QRS detectors using band pass filter between 9 and 30Hz. Chen and Chen (2003) introduced a QRS detection algorithm based on real-time moving averaging and assume the QRS frequencies are concentrated at approximately 5-15 Hz. Mahmoodabadi et al. (2005) used Daubechies2 to detect QRS complex using scales of 2^3-2^5 which is in the frequency range between 2-40Hz. Most of these authors evaluated their algorithms using the MIT-BIH database.

Using the QRS detection algorithm described below, we compare various frequency pass bands to identify the appropriate frequencies that maximizes the QRS complex compared to the other ECG features (P and T waves) and to noise (60 Hz, EMG, motion artefacts).

2 DATA

Fourty eight ECG records from the MIT-BIH Arrhythmia database (Moody and Mark, 1990) were used to test the algorithm. These 30-minutes recordings were sampled at 360 Hz with a 11-bit rate resolution over a 10 mV range. Lead I from each record is used here. No episodes have been excluded from our analysis.

The MIT-BIH Arrhythmia database is preferable to other ECG databases for two reasons:

- The MIT-BIH database contains 30-minutes recordings for each patient which is considerably longer than the records in other databases. The CSE database for example contains 10-seconds recordings only(J.L. Willems, 1988)
- The MIT-BIH Arrhythmia database contains records of normal ECG signals as well as records of ECG signals that are affected by non-stationary effects, low signal-to-noise ratio, premature atrial complexes, premature ventricular complexes, left bundle blocks, and right bundle blocks. This provides the opportunity to test the robustness of the QRS wave detection method.

3 METHODOLOGY

To compare different frequencies bands that have been described in literature, for the QRS detection band pass filter, a sensitive QRS detection algorithm is needed. The algorithm proposed here consists of three main stages: bandpass filtering, generating potential blocks and thresholding.

3.1 Bandpass Filter

Band pass filtering is the first stage of any QRS detection algorithm. As shown in Table. 1, different frequency bands have been described in literature to detect the QRS complex. We investigate here the optimal frequency bands for accurate QRS detection in the time-domain. A second order Butterworth filter with selected pass bands, shown in Table 1, is used.

$$s[n] = Butterworth(ECG[n])$$

3.2 Generate Potential Blocks

We demarcate the onset and offset of the potential QRS waves in the ECG signals by using two moving averages, based on the normal duration of the QRS interval which for a healthy adult is 100±20ms (Gari D. Clifford, 2006).

Table 1: Proposed frequency bands for the detection of QRS complexes

Proposed frequency bands in literature	**Frequency Band**
(Thakor et al., 1983.) and (Chen and Chen, 2003)	5-15Hz
(Pan and Tompkins, 1985)	5-11Hz
(Cuiwei et al., 1995)	8-58.5Hz
(Sahambi et al., 1997)	3-40Hz
(Benitez et al., 2000)	8-20Hz
(Moraes et al., 2002)	9-30Hz
(Mahmoodabadi et al., 2005)	2-40Hz

For a sampling frequency of 360 Hz, the maximum window size corresponding to the QRS interval is approximately 44 points and the maximum window size corresponding to every beat interval is approximately 231 points. The two moving averages to detect the R waves are:

First moving-window integration: the first moving window integration used to capture the QRS area.

Moreover, the first moving window integration used as a threshold for the output of the second moving-window integration, calculated as follows:

$$MA_{QRS}[n] = \frac{1}{W_1}(y[n-(W_1-1)] + y[n-(W_1-2)] + ... + y[n])$$

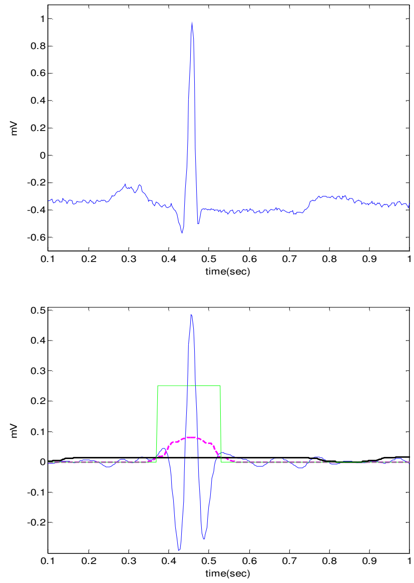

Figure 1: Demonstrating the effectiveness of using two moving averages to detect QRS complex (a) filtered one beat ECG signal with Butterworth bandpass filter (b) generating blocks of interest after using two moving averages: the dotted line is the first moving average and the solid line is the second moving average (c) the detected R peak after applying the thresholds.

where $W_1 = 44$ which is the window width of QRS segment. This is shown as the dotted line in Fig. 1(b).

Second Moving-window Integration: The purpose of the second moving window Integration, shown as the solid line in Fig. 1(b), is to capture a complete beat.

$$MA_{Beat}[n] = \frac{1}{W_2}(y[n-(W_2-1)] + y[n-(W_2-2)] + ... + y[n])$$

where $W_2 = 231$ is the window width of a complete heart beat.

When the amplitude of the first moving average filter (MA_{QRS}) is greater than the amplitude of the second moving average filter (MA_{Beat}), that part of the signal is selected as a block of interest, as follows:

IF $MA_{QRS}[n] > MA_{Beat}[n]$ **THEN**
$BLOCKS[n] = 1$
ELSE
$BLOCKS[n] = 0$
END

Fig. 1(b) shows an overview of the result of applying the two moving averages.

We show one QRS interval in Fig. 1 to demonstrate the idea of using two filters to generate blocks of interest. Not all of the blocks are potential QRS complex. Some block are caused by noise and need to be eliminated.

3.2.1 Thresholding

The expected size for the QRS interval is based on the statistics for healthy adults, as described above.

We reject blocks that are smaller than the expected width of the QRS complex. This corresponds to:

$$width(BLOCKS) < 44$$

The rejected blocks are considered as noisy blocks and the accepted blocks are considered to be containing R wave.

The maximum absolute value within each accepted block is considered to be the R peak.

Table 2: QRS detection results for different frequency bands

Tested frequency bands	SE	+P
5-15Hz	97.00%	99.87%
5-11Hz	95.93%	99.81%
8-58.5Hz	97.61%	99.92%
3-40Hz	92.66%	99.87%
8-20Hz	98.31%	99.92%
9-30Hz	97.73%	99.92%
2-40Hz	93.91%	99.80%

Table 2 shows the QRS detection results with different frequency bands. The frequency range that optimizes QRS detection is 8-20Hz, first proposed by Benitez et al (2000). The QRS detection results of 48 records using this particular frequency band are shown in Table. 3

4 CONCLUSIONS

We compared different frequency bands that have been proposed in literature for band pass filtering in order to detect the QRS complex.

Table 3: QRS detection results for a 8-20Hz band pass filter

Record	No of beats	TP	FP	FN	SE	+P
100	**2273**	2272	1	0	100.00%	99.96%
101	**1865**	1864	1	4	99.79%	99.95%
102	**2187**	2187	0	0	100.00%	100.00%
103	**2084**	2084	0	0	100.00%	100.00%
104	**2229**	2226	3	9	99.60%	99.87%
105	**2572**	2564	8	22	99.15%	99.69%
106	**2027**	2027	0	61	97.08%	100.00%
107	**2136**	2136	0	0	100.00%	100.00%
108	**1763**	1761	2	109	94.17%	99.89%
109	**2532**	2532	0	0	100.00%	100.00%
111	**2124**	2124	0	1	99.95%	100.00%
112	**2539**	2539	0	0	100.00%	100.00%
113	**1795**	1794	1	49	97.34%	99.94%
114	**1879**	1879	0	53	97.26%	100.00%
115	**1953**	1952	1	1	99.95%	99.95%
116	**2412**	2406	6	1	99.96%	99.75%
117	**1535**	1535	0	1	99.93%	100.00%
118	**2278**	2278	0	5	99.78%	100.00%
119	**1987**	1987	0	7	99.65%	100.00%
121	**1863**	1863	0	3	99.84%	100.00%
122	**2476**	2476	0	0	100.00%	100.00%
123	**1518**	1518	0	5	99.67%	100.00%
124	**1619**	1619	0	15	99.08%	100.00%
200	**2601**	2601	0	42	98.41%	100.00%
201	**1963**	1963	0	86	95.80%	100.00%
202	**2136**	2134	2	15	99.30%	99.91%
203	**2980**	2936	44	36	98.79%	98.52%
205	**2656**	2654	2	0	100.00%	99.92%
207	**1860**	1860	0	61	96.82%	100.00%
208	**2955**	2954	2	3	99.90%	99.93%
209	**3005**	3005	0	0	100.00%	100.00%
210	**2650**	2633	17	5	99.81%	99.36%
212	**2748**	2748	0	0	100.00%	100.00%
213	**3251**	3250	1	0	100.00%	99.97%
214	**2262**	2262	0	10	99.56%	100.00%
215	**3363**	3362	1	0	100.00%	99.97%
217	**2208**	2207	1	1	99.95%	99.95%
219	**2154**	2154	0	31	98.58%	100.00%
220	**2048**	2047	1	0	100.00%	99.95%
221	**2427**	2427	0	50	97.98%	100.00%
222	**2483**	2481	2	47	98.14%	99.92%
223	**2605**	2605	0	0	100.00%	100.00%
228	**2053**	2053	0	101	95.31%	100.00%
230	**2256**	2256	0	0	100.00%	100.00%
231	**1571**	1571	0	432	78.43%	100.00%
232	**1780**	1780	0	449	79.86%	100.00%
233	**3079**	3078	1	0	100.00%	99.97%
234	**2753**	2753	0	0	100.00%	100.00%
	109493	109397	97	1715	98.31%	99.92%

The results show that the accuracy of QRS detection is affected by the selected frequency band. The QRS detection algorithm was applied to ECG signals that suffer from a) non-stationary effects, b) low signal-to-noise ratio, c) atrial premature complexes d) ventricular premature complexes, e) left bundle blocks, and f) right bundle blocks. Analysis of 109493 QRS complexes in 48 records of MIT-BIH arrhythmia database shows that the optimal QRS frequency band is 8-20Hz. It is an optimal band pass filter for QRS detection and it should be useful in the design of cardio-tachometers, arrhythmia monitors, and implantable pacemakers.

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