OPTIMAL FREQUENCY AND BANDWIDTH FOR FIR BANDPASS FILTER FOR QRS DETECTION

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Abstract: The MIT-BIH arrhythmia database (48 ECG records of 30 min each) was used to find out, experimentally, which combination of centre frequency and bandwidth is 'optimal' for a pre-emphasis digital Finite Impulse Response (FIR) band-pass filter for QRS detection. An exhaustive search was performed for centre frequencies ranging from 13 to 20 Hz and for bandwidths from 5 to 12 Hz, at integer values of 1 Hz for both. The criterion for optimality was simply the filter that, coupled with a simple threshold detector, produced the minimum number of errors (defined as the sum of false-positives and false-negatives). For the whole MIT-BIH database the 'optimum' point was found to be that where centre frequency, f_c=19 Hz and bandwidth, BW=9 Hz.

Keywords: QRS detection, optimal frequency, pre-emphasis QRS filter, FIR filter.

INTRODUCTION

The accurate detection of QRS complexes from both normal and arrhythmic beats is an important part of any ECG analysis system. Noise is one of the main causes of problems in detection [3] and can arise from EMG interference, power supply 'hum', movement saturations, baseline wandering and artificial pacemakers. In this work the P, T and U waves are also seen as noise.

Often the first stage in QRS detection uses a band-pass filter to reduce noise [1, 2]. The centre frequency and bandwidth are chosen to obtain the maximum signal to noise ratio and, together with the shape of the filter, determine how well the noise is eliminated. Differences which occur when detecting arrhythmic beats in comparison with normal beats and clean signals or noisy records must also be taken in to account.

In this work we use 64 combinations of centre frequency and bandwidth for the digital FIR band-pass filter. This was coupled with a simple QRS detector, to test performance in recognising QRS complexes contained in the ECG signals in the MIT-BIH database [4]. The use of an annotated database allows the objective evaluation of the system of filter and detector: We know both the number and the time position of all QRS complexes, therefore both false negative and false positive detection errors can be counted. The combination of centre frequency and bandwidth found to give the lowest errors (FP+FN) for the database overall is deemed to be optimal. The results are compared with the seminal works of Thakor, Webster, Pan and Tompkins [5, 7, 8] who suggested a centre frequency of 17Hz and quality factor of Q=5, implying a bandwidth of 3.4 Hz, as optimal.

METHODS

To allow the optimal combination of centre frequency and bandwidth for the filter to be found, 64 combinations of these two parameters were tested. The optimal centre frequency, fc of the filter is known to lie between 6.25 Hz and 25 Hz. The lower boundary comes from considering the candidate QRS complex to be a monophasic wave i.e. a half cycle with a width of 80ms; the upper boundary by considering it to be a tri-phasic wave with a 60ms width. It was decided to search the 'optimum' point over a range of fc from 13 to 20 Hz and of bandwidths BW from 5 to 12 Hz. For incremental steps of 1 Hz this results in the 64 above-mentioned combinations of centre frequency and bandwidth. The decision to implement a symmetrical FIR filter was mainly due to the flat group delay and the resulting stability of fiducial points derived from the filtered signals. The choice of 60 coefficients for the FIR filter and the Hamming window used in its design was arbitrary. A simple detector was then implemented; this was purposely chosen not to be sophisticated since it is the pre-emphasis filter being investigated and not the detector. A classical detector which consisted of the digital FIR filter followed by an adaptive threshold detector was used, which accepted those samples whose magnitude was bigger than the threshold, as a QRS and then ignored subsequent data for a 160 ms refractory period, before continuing the search. This rather short refractory period was chosen to ensure that very few false negatives occurred and is shorter than the 208 ms suggested by Poli et al. [6].

The MIT-BIH database was used because it is annotated, allowing the evaluation of the performance of the pre-emphasis filter and detector for each of the 64 filters. The database contains signals with both normal and arrhythmic beats and both clean and noisy records, which allowed the usability of the filter in this wide range of circumstances to be found. Only channel 1 of the database was used. The error for each filter was the total number of false positives and false negatives (FP+FN); the error for each signal using that particular filter was then summed to give the overall error for the whole database. The whole simulation (64 situations for the 48 signal records) was run on an 800 MHz Pentium-based microcomputer under Windows 2000 programmed in Microsoft C++ and took 46 hours.

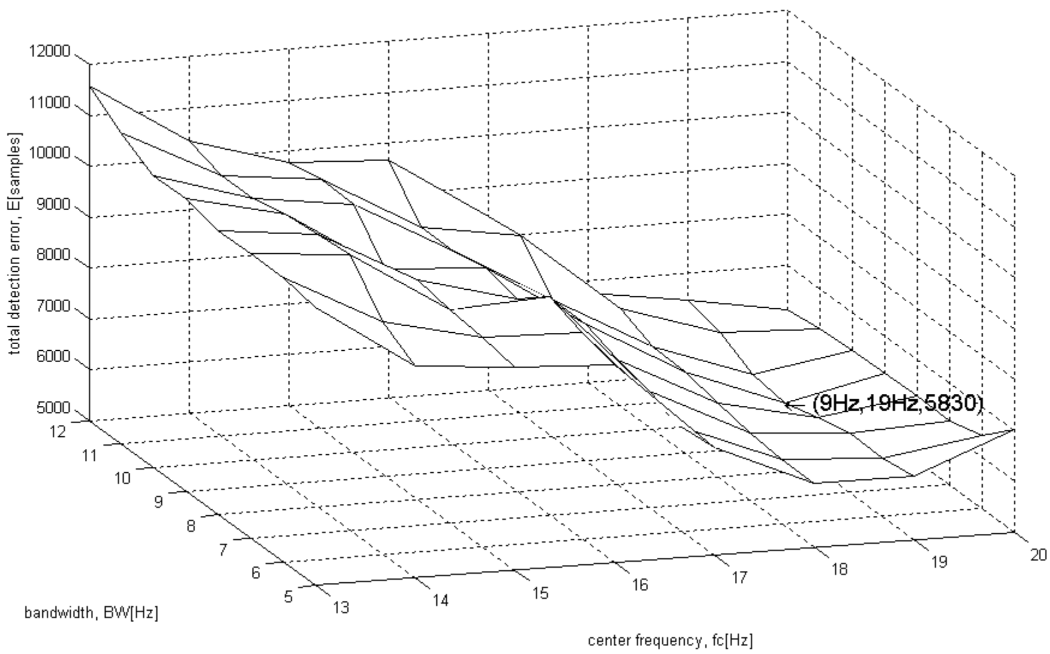

Fig. 1: 3-D surface plot of total detection error against fc and bandwidth BW. The whole MIT-BIH database was used here, with its mixture of both normal ECG traces and ECG with arrhythmias.

RESULTS

Figure 1 and table 1 show the optimal centre frequency and bandwidth for the pre-emphasis filter to be 19Hz and 9Hz respectively and that the sensitivity to fc is higher than to the bandwidth BW. Figure 2 shows the result for selected frames with almost exclusively normal QRS complexes.

E total *vs.* BW/fc	fc: 13	14	15	16	17	18	19	20
BW: 5	10481	9174	9003	8898	7117	6263	6252	7013
6	10588	9587	9113	9069	7058	6255	6141	6425
7	10605	10425	9209	9301	7284	6331	6171	6266
8	10598	10362	9314	8800	7435	6436	6004	6281
9	10772	10298	9073	8949	7676	6604	5830	6276
10	10743	10140	9874	8816	7693	6617	5931	6242
11	11118	10142	9907	8822	8511	6924	6295	6215
12	11586	10343	9778	9662	8412	6753	6456	6117

Table 1: Total detection error E (false positives + false negatives), for centre frequency fc and bandwidth BW, both in Hz. Whole MIT-BIH database used, with a mixture of both normal ECG traces and ECG with arrhythmias.

E total *vs.* BW/fc	fc: 13	14	15	16	17	18	19	20
BW: 5	22	12	13	13	35	39	95	32
6	29	14	11	16	34	39	56	34
7	29	13	10	15	32	35	39	25
8	37	17	11	13	32	35	39	25
9	52	20	12	13	13	34	37	21
10	65	29	14	10	12	33	36	22
11	90	34	19	10	10	32	35	34
12	144	34	20	11	12	12	34	38

Table 2: Total detection error **E** (false positives + false negatives), for centre frequency fc and bandwidth BW, for selected ECG records with very few arrhythmias (Records: MIT100, 112, 113, 115, 117, 121, 122, 209, 220).

DISCUSSION

The optimal centre frequency found here is comparable with that used by Thakor et al. [8]; the bandwidth, though, is wider. This is due to the different kinds of signals tested: the ECG records that we used included more arrhythmic beats, and these have a wider base than normal QRS complexes, thus requiring a higher bandwidth for the filter. The results are also comparable with our choices, about 20 years ago, in Lima et al. [9] and Pereira et al. [10], although at that stage, of course we hadn't done such a complete experimental, statistical search for the optimal parameters.

Signals containing mainly normal beats (records 100, 112, 113, 117, 121, 122, 209 and 220 of MIT-BIH database) were also looked at separately and here it was found, somewhat surprisingly, that a lower centre frequency of 17 Hz coupled with a bandwidth of 11 Hz gave the optimum pre-emphasis filter design. This unexpected decrease in centre frequency is possibly explained by the fact that signals of patients with paced beats were included in the N=48 cohort.

Of course the detector used for this study is rather crude since the intention was to measure the performance of the pre-emphasis filter, not of the detector. We have implemented sophisticated real-time QRS detectors that deal with both normal ECG records and also ECG signals containing various arrhythmias (training the system on half of the MIT-BIH database and evaluating it on the other half), first using one single channel of ECG signal [9], and later using the two available ECG channels from the MIT-BIH database [10], achieving sensitivities of 99.58% and 99.73% respectively. These (which, at the time were implemented on a Z80-based, 3 MHz microcomputer and using FIR filters with integer coefficients for speed), still compare quite well with much more recent research results, such as those by Martínez et al. [11], who used a wavelet-based detector and delineator and achieved a sensitivity of 99.66%.

CONCLUSIONS

In this work the pre-processing aspect of the QRS detector, specifically the optimal centre frequency and bandwidth of the band-pass filter were looked at. For a variety of signals including more than 108000 QRS complexes and containing both arrhythmic and normal QRS complexes, as well as noisy signals, a centre frequency of 19 Hz and bandwidth of 9 Hz were found to be optimal for the pre-emphasis FIR filter. For the detection of mainly normal beats a centre frequency around 16-17 Hz and bandwidth of between 9 and 12 Hz are recommended.

This study provides an initial guide (with a wide base of experimental evidence) for the choice of the 2 main parameters of band-pass filters to be used as pre-processors for QRS detection for both normal and arrhythmic beats.

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