FILTER BANK-BASED QRS COMPLEX DETECTORS

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ABSTRACT

Detectors of the QRS complexes in electrocardiogram (ECG) signal are used in cardiology for many years. According to the relatively massive usage of the filter banks in digital signal processing during last years, mainly to implement of wavelet transform to compression and filtering one-dimensional or image data, new algorithms have been started written to realize more robust QRS detectors based on transforms which are implemented by various filter banks. This paper shows possible design of off-line QRS detector (inspired by [1]) and its performance.

1 INTRODUCTION

It is not easy to reliably detect QRS complexes or R waves in an ECG signal due to its nonstationary character. ECG signal has a time-varying morphology, it is subject to physiological/pathological variations due to the patient and it is corrupted due to many kind of noise such as transient variations and wandering of baseline due to poor contact of ECG electrodes and patient movement, high-frequency interference due to muscle contractions or amplitude modulation of ECG signal due to respiration [2]. Detection of the QRS complexes could be degraded by possible similarity of P or T waves to R waves [3]. QRS detector must be equally robust to these noises.

Most of the current QRS detectors are based on bandpass filtering to reduce the noise and differentiation or powering signal to emphasize R waves. Then the ECG signal is searched for R peaks. However, these techniques don't respect time-varying morphology of ECG signal and fixed bandpass filters are designed as compromise between noise reduction and loss of higher-frequency details in signal [3]. In this paper are briefly described QRS detectors which can reduce mentioned disadvantages. Strictly speaking, QRS detectors based on dyadic redundant wavelet transform (DyWT) were designed. Also two another types were designed derived from them.

DyWT can be realized by filter bank containing a set of analysis filters which decompose the bandwidth of the input signal into subband signals with uniform frequency bands.

2 PRINCIPLES OF DESIGNED QRS DETECTORS

2.1 DETECTOR *WT*

Fundamental detector, named as *WT*, is based on redundant DyWT which can be realized by nodes of decomposition tree structure (1,0), (1,1), (2,0), (2,1) etc. with outputs (1,1), (2,1), (3,1) etc. (see fig. 1) where top branches represent the filters with $H_h(z^n)$ and bottom branches represent the filters with $H_d(z^n)$; $n = 2^{level-1}$ where the first pair ($H_h(z^1)$, $H_d(z^1)$) are original octave band filters – lowpass and highpass.

So these filters represent daughter wavelets derived from chosen mother wavelet by changing time scale. Therefore, outputs of DyWT are obtained as convolution original signal and dyadically time-scaled daughter wavelet [4, 5].

In relation to bandwidth of the QRS complexes and sampling frequency of the original ECG signal 500 Hz, the detector operates in bandwidth of 3^{rd} – 7^{th} level. Its outputs correspond to nodes (3,1), (4,1), (5,1), (6,1), (7,1) in this sequence, (see fig. 1).

2.2 DETECTOR *PT*

Derived detector, named as *PT*, is based on the similar principle like detector *WT*, but its outputs are given by nodes (4,1), (5,1), (5,3), (6,1), (6,3). We can regard to this detector as realization of non-uniform packet transform. According to gradual decreasing of R waves in particular outputs, has been processing sequence of outputs chosen (4,1), (5,3), (5,1), (6,3), (6,1), (see fig. 1).

Example of decomposed ECG signal with QRS detections is shown on figure 2.

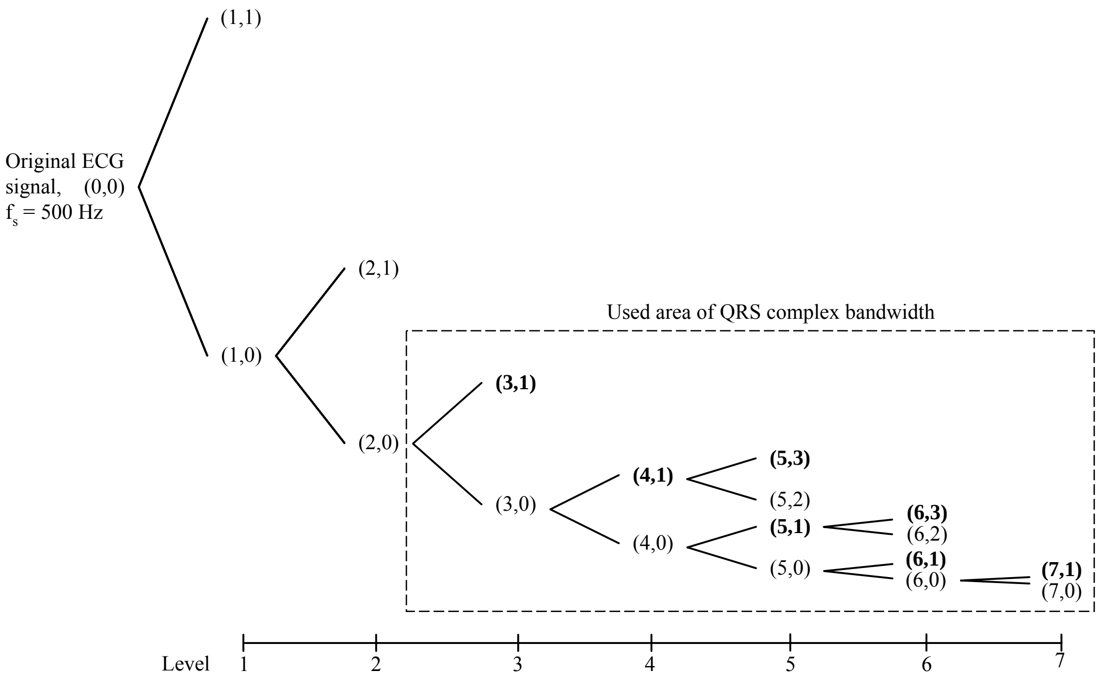

Fig. 1: *Decomposition tree structure of the used filter banks.*

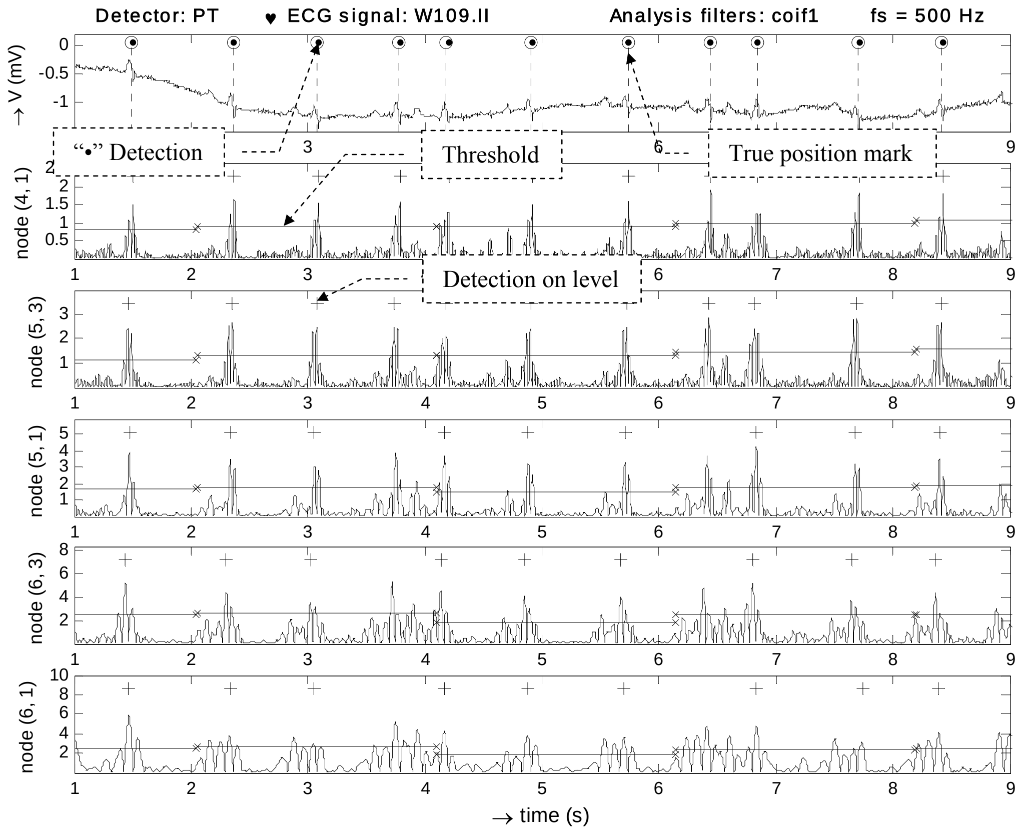

Fig. 2: *Example of successful QRS detection.*

2.3 DETECTOR *3S*

Both detectors *WT* and *PT* operate with ECG lead II, but third designed QRS detector, named as *3s*, derived from detector *PT*, operates with three ECG leads – II, V2, V6. The final determining of QRS positions depends on the particular ECG leads. It is compared reciprocal positions of QRS complexes in lead II with V2, II with V6, V2 with II and V2 with V6.

3 QRS DETECTION

As we can deduce from above, detector *WT* operates at bandwidth cca [3.9, 125.0] Hz. Detectors *PT* and *3s* operate at bandwidth cca [7.8, 62.5] Hz and frequency distances of their outputs are smaller.

Input ECG signal is analyzed into five outputs which are converted to absolute values and split into 2.048 s blocks (1024 samples). So all next processing is executed with absolute values and in these blocks.

Then threshold values are computed by

$$\frac{\sum_{n=1}^{N} output(n)}{N}\left(p - q \cdot u\right) \tag{1}$$

in each output where *output(n)* are the absolute values of samples of particular output level, N is length of the block, *u* represents sequence number of the outputs (1 – 5), and *p,q* are constants for particular type of analysis filters (adjusted within testing).

Local thresholded maxima are determined in several outputs and then possible QRS complex positions are determined with regard to refractory interval (minimal possible value of RR interval) and maximal possible width of QRS complex. Chosen values are:

Refractory interval = 200 ms; maximal width of QRS complex = 160 ms.

The final determining of QRS positions, inspired by [1], is based on comparison of a number of possible QRS complexes across consecutive outputs. If the first and second output contains the same number of possible QRS complexes in a block, the QRS positions in the first output are declared as resultant QRS positions. But if the condition is not satisfied, second and third outputs are compared etc.

4 IMPLEMENTATION

The filter bank-based detection algorithms were implemented using Matlab programming language. Analysis filters were derived from mother wavelets in Matlab.

The most successful filters (named as mother wavelets) were chosen: *bior2.4*, *coif1*, *db3*, *sym5* [5].

5 PERFORMANCE TESTS

Testing was performed on CSE database which contains normal and abnormal 125 rest records and 5 exercise records.

If position of detected QRS complex is not within ±80 ms (±40 samples) neighborhood of true QRS position, the detection is marked as failed. It means that spacing of detected QRS complex from true QRS complex greater than ±40 samples causes false positive and false negative detection.

Two parameters are used to check detectors performance. The sensitivity and positive predictivity of the detection algorithms are computed by

$$Se = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FN}} \quad (\%) \tag{2}$$

$$+P = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FP}} \quad (\%) \tag{3}$$

where TP is the number of true positives, FN the number of false negatives, and FP the number of false positives [3]. The sensitivity reports the percentage of true QRS complexes that were correctly detected. The positive predictivity reports the percentage of detected QRS complexes which were in reality true QRS complexes.

Total error rate is computed by

$$error = \frac{\mathrm{FN} + \mathrm{FP}}{\mathrm{TP}} \cdot 100 \quad (\%)\,. \tag{4}$$

6 RESULTS

The most successful detection (see Tab. 1) was obtained by detector *3s* using analysis filters *coif1*. FN was registered due to overly disturbed – featureless R wave of the QRS complex in ECG lead V2. FP represents false detection at the end of the ECG record where R wave is beginning and threshold was exceeded in lead II, V6.

filters	detector	TP	FN	FP	*Se* (%)	+*P* (%)	*error* (%)
coif1	*3s*	1502	1	1	99.93	99.93	0.133
coif1	*PT*	1712	3	0	99.83	100.0	0.175
bior2.4	*PT*	1712	4	1	99.77	99.94	0.292
bior2.4	*3s*	1502	4	2	99.73	99.87	0.399
sym5	*PT*	1712	6	1	99.65	99.94	0.409
db3	*WT*	1712	2	6	99.88	99.65	0.467

Tab. 1: *Detection performance on CSE database*

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REFERENCES

[1] Kadambe, S. et al.: Wavelet transform-based QRS complex detector. IEEE Trans., BME, July 1999, vol. 46, no. 7, pp. 838–847

[2] Friesen, G. M. et al.: A comparison of the noise sensitivity of nine QRS detection algorithms. IEEE Trans., BME, 1990, vol. 37, no. 1, pp. 85–89

[3] Afonso, V. X. et al.: ECG beat detection using filter bank. IEEE Trans., BME, February 1999, vol. 46, no. 2

[4] Kozumplík, J.: Nové algoritmy zpracování signálů, Lessons, FEKT - VUT v Brně, ÚBMI, URL: < http://www.dbme.feec.vutbr.cz/ubmi/courses/AZS>

[5] Misiti, M. et al.: Wavelet toolbox for use with Matlab. User's guide ver. 2, MathWorks, 2002