Efficient and Fast ECG Baseline Wander Reduction without Distortion of Important Clinical Information

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Abstract

Baseline wander makes manual and automatic analysis of ECG records difficult, especially the measuring of ST-segment deviation. Since the spectrum of baseline wander and low frequency component of ECG signal usually overlaps, removing of baseline wander can cause distortion of important clinical information, particularly ST-segment distortion. The use of digital linear phase high-pass filter minimizes this undesirable effect, but it requires large computational complexity. A multirate architecture with linear phase low-pass filter working at low sampling rate is presented for removal of the baseline wander. Design tradeoff between transition band width and filter delay was considered. We determined the optimal decimation factor with respect to complexity and filter delay. For testing and assessment of behavior of baseline filter we used test signals, normal and wide QRS complexes with different heat rate.

1. Introduction

Baseline wander can be caused by respiration, electrode impedance change and body movements. Baseline wander makes manual and automatic analysis of ECG records difficult, especially the measuring of ST-segment deviation, which is used for diagnostic ischemia. Since the spectrum of baseline wander and low frequency component of ECG signal usually overlaps, removing of baseline wander can cause distortion of important clinical information, particularly ST-segment distortion. There are two main approaches used for eliminating the baseline wander. The first method uses cubic spline fitting for estimating the baseline drift [1]. It assumes the PR segments are well defined, recognizable, and their position is known. The other method uses linear phase filtering [2]. The use of digital linear phase high-pass filter minimizes undesirable distortion of ECG signal, but it requires large computational complexity. A multirate architecture with linear phase low-pass filter, working at low sampling rate is presented for removal of the baseline wander. This kind of baseline filter has significantly less computational complexity.

2. Methods

Base sampling frequency (F_s) of the filter is 500 Hz. Linear phase filtering is highly desirable in order to avoid distortion of ST-segment. Therefore filters with finite impulse response were applied.

2.1. High-pass baseline filter design

Filters designed by Kaiser window method have equal error in passband and stopband. Let this error be approximately 0.5 %, which provides appropriate suppressing of baseline wander. This value corresponds to 0.1 dB maximum passband ripple and 44.8 dB minimum stopband attenuation. In this case the product of filter order (N) and transition width (ΔF) is constant according to equation (1). The calculated values for several cases are shown in Table 1. As a good compromise we chose ΔF=0.6 Hz and delay =2.14 s.

$$(N-1)\cdot \Delta F \geq 2.56 \cdot F_s = 1283 \qquad (1)$$

Table 1.

N	Delay, s	ΔF, Hz
4279	4.28	0.3
3209	3.21	0.4
2567	2.57	0.5
2141	2.14	0.6
1835	1.84	0.7
1605	1.61	0.8

The cutoff frequency should be selected so that the important clinical information remains undistorted. In case of too high cutoff frequency the baseline filter output contains an oscillatory component that is strongly correlated to the heart rate. For this reason we chose 0.3 Hz for stopband-edge frequency and 0.9 Hz for passband-edge frequency. Parameters of the designed filters are:

- Filter length – 2141
- Max. passband ripple – 0.1 dB
- Min. stopband attenuation – 44.8 dB
- Stopband-edge frequency – 0.3 Hz
- Passband-edge frequency – 0.9 Hz.

This is a very good filter with high filtering performance of the baseline wander, and small distortion at the heart rates higher than 45 bpm, but it requires large computational complexity.

2.2. Baseline filter using multirate signal processing

To estimate the baseline wander we can use a low-pass filter working at low sampling rate and then we can subtract the estimated baseline wander from the original signal. This multirate architecture is shown in Figure 1.

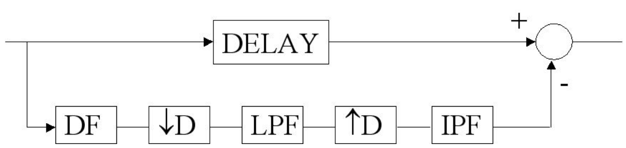

Figure 1. Multirate baseline filter

On one hand, if the maximum passband ripple and minimum stopband attenuation of the low-pass filter were the same as they were for high-pass filter, the order of the low-pass filter would be D-times smaller than the order of the high-pass filter (Equation 1.). On the other hand the low-pass filter works at D-times smaller sampling rate. Improvement in speed is the square of the decimation factor. Of course this improvement decreases because of decimation and interpolation filters. Fortunately decimation filter just needs to produce an output for every Dth sample and the signal after upsampling has (D–1) zero samples out of D samples, thus making most filtering multiplications unnecessary.

Determination of the optimal decimation factor is the most important issue in the design process. First we have to choose the parameters of filters. These parameters are shown in Table 2. Since the passband-edge frequency of LP filter is 0.3 Hz, the passband-edge frequency of decimation filter can be 0.5 Hz. The transition band of decimation filter can be between 0.5 and $F_s/D/2$–0.5 Hz.

Table 2.

	LP filter	Decimation / Interpolation filter
Sampling frequency, Hz	500/D	500
Max. passband ripple, dB	0.1	0.02
Min. stopband attenuation, dB	44.8	60
Passband-edge frequency, Hz	0.3	0.5
Transition band width, Hz	0.6	F_s / D / 2 – 1

Relation between the decimation factor and the average MAC operation per sample is presented in Figure 2. The function has the minimum at 38. The decimation factor should be divisor of F_s. Therefore the decimation factor has to be 40. But the function delay=f(decimation) is strictly increasing as shown in Figure 3. At the decimation factor 40 the number of required MAC operation is less only by 3 than at the decimation factor 20, but the delay is more by 0.4 s. Therefore we chose 20.

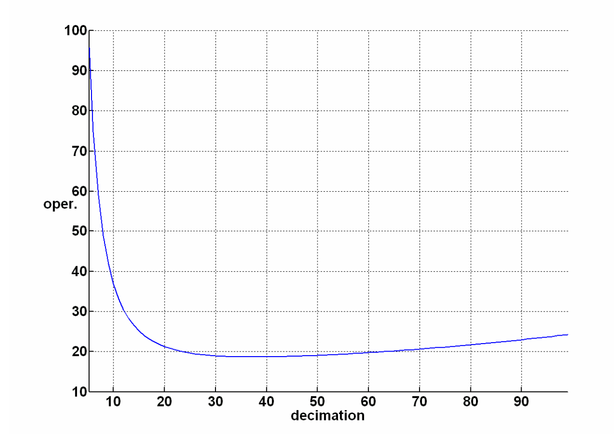

Figure 2.

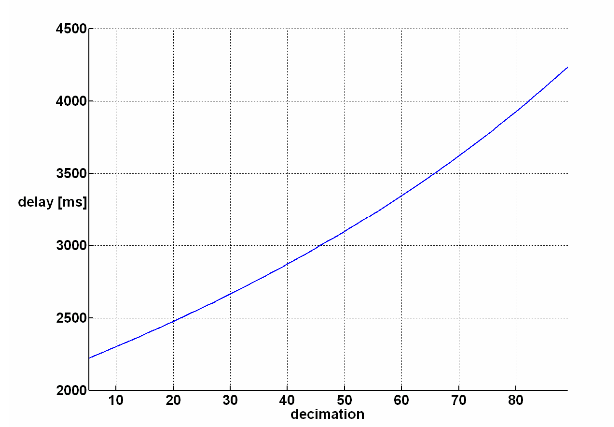

Figure 3.

Parameters of designed filters are in Table 3.

Table 3.

	LP filter	Decimation / Interpolation filter
Sampling frequency, Hz	25	500
Max. passband ripple, dB	0.1	0.02
Min. stopband attenuation, dB	44.8	60
Passband-edge frequency, Hz	0.3	0.5
Transition band width, Hz	0.6	11.5
Filter order	109	159

The delay of multirate baseline filter is equal to 2.47 s, the average MAC operation per sample is equal to 22.

The frequency response of baseline filter is shown in Figure 4. The frequency response of multirate filter is almost the same as for HP baseline filter, however the number of required MAC operation is 100 times less.

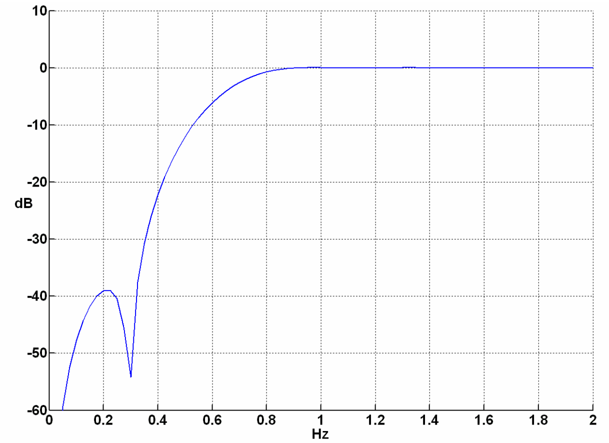

Figure 4.

2.3. Filtering performance in case of sinusoids

First the frequency response of baseline filter was tested. The input was the sum of sinusoids with different amplitudes and frequency. The filter suppresses almost completely the sum of sinusoids with frequencies lower than 0.3 Hz as shown in Figure 5.

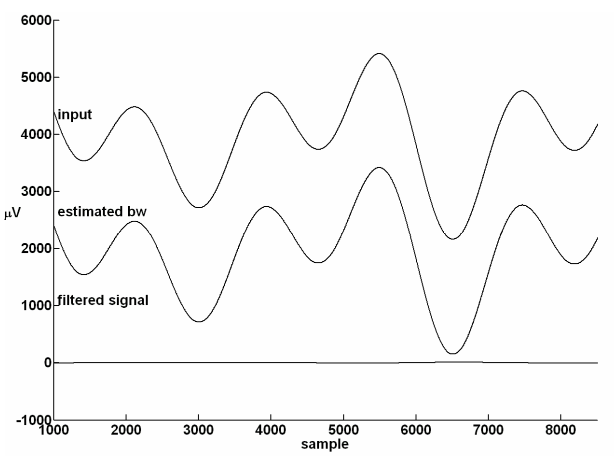

Figure 5. Sum of sinusoids with frequencies 0.13, 0.21 and 0.29 Hz

The filter passes the sum of sinusoids with frequencies higher than 0.9 Hz without significant distortion (Figure 6). The error is less than ±6 μV.

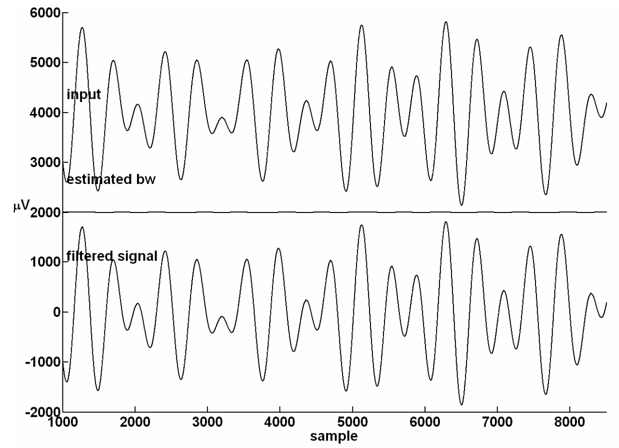

Figure 6. Sum of sinusoids with frequencies 0.9, 1.21 and 1.29 Hz

2.4. Filtering performance and ECG signal distortion

As shown in Figure 7, the proposed baseline filter removes significant baseline wander efficiently, whereas the filter does not alter important clinical information of ECG signal with heart rate of 60 bpm. There is no either significant distortion in case of 48 bpm as shown in Figure 8.

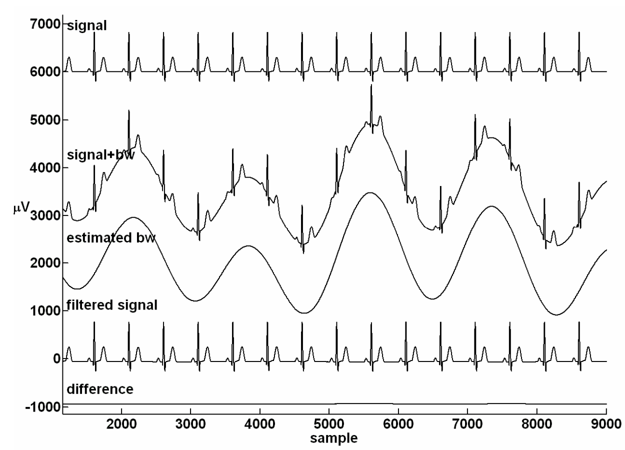

Figure 7. Record ANE20000+baseline drift. HR=60 bpm

In case of low heart rate the baseline filter output may contain an oscillatory component that is strongly correlated to the heart rate (Figure 9). The peak-to-peak amplitude of the oscillatory component is equal to 25 μV. But this error is not noticeable at standard gain and speed scales, and it caused only 20 μV ST segment deviation. The distortion in the neighborhood of wide QRS is shown in the Figure 10. This ST-segment displacement is not either noticeable at standard gain and speed.

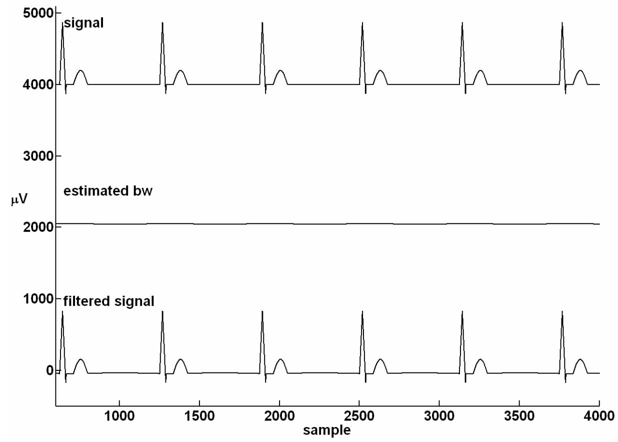

Figure 8. Artificial ECG. HR=48 bpm

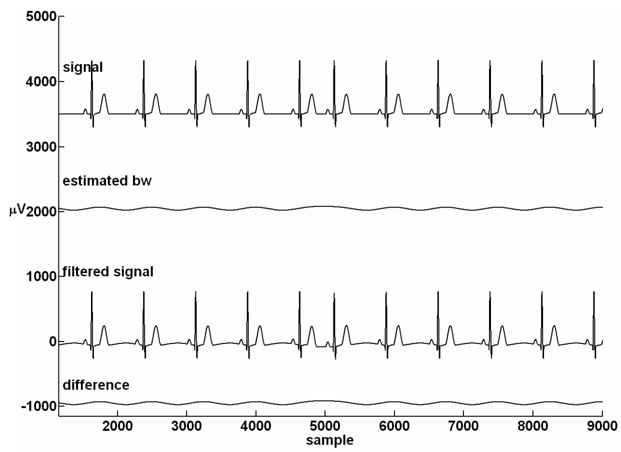

Figure 9. Record ANE20001. HR=40 bpm

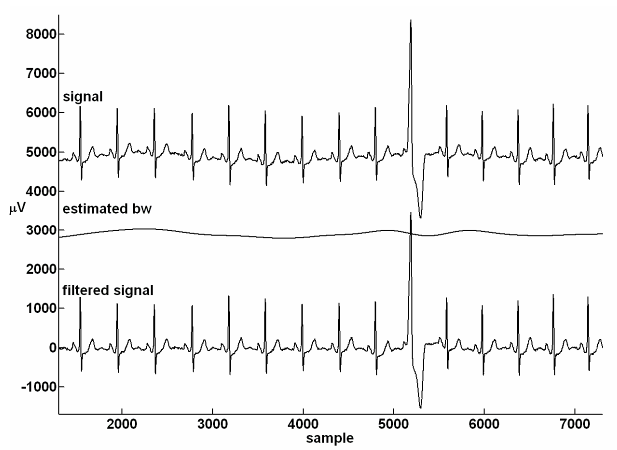

Figure 10. Record AHA 2203

2.5. Testing according to EN 60601-2-51

300 µVs impulse (3 mV, 100 ms) shall not produce an offset on the ECG record from the isoelectric line greater than 100 µV, and shall not produce a slope greater than 250 µV/s in a 200 ms region following the impulse and a slope of 100 µV/s anywhere outside the region of the impulse.

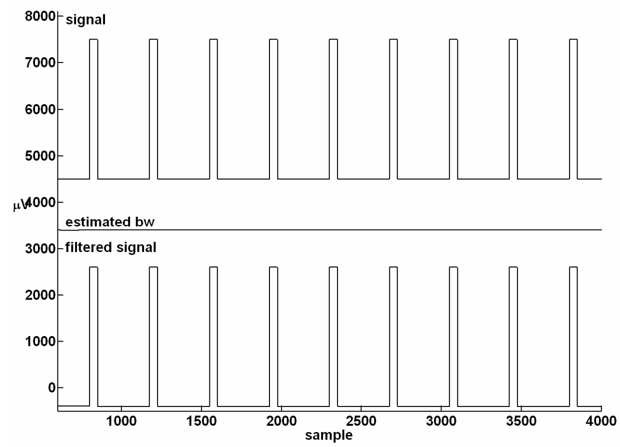

Figure 11. 3 mV, 100 ms, 80 bpm

3. Results

The proposed baseline filter does not produce noticeable ST-segment distortion in case of normal QRS complexes with heart rate higher than 45 bpm and it complies with the requirements of standard EN 60601-2-51. This multirate architecture requires only 22 MAC operations per sample.

4. Discussion and conclusions

The proposed realization of baseline filter has low complexity and minimizes the distortion of important clinical information while it performs an efficient removal of the baseline wander.

References

[1] Meyer CR, Keiser HN. Electrocardiogram Baseline Noise Estimation and Removal Using Cubic Splines and State-Space Computation Techniques. Computers and Biomedical Research, 1977;10:459-470.

[2] Van Alste JA, Van Eck W, Herrmann OE. ECG baseline wander reduction using linear phase filters. Computers and Biomedical Research, 1986;19:417-427.

[3] European Standard EN 60601-2-51. 2003.

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