Open access • Proceedings Article • DOI:10.1109/ICBEM.1998.666440

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Published on: 15 Feb 1998

Topics: Adaptive filter, High-pass filter, Filter design, Median filter and Voltage-controlled filter

ECG Noise Cancellation Using Digital Filters

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ABSTRACT: *A digital filter structure is proposed to maximally remove noise from the ECG signals. This structure is based on cascading a zero-phase band-pass, an adaptive filter, and multi-band-pass filter. It provides an efficient method for removing noise from the ECG signals. This filter structure has low implementation complexity and introduces little noise into a typical ECG. It can be applied to real-time applications particularly automatic cardiac arrhythmia classifiers.*

1. INTRODUCTION:

The electrocardiogram (ECG) is the recording of the heart's electrical potential versus time. This signal is normally corrupted with two major noises generated by biological and environmental resources. The first group includes muscle contraction or electromyographic (EMG) interference, baseline drift, ECG amplitude modulation due to respiration, and motion artefacts caused by changes in the electrode-skin impedance with electrode motion. The second group includes power line interference, electrode contact noise, instrumentation noise generated by electronic devices used in signal processing, electrosurgical noise, and radio-frequency.

Digital filters operate on the signal as a linear system to remove noise. They can be implemented either in hardware or software. Hardware implementation can be performed efficiently in real-time by a DSP processor such as the TMS320C25 [1]. In addition to this processor, other interfaces (such as analog to digital converter) must be also provided, depending on the type of data source . On the other hand, software implementation employs suitable algorithms as a digital filter using a high-level computer programming language or a DSP software toolbox such as MATLAB signal processing toolbox [2].

For real-time applications the computational requirements of a digital filter must be taken into account. For an ECG signal with a heart rate of 72 beats/minute the filtering operation must be performed once every 0.83 seconds for each beat. Allowance must be also made for other overheads such as loading the input data or saving the filtered data samples, as well as other buffering operations. However, the overall time taken for the entire filtering process remains short enough to justify choosing software implementation for this study.

Power line noise (50 or 60 Hz) is a significant source of noise in biomedical signal recording. It can be removed using well recognised methods such as non-adaptive notch filter or Ahlstrom & Tompkins' adaptive filter [3]. The method described in this paper aims to remove not only the power line noise and its harmonics, but also to remove other ECG noises such as respiratory signal and body movements which cause problems during ECG arrhythmia detection and classification processes.

2. METHODS:

2.1 Filtering

A combination of zero-phase band-pass, adaptive, and multi-band-pass filters has been developed for maximum noise reduction from the ECG signal in real-time applications.

The developed noise canceller can be applied to different sources of noisy ECG signals, and is comprised of the following four stages:

- Stage 1 - Data buffer

A large amount of ECG data is obtained during one hour of data collection ($1.5x10^6$ samples with the sampling frequency of 360 Hz). This necessitates some kind of data management process to divide the data into smaller data blocks. This is achieved using buffering techniques. Either a hardware buffer or a software-oriented first-in first-out (FIFO) buffer can be employed to retain a specific amount of data for processing.

- Stage 2 - Pre-removing filter

This filter removes some of the fixed noise components using a zero-phase band-pass (ZPBP) filter. These fixed noises include: power line interference and its harmonics, low-frequency baseline wander (0 to 0.5 Hz), and all high frequency noises (>170 Hz) including EMG noise. The band-pass filter proposed by T.Y. Lo et al. was selected for this purpose [4]. This filter is a combination of a low-pass and a high-pass filter. The low-pass filter is a linear phase filter with cut-off frequency at about 18 Hz, implemented with its first side-lobe zero amplitude response placed at 60 Hz (power line noise in MIT/BIH data base). The cut-off frequency of the high-pass filter was set at about 1 Hz, where the gain is unity.

After filtering in the forward direction, the filtered sequence is then reversed and run back through the filter. The resulting sequence has precisely zero-phase distortion and twice the filter order.

This stage of the noise canceller improves signal to noise ratio. However, the output of the ZPBP filter still contains those noises in the frequency range of the ECG signal (0.5 to 170 Hz). The next stage is designed to cancel these noises.

- Stage 3 - Adaptive filter

Least mean square (LMS) and recursive least squares (RLS) algorithms are the two most widely used algorithms in adaptive signal processing. The LMS algorithm demonstrates an efficient performance in terms of computation and storage requirements. Furthermore, it does not suffer from any numerical instability problems [1]. In the ECG noise removal an adaptive self-tuning filter structure was selected for minimising noise, using the LMS algorithm.

- Stage 4 - Post-removing filter

A multi-band-pass filter is cascaded to the previous stages of the proposed ECG noise canceller to attenuate the low amplitude noise detectable at the output of the adaptive filter. This filter has a sharp cut-off frequencies at .5, 60, 120, and all components greater than 170 Hz.

2.2 Input signals

ECG signals from the MIT/BIH data base were used as test data for the filtering process. A block of 1600 samples of data (approximately six heartbeats) was buffered each time and applied as input to the filter. When the filtering process is completed, the filtered data was transferred from the buffer into a temporary memory to make room for the next block of data.

3. RESULTS AND DISCUSSION:

The results of evaluating different ECG signal processing algorithms show that many are sensitive to the ECG source. In other words the performance of each algorithm changes from patient to patient. One way to overcome this problem is processing the buffered noise-free heartbeats individually. The output of buffer as a cleaned heartbeat vector can be used for further ECG signal processing steps. The adaptive filter can also improve the performance of the proposed filter structure in solving the source dependency problem. The adaptive filter is acting as a self adapting algorithm which processes according to the characteristics of the present data instead of using the general properties of the ECG signal.

The developed band-pass filter performed very well in removing power line noise, muscle tremor noise up to about 200 Hz, and the drift caused by respiration at about 0.2 Hz. Figure 1(b) shows the effect of noise reduction by the band-pass filter (Stage 2).

The result of applying the adaptive filter (Stage 3) to the output of ZPBP filter is plotted in Figure 1(c). It was observed that the signal to noise ratio could be further improved by applying more stages of this filter to the ECG signal.

4. CONCLUSION:

Results of this investigation have shown that both adaptive filter and band-pass filter methods can successfully remove major components of noise from the ECG signal. As the number of stages in the cascaded digital filtering system is increased, so the signal to noise ratio improves. On the other hand, increasing the length of the filter creates a longer delay and a greater calculation load which is not acceptable for real time signal processing applications. The proposed filter structure is based on satisfying both an acceptable signal to noise ratio and real time analysis of the ECG signal. However, this method can be applied to other biomedical signals with some modifications.

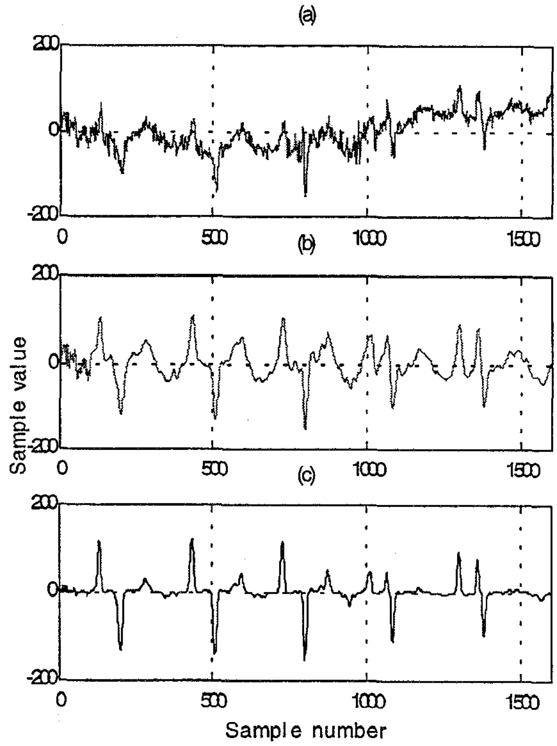

Figure 1 The result of noise reduction by proposed filter structure. (a) Noisy ECG signal. (b) Output of ZPBP filter. (c) The final output of the proposed filter.

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