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Noise Cancellation using Adaptive Filtering in ECG Signals: Application to Biotelemetry

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Abstract

The ECG (electrocardiogram) is a system that provides patient's critical heart activity. The adaptive electrocardiogram filter will be designed to reduce noise caused by external systems & body artifacts. This paper aims to help to reduce the noise interference in the ECG signals and better diagnose results. Some of the most common examples of noise that the ECG filter would need to remove in order to give useful results includes power line interference, motion artifacts, muscle contraction, electrode contact noise and interference caused due other electronic equipment. ECG signals are weak and easily susceptible to noise and interference. In this paper I have presented an implementation of Least Mean Squares (LMS).

Keywords*: Adaptive filtering, Artifact, LMS algorithm, ECG, Noise cancellation.*

1. Introduction

One of the problems in biomedical data processing like electrocardiography which is the separation of the wanted signal from noises caused by power line interference (PLI), external electromagnetic fields, high frequency interference and random body movements and respiration [1]. To remove signal components from unwanted frequency ranges various different types of digital filters are used. It is difficult to apply filters with fixed coefficients to reduce random noises, because human behaviour is not exact known depending on the time. To overcome this problem Adaptive filter technique is required. Electrocardiogram (ECG) is the most important parameters for heart activity monitoring. By the full form analysis of the ECG signal a doctor can detect different types of deflections. In some applications of biomedical signal processing various useful signals are superposed by various components. Interference caused by them may have technical sources, for example:

Power line interference: This interference consists of 50 Hz harmonics mainly of sinusoidal signal.
Parameters such as
Frequency content 50 Hz with harmonics;
Amplitude is 50% of peak-to-peak ECG amplitude.

Muscle contraction noise: The baseline of electromyogram is usually in the microvolt range which makes it insignificant.
Parameters:
Standard deviation is 10% of peak-to-peak ECG amplitude;
Duration is 50ms;
Frequency is 10000 Hz.

Electrode contact noise: This noise is caused by loss of contact between the skin and electrode, which also effect the measurement of signal.

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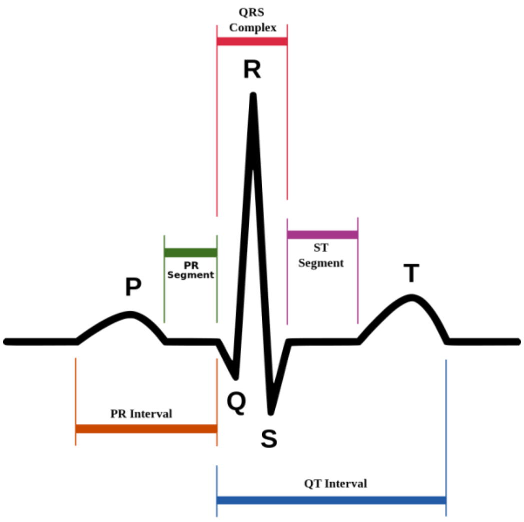


Figure 1. Shows the Standard ECG Signal

Parameters:
Duration is 1s;
Frequency is 50 HZ;
Time constant is about 1s.
Patient movement: Patient movements are transient therefore baseline changes with the variations in the electrode skin impedance.
Parameters:
Duration is 100 to 500ms;
Amplitude is 500% peak-to-peak.
Electrosurgical noise: This noise completely destroys the ECG signal. It can be represented by large amplitude. Parameters:
Amplitude is 200 % peak-to-peak;
Frequency is 100 kHz to 1 MHz;
Duration is 1 to 10s.

2. Methodology

A filter that self-adjusts its transfer function according to an algorithm driven by an error signal is called an adaptive filter. Due to the complexity of the optimization algorithms, such filters are sometimes called as digital filters. In order to minimize the error it adapts to the change in signal characteristics. Therefore it has wide applications such as in adaptive noise cancellation, frequency tracking, system identification and channel equalization.

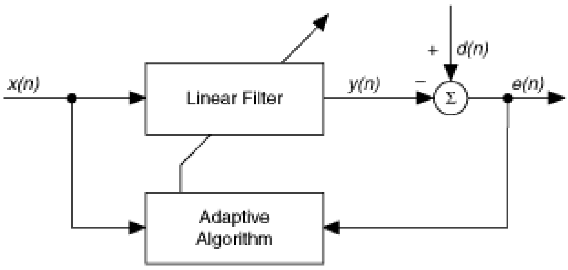


Figure 2. Shows the Basic Structure of an Adaptive Filter

In Fig. 2, x(n) represents the input signal. A digital filter is applied on the input signal x(n) which produce output signal y(n). Adaptive algorithm adjusts the filter coefficient of vector w(n), in order to get the smallest error signal e(n). Eq(1) represents the vector x(n). Noise corrupts this input signal. Therefore it represents the sum of desired signal d(n) and noise v(n), as given in Eq(2). The input signal vector x(n) is given by

$x(n)=[x(n),x(n-1),x(n-2),\ldots\ldots..x(n-N-1)]T$ ..(1)

$x(n)=d(n)+v(n)$ ..(2)

The adaptive filter has a structure of Finite Impulse Response (FIR). For FIR structure, the impulse response is equal to the filter coefficients. For a filter of order N , the coefficients are defined as

$W(n)=[wn(0),wn(1),\ldots\ldots..wn(N-1)]T$ ..(3)

The output of the adaptive filter is y(n) is given by

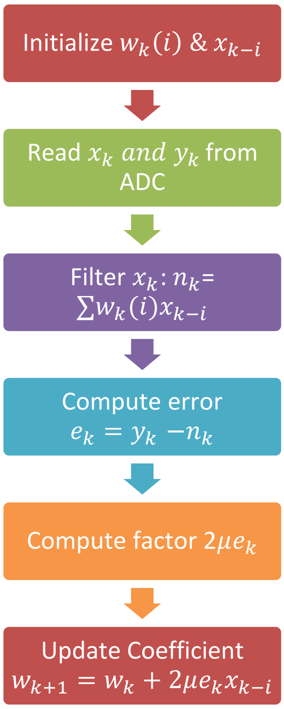
$y(n)=W(n)Tx(n)$ ..(4)

The error signal is the difference between the desired signal and the estimated signal.
$e(n)=d(n)-y(n)$ ..(5)

Also the variable filter updates the filter coefficients at every instant of time
$W(n+1)=W(n)+\Delta W(n)$ ..(6)

Where $\Delta W(n)$ is a correction factor for the filter coefficients. This correction factor is generated by adaptive algorithm based on the input and error signals.

Least mean squares (LMS) algorithms are a type of adaptive filter which is used to mimic a desired filter by finding the filter coefficients that related to the least mean squares of the error signal. It is a gradient descent method which is only adapted based on the error at the current time.
LMS algorithm flowchart is shown:



1. Adaptive Noise Canceling (ANC) Applied to Fetal ECG.

The creating of the Maternal Heartbeat Signal: The electrocardiogram shapes for both the mother and fetus has been simulated in this example. Sampling rate is 4000 Hz. The heart rate for this signal is 89 beats/min, and the peak voltage of the signal is 3.5 millivolts.

The creating of the Fetal Heartbeat Signal:
The heart of a fetus is faster than that of its mother that is 160 and 120 beats per minute respectively. The amplitude of the fetal electrocardiogram is much weaker than that of the maternal electrocardiogram. The example shows an electrocardiogram signal having a heart rate of 139 beats per minute and a peak voltage of 0.25 millivolts for simulating fetal heartbeat.

The Maternal Electrocardiogram: The maternal electrocardiogram signal is measured from the chest of the mother. The adaptive noise canceller removes the maternal heartbeat signal from the fetal electrocardiogram signal. To perform this task the canceller needs a reference signal generated from a maternal electrocardiogram. As the fetal electrocardiogram signal contains some additive broadband noise, so does the maternal electrocardiogram signal.

The Fetal Electrocardiogram:
The fetal electrocardiogram signal which is measured from the abdomen of the mother is dominated by the maternal heartbeat that propagates from the chest cavity to the abdomen. This propagation path will be described as a linear FIR filter with 10 randomized coefficients. Also, we should add a small amount of uncorrelated Gaussian noise so that we can simulate any broadband noise sources within the measurement.

The Adaptive Noise Canceller

The adaptive noise canceller use adaptive procedure to perform its task. To reduce complexity, we shall use the LMS adaptive filter of step size 0.00007 with 15 coefficients. With the above settings, the adaptive noise canceller converges very well.

Recovering the Fetal Heartbeat Signal

The output of the adaptive filter contains the estimated maternal heartbeat signal, which is not the desired signal. After the system convergence the error signal e(n) contains an estimate of the fetal heartbeat signal and noise. By using this error signal, we can estimate the heart rate of the fetus.

2. Removing external noise interference in ECG signal: The removal of single frequency tones from ECG signal and power line interference using the advanced adaptive filtering technique with least mean square algorithm. The thesis is based on digital signal processing techniques with MATLAB simulation, with the main target on design of adaptive LMS algorithm. For removal of power line interference in various applications such as recording Electrocardiograms (ECG), the adaptive interference removal technique can be used.

3. Results

Using MATLAB Tools, figure 3-4 results are computed. The noisy ECG signal which is taken as input is filtered using adaptive filter algorithms LMS. The original ECG signal is passed through the LMS adaptive algorithms and hence improving the SNR ratio of the signal to a greater extent.

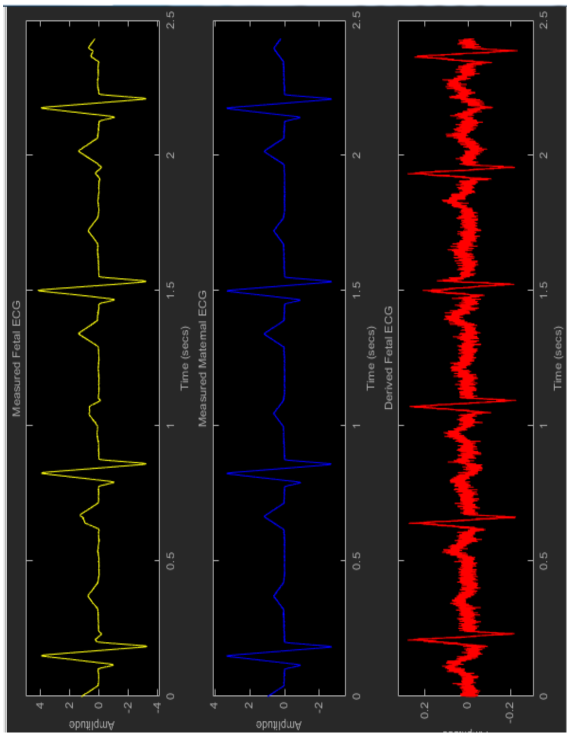


Figure 3

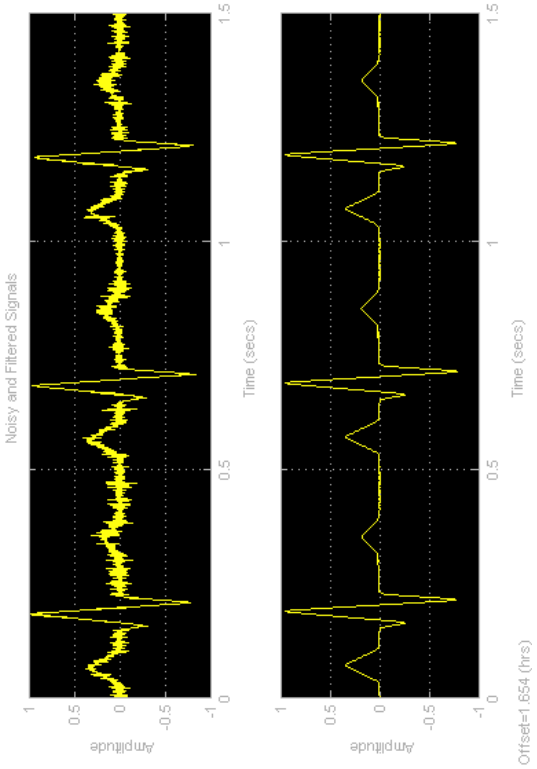


Figure 4. Removing Ext. Noise

Table : Illustrates the SNR ratio evaluation of the ECG signal after being filtered through LMS.

SNR before filtering	SNR after filtering	SNR improvement
-8.6948	**2.3801**	**11.0749**

4. Conclusion

This paper shows the simplicity of LMS algorithm and ease of implementation, evident from above make this algorithm better in many real time systems to improve the SNR and to reduce the noise of signal. Information of fetal heart rate, derived from the fetal ECG, is valuable in assessing the condition of the baby before or during birth of a baby. Adaptive filter have been used to derive a noise free fetal electrocardiogram signal.

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