BBT.HTI.501-2023-2024-1 Processing of Biosignals

Assignment 3: Fetal ECG extraction using adaptive filter.

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Introduction

Biosignals are complex in nature and susceptible to noise, interference, and artifacts. Filtering is a signal processing approach which allows us to remove the unwanted components of the signal. There are mainly two types of filters; frequency domain filters and time domain filters. Frequency domain filters are based on removing known frequency components of the signals while time domain filters work independently of frequency components and remove undesired components in real time [1].

Adaptive filtering is a time domain filter that is time variant indicating towards changing properties of the filter for optimization. This type of filter is useful when the signal properties of the desired and undesired signal either overlap with each other or they are unknown. There are two methods of adaptive filtering, Adaptive Noise Cancellation (ANC) and Adaptive Line Enhance (ALE). In ANC, a known reference signal is provided to the filter that is highly correlated with the noise in our original signal. The filter continuously compares the signal with the reference signal and adapts itself automatically to remove the noise to provide the desired signal. In ALE, the reference is created from the original signal by delaying the signal because the known reference signal is not always available. Two main algorithms used for optimization of the filter are; least mean square (LMS) and recursive least square (RLS) methods. [1]

LMS algorithm adjusts the filter coefficients or tap weights by taking an error difference between the reference signal (desired output) and the original signal. The goal is to keep minimizing the error and update the tap weights using a parameter called rate of convergence or learning rate parameter (μ) towards optimization. This parameter is quite important for optimization as high values can converge faster but may cause instability while low learning rate can take a long time to converge and can require many iterations to get desired results. [1]

There are many applications of adaptive filtering such as extracting fetus signal from the recording of parent's abdomen. Recording of fetus ECG is challenging because parent's ECG interference is quite high. In this case, the frequency component of parent's ECG significantly overlaps with the ECG of fetus and frequency domain filters are not suitable. Moreover, the fetus heartbeat is quite weaker than the parent's heartbeat. Therefore, we can use time domain filtering, especially adaptive filtering because we need the filter to give accurate output of the fetus signal and it is possible to record parent's ECG as the reference signal. One way of implementing adaptive filtering is using FIR structure where most recent samples of the input are fed to compute the error. [1]

Methods

In this report, we will use LMS algorithm using ANC method to remove the parental ECG from the measured signal from the parent's abdomen to extract fetus ECG. To achieve our objective, we have implemented an LMS algorithm as a transfer function in MATLAB. A reference signal of the parent's ECG was measured from the chest. The function (*adaptive*) takes the reference ECG (*S_chest*), the original ECG from the abdomen (*S_abdomen*), rate of convergence as a multiple of 2 (*delta*), filter order (*N*) and filter coefficients (*H*). The frequency response of the function is also visualized.

First, the filter coefficients are initialized as zeros. The function takes the *N* most recent samples over the whole signal of the reference signal, calculates an error signal, updates the coefficients, and compares the output with the original signal. The error (*e(n)*) is calculated using the following equations:

$$y(n) = H * r(n)$$

$$e(n) = S\_abdomen(n\_delayed) - y(n)$$

where,

r(n) is the most recent n samples from the chest signal. The error signal should give us an approximation of the fetus ECG.

The coefficients are updated using the following equation:

$$H = H + (delta * e(n) * r(n))$$

where,

delta is 2μ.

The filter order and delta values are manipulated to optimally extract the ECG of fetus. The signal is fed to the filter multiple times to obtain accurate results, stable filter coefficients, and study the behavior of different parameters in the algorithm. Many combinations of delta and *H* have been tried to get the optimal results.

Results

The recording of ECG from abdomen (parent and fetus ECG) and chest or our reference ECG (only parent's ECG) are demonstrated in Figure 1 with the same amplitude and time scale.

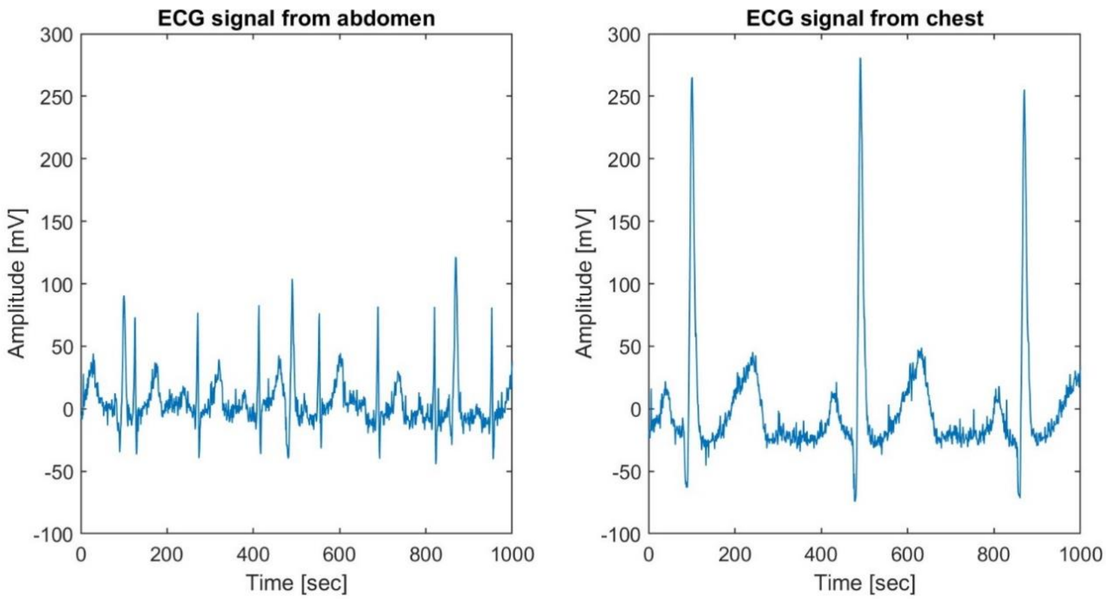

Figure 1: ECG signal from abdomen and chest

After many iterations, the most appropriate results were found at the parameters values and a part of fetus signal is illustrated in Figure 2:

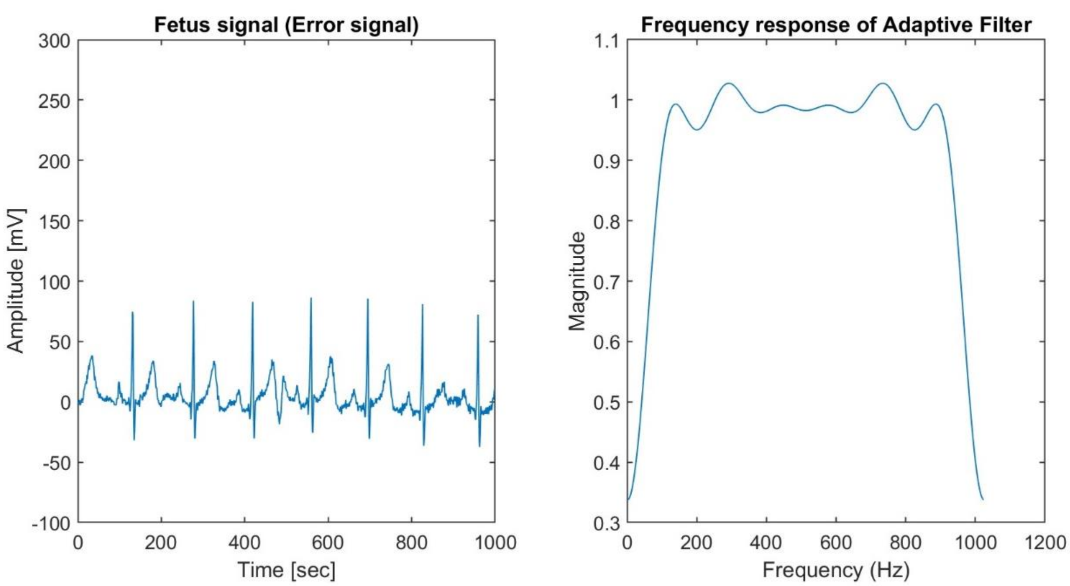

Figure 2: Error signal with delta = 0.000001, N = 13, no. of iteration = 50

One example of poor extraction of fetus signal is illustrated in Figure 3:

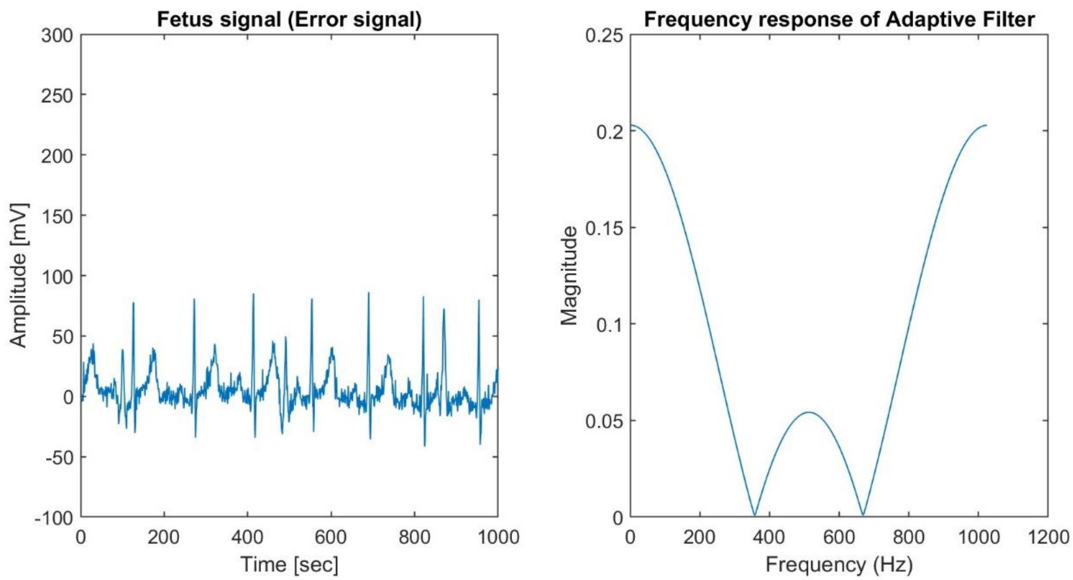

Figure 3: Error signal with delta = 0.000000001, N = 3, no. of iterations = 10

Discussion

In Figure 1, we can see the difference in ECG from abdomen and ECG from the chest. The abdomen ECG represents fetus ECG while chest ECG represents parent's ECG. We can notice that fetus ECG is quite weaker than parent's ECG in terms of amplitude. We can also notice that there is some noise in the form of multiple QRS and high peaks that represent interference from parent's ECG.

Filter order:

Many filter orders such as 3, 5, 15, 17, 21, 31, 43, 57 because FIR structures work better at higher filter orders. It was observed that the best results were observed at the 13th filter order as shown in Figure 3. At low filter orders such as $N = 3$, the additional parent's QRS complex that is shown in the original signal was not removed by this filter order. This shows that our filter is underperforming at low filter orders and accurately performing at relatively high filter orders. However, extremely high filter orders affect the calculation of error signal as it exceeds the window exceeds the number of samples in the reference signal.

Delta parameter:

The delta parameter was tried with low, medium, and high values. Delta values lower than 1e-08 were not able to produce desired results. This may be because the algorithm is very slowly moving towards the optimal results and will take numerous numbers of iterations to achieve desired results. Delta values greater than 1e-04 were not producing any result and showed NaN as filter orders in MATLAB. This indicates that the algorithm is overshooting and creating instabilities during optimization. The appropriate delta value was found to be at 0.000001 and produced acceptable results.

Number of iterations:

The filter was iterated over 5, 10, 15, 20, 30, 40, 50 times. It was noticed that optimal frequency response of the filter with low ripple effect was found at 50 iterations. Iterations lower than 15 did not produce smooth pass band as shown in Figure 3 which affected the correct extraction of fetus signal. This is because adaptive filter has to learn itself and initially it performs poorly but after many iterations, it can learn from past inputs and outputs. Further iterations could also be performed to increase the resolution of the signal.

Frequency response:

While looking at the frequency response in Figure 2, we can notice that a bandpass frequency response of frequency range of 0 - 1000 Hz. However, we are not aware of the sampling frequency so aliasing effect cannot be determined. We can also notice that the ripple effect is reduced at the parameters provided. In Figure 3, we can see a notch type filter is constructed where the magnitude of approximately 400 – 700 Hz is attenuated to lower magnitude as compared to other frequencies. This does not produce the desired result of removing the QRS complex of the parent’s ECG.

Conclusion

In this exercise, we extracted the fetus signal from an ECG recording corrupted by parent’s ECG using adaptive filtering technique. We had to feed the signal approximately 50 times to the filter, low filter orders caused undershooting of the LMS algorithm and high delta parameter caused overshooting of the LMS algorithm which created instabilities.

References

1. Rangayyan, R. M. (2015, April 24). Biomedical Signal Analysis. Wiley eBooks. https://doi.org/10.1002/9781119068129