Fetal ECG extraction using NLMS adaptive filter

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Abstract

Fetal electrocardiogram (ECG) gives information about the health status of fetus and so, an early diagnosis of any cardiac defect before delivery increases the effectiveness of appropriate treatment. The FECG signal which is recorded from the abdominal electrode and thoracic electrode. In this paper we use the abdominal signal comes from real world to extract fetal ECG. Base on normalized Least-mean-square (NLMS), we present simulation results illustrating the performance of our proposed method. In this work, we focus specifically on the separation of the ECG signal sources taken from abdomen on a pregnant woman's body. We use two methods to estimate or extract Fetal ECG signal, which are use clean fetal ECG as desired signal and use two of abdominal data to estimate fetal ECG signal. Comparing both methods, the first one got a high performance and the second one does not utilize the clean fetal ECG signal, however, it has not get the perfect performance.

Introduction

Fetal electrocardiogram (ECG) waveform analysis is performed by measuring electrical activity of fetal heart in maternal body. It provides information about the physiological state of the fetus that can help clinicians to make appropriate diagnosis. However, the fetal ECG signal are mixed by other signals such as, maternal heart beats, the noise signal in abdomen, and the noise signal comes from the detecting instrumentations. Moreover, the amplitude of fetal ECG signal is weak comparing to other noise signal and maternal heart beats so that it cannot be extracted easily. But, fetal ECG has high frequency than maternal ECG signal. From this characteristic, we build NMLS adaptive filter to extract fetal ECG. As for my work, first of all, I get the data from real world. Secondly, I did some research on ECG signal processing corresponding to adaptive filter methods and non-adaptive filter methods. Thirdly, base on NLMS build the adaptive filter. In addition, I do the simulation with the method by using two different ways which I have two results. Finally, I make power spectrum density analysis for my result.

Literature Survey

For fetal ECG signal processing, there are several techniques to extract ECG signals such as, non-adaptive filtering, combining digital filter, and adaptive filtering. For instance, using LMS algorithm to separate maternal ECG and fetal ECG[1]. The block diagram is illustrated in Fig.1. It uses the basic structure of adaptive filter and this paper has full analysis for each wave of ECG signal, also it obtained a high performance.

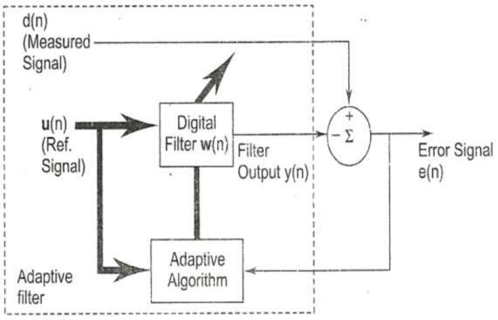

Fig.1 basic block diagram of adaptive filter

However, the raw data comes from MATLAB simulation, in another word, the paper use different magnitude and frequency as well as different type signal to synthesize the signal mixed with maternal and fetal ECG signal. Therefore, it did not come from real world which means it have less noise than the signal comes from real maternal body. Some papers use wavelet analysis to rebuild the fetal ECG signal[2]. Unlike the Fourier transform, wavelet analysis gives a multi-resolution analysis of signals. It could focus on any signal's details and is an efficient method in signal processing. Wavelet transform can decompose a signal into several scales that represent different frequency bands, and at each scale, the positions of the signal's instantaneous structures can be determined approximately. The Fig.2 shows the ideal FIR filter bank.

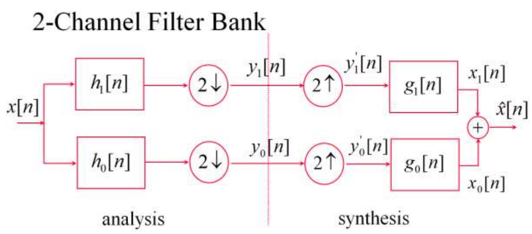

Fig.2 2-channel Perfect Reconstruction Filter Banks

Moreover, one of the papers use digital filter such as, low-pass filter, high-pass filter, and notch filter to do pre-processing for the abdominal signal and construct a peak detector to remove maternal ECG peak [3]. The Fig.3 is the flow diagram of the method of QRS peaks cancellation. This method was enlightening me that we also have this methodology to extract fetal ECG signal.

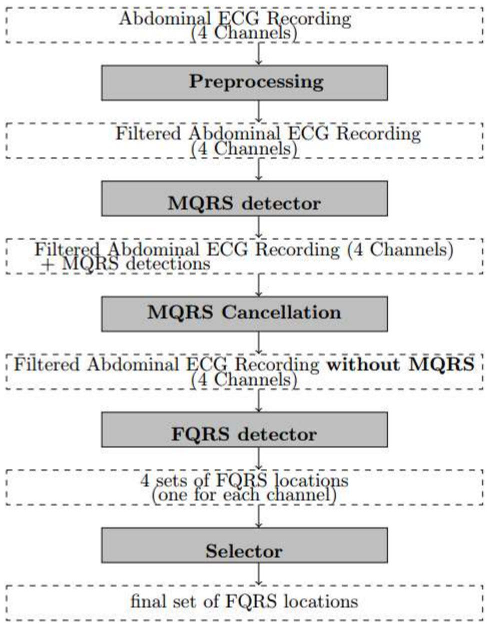

Fig.3. maternal QRS peaks elimination

Also, block LMS and RLS algorithms are used to improve the convergence speed as well as high performance [4].

Overall, most of papers based on simulated data are able to obtain a high performance, however, only less paper use the real world data. That is because the data which is generated by Matlab is ideally. Also, it can build desired signal more easily than the real world signal. Therefore, this report use real world data which has several noise, for example, baseline wander, power line noise, electrode movement， white noise as well as other maternal abdominal signals that cannot be simulated easily.

Approach

1. Introduction of LMS and NLMS algorithm.

Before talking about LMS, we need introduce the steepest descent algorithm.

$$e(n) = d(n) - dhat(n) \quad (1)$$

Then, we evaluate the partial derivatives of the cost function with respect to the coefficient values. Then we get,

$$\frac{\partial E(e^2(n))}{\partial W(n)} = E\left\{\frac{\partial\left(e^2(n)\right)}{\partial W(n)}\right\} \quad (2)$$

After that,

$$\frac{\partial E(e^2(n))}{\partial W(n)} = -2E\{e(n)X(n)\} \quad (3)$$

$$E\{e(n)X(n)\} = P_{dx} - R_{xx}(n)W(n) \quad (4)$$

Finally, we can obtain that,

$$W(n+1) = W(n) + \mu\left(Pdx(n) - Rxx(n)W(n)\right) \quad (5)$$

The equations above indicate that how we get the steepest descent algorithm. The LMS algorithm is derived by this algorithm. The updating function is

$$W(n+1) = W(n) + \mu e(n)X(n) \quad (6)$$

The coefficient vector W(n) may be initialized arbitrarily and is typically chosen to be the zero vector. The only difference between the LMS algorithm and steepest descent algorithm is we have removed the expectation operator E{.} form the gradient estimate. It is the most widely-used adaptive filter today. However, we can observe that the value of step size is fixed in LMS algorithm which may not have a good performance for input signal with time-varying statistics. That is why we need the NLMS algorithm to robust our signal processing. The NLMS adaptive filter has coefficient update given by

$$W(n+1) = W(n) + \frac{\mu ha}{\beta + L\sigma_x^2} e(n)X(n) \quad (7)$$

Especially, in this paper we use moving average filter to estimate power of σ_x^2.

$$\sigma_x^2 = \frac{1}{N}\sum_{i=0}^{N-1} x^2(n-i)$$

(8)

Where N is the window length for the moving average filter. This procedure uses only the most recent N samples of the input signal to compute the power estimate. If N=L, the normalized LMS adaptive filter becomes

$$W(n+1) = W(n) + \frac{\mu hat * e(n)X(n)}{\beta + ||X(n)||^2} \quad (9)$$

The above update equation is the most commonly employed normalized LMS adaptive filter. Therefore, this paper is base on this NLMS update equation.

2. Data collection

Base on the principle of processing signal in real world. I do not use MATLAB to generate simulated maternal ECG and fetal ECG signal. I collect the abdominal signal from physionet.org dataset where signals are from pregnant women's body. The Fig.4 is the data I need process.

Fig.4 abdominal signal data

From the data above, the first one is referential fetal ECG signal, and another four signals are abdominal signals which have different types of noise. Our goal is to use abdomen_1 to abdomen_4 to estimate the fetal ECG signal.

3. Extract fetal ECG signal by using two methods

The following diagram shows the basic structure we used to build the adaptive filter.

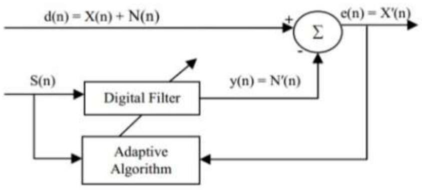

Fig.5 basic AF structure

First of all, we set the referential fetal ECG signal as d(n) and one of the abdominal signal as x(n), So we can get dhat(n)=W(n)X(n), and e(n)=d(n)-dhat(n) is the noise signal and the useless abdominal signal. Secondly, we set two of the abdominal signals as x(n) and d(n). Because these signal come from different electrode, the noise can be cancelled each by adding some delay in d(n). Based on both methods, we test several cases for better performance of adaptive filter. They both have their advantages and disadvantages. If we have desired signal of fetal ECG signal, we can extract the signal accurately. However, in some real world cases, we can hardly get the referential signal, that why we need use the second method to estimate the signal we want, but, this method may cause more mistakes. Because the signal we use is from real world, we are unable to get the perfect waveform and performance. The value of the experimentation is improving our experience for the real world signal processing.

Result

To show that NLMS algorithm is appropriate for ECG denoising we have used real ECG signals. We used the abdominal signal and Direct Fetal ECG database. For getting the result, we have tried several cases by using different abdominal signals to test whether this method can work.

A. d(n) is the direct fetal ECG signal

For this result, we can find that we use desired signal d(n) to train X(n), which can make that dhat(n)=W(n)X(n) access to the fetal ECG signal d(n). First of all, We need obtain the value of Wopt and use the algorithm to update and make sure that W(n) accesses to Wopt. Therefore, we are able to get the minimized mean-square error (MSE).The Fig.6 is the result of d(n), x(n), and e(n). The Fig.8 shows the comparison of d(n) and dhat(n).

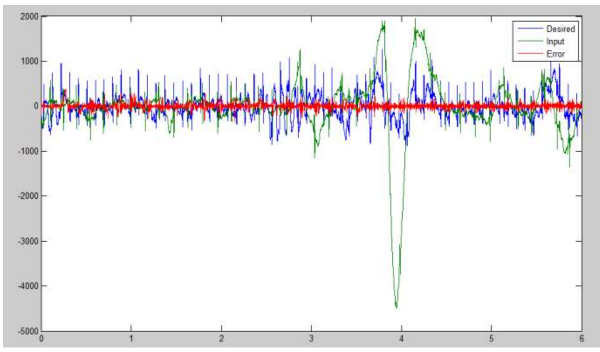

Fig.6 d(n), x(n), and e(n)

For the waveform above, we tried to minimize the MSE for getting the perfect waveform of dhat(n).

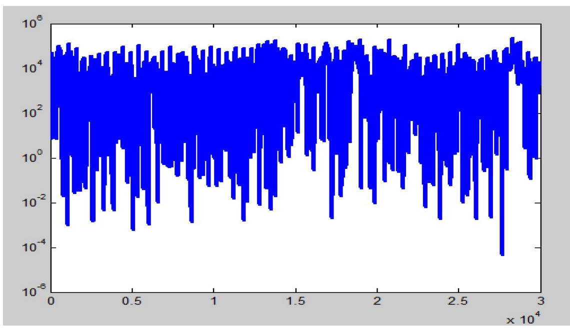

Fig.7 convergence situation

However, I cannot get MSE converged which is really confused me. The waveform of MSE shows that the situation of W(n) converges to Wopt. The Fig.7 shows the situation of convergence.

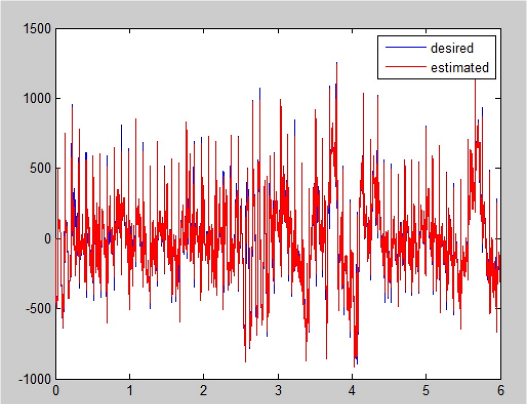

Fig.8 comparison of dhat(n) and d(n)

It can be observed that the estimated signal covers 99% of the desired signal which manifest that this algorithm works well. For fully testing and analysis, we need zoom in the diagram.

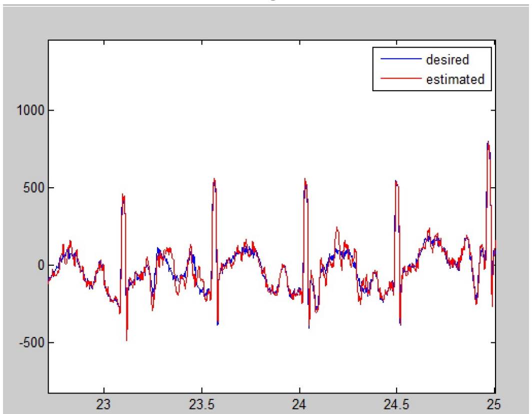

Fig.9 zoomed version of dhat(n) and d(n)

In this diagram, we can find it works well for covering the peak of the ECG signal which is very significant for fetal ECG recognization. However, for the small peak it does not do a good job for following the waveform. Until now, we need test whether the red on is fetal heart beats. My total data is 30000 that is divided by 1000, and total time is 30 sec. According to the Fig.9, We can estimate the heart beats roughly, which is in 1 sec there is 3 peaks. Therefore, the heart beat is 60/0.45 =133 times that is the fetal heart beats.

2. x(n) and d(n) are two of the abdominal signals

Recall the basic architecture of Fig.5. We set d(n) is abdomen_1 signal and S(n) is abdomen_2 signal. Hence, e(n) is the fetal ECG signal. The Fig.10 is the result.

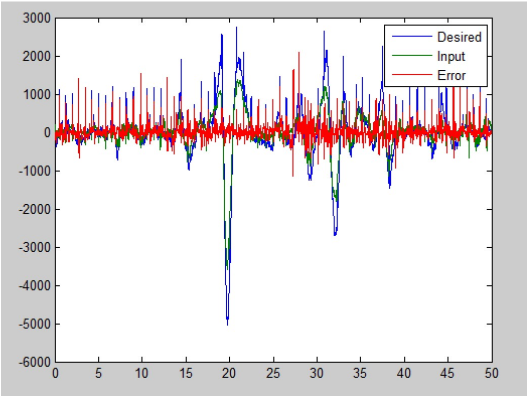

Fig.10 result of second method

When we zoom in we obtain Fig.11.

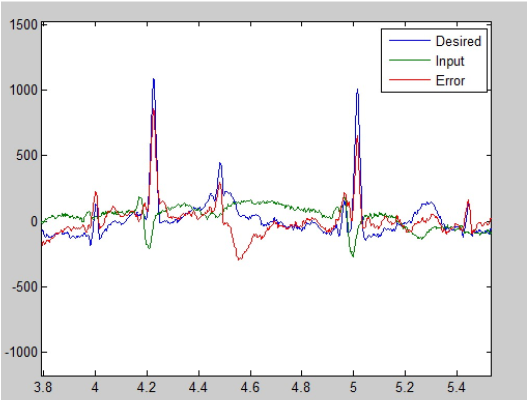

Fig.11 zoomed result

Obviously, we can find that the small peaks on the diagram above is the fetal ECG peaks, on the other hand, the high peaks is maternal ECG signal. Also, another proof is the frequency of the small peaks is bigger than the high peaks.

We compute the heart beats per minute are 75 and 129.1 which are corresponding to the maternal ECG and fetal ECG. In conclusion, this method does not ensure we can extract fetal ECG signal. It is just cancelled out the abdominal noise.

Analysis

There are two problems that we need figure it out in the further analysis. Firstly, the first method does not converge, therefore we need figure it out that why W(n) cannot access to Wopt. Secondly, for the second method, the result we have contains both maternal and fetal ECG signal, hence, we need do further processing to extract fetal ECG signal. Then I use MATLAB to compute power spectrum density of each e(n). The following diagram shows the comparison.

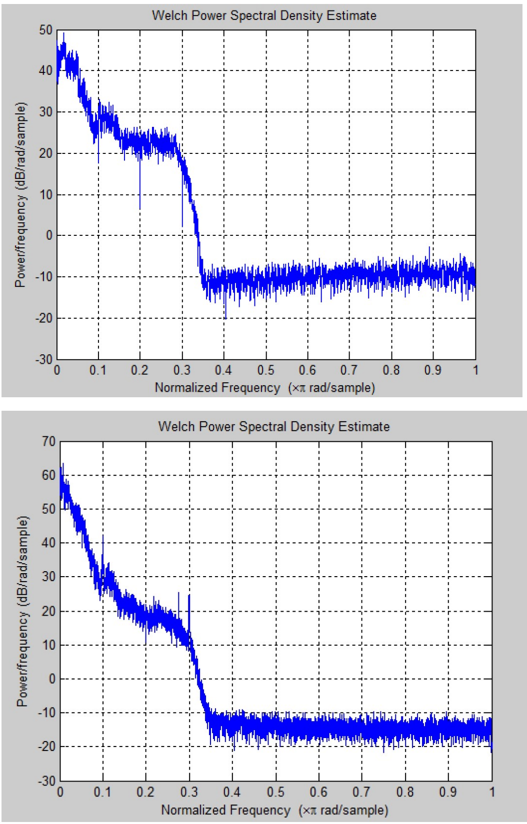

Fig.12 spectrum density of each e(n)

In the power spectrum density function, we observe that there are 50Hz and 20Hz still mixed in the ECG signal. Therefore, this method remains some low frequency noise. That shows this method get inaccuracy result. However, the second method also has positive influence. According to the Fig.12, this big wave below is possibly caused by electrode movement. We find that this method can easily remove the noise like electrode movement, baseline wander, white noise.

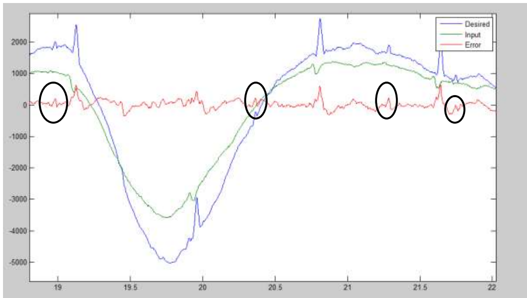

Fig.11 positive influence in second method (peaks in circle is fetal ECG)

For removing the 50Hz and 18Hz noise, we use IIR notch filter. The result is

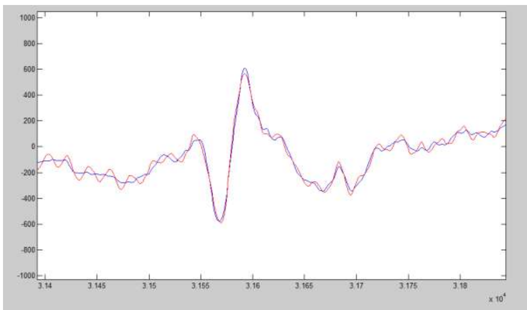

Fig.12 notch filter

We can observe that the waveform is becoming more smoother.

Conclusion

In this paper the problem of extracting fetal ECG signal from abdominal signal using a normalized LMS algorithm is presented. Its performance was found to be better than the LMS and we can obtain a better result when we have a referential fetal ECG signal. In order to get accurate result in second method, we need do the simulation by using different types of abdominal signal and choose a suitable delay to make these two signal correlated. Also, we are already getting the combined signal (maternal and fetal ECG). Therefore, the following work should extract fetal ECG signal from the combined signal and he maternal ECG should be acquired easily.

Reference

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