CHAPTER 6

FETAL ECG EXTRACTION USING ANFIS AND ADAPTIVE EQUALIZER

In this chapter, the unique characteristics of adaptive equalizer in fetal ECG extraction with minimum mean square error has been discussed.

6.1 INTRODUCTION ABOUT EQUALIZER

Equalization is the process of adjusting the balance between frequency components within an electronic signal. The most well known use of equalization is in sound recording and reproduction but there are many other applications in electronics and telecommunications. The circuit or equipment used to achieve equalization is called an equalizer. These devices strengthen or weaken the energy of specific frequency bands.

The goal of equalizers is to eliminate inter-symbol interference (ISI) and the additive noise as much as possible. Inter-symbol interference arises because of the spreading of a transmitted pulse due to the dispersive nature of the channel, which results in overlap of adjacent pulses.

Equalizers are used to overcome the negative effects of the channel. In general, equalization is partitioned into two broad categories:

- Maximum likelihood sequence estimation (MLSE) which entails making measurement of channel impulse response and
then providing a means for adjusting the receiver to the transmission environment. (Example: Viterbi equalization).

- Equalization with filters, uses filters to compensate the distorted pulses. The general channel and equalizer pair is shown in Figure 6.1.

![Figure 6.1 General Channel and equalizer pair](image)

These type of equalizers can be grouped as preset or adaptive equalizers. Preset equalizers assume that the channel is time invariant and try to find $H(f)$ and design equalizer depending on $H(f)$. The examples of these equalizers are zero forcing equalizer, minimum mean square error equalizer, and decision feedback equalizer. Adaptive equalizers assume channel is time varying channel and try to design equalizer filter whose filter coefficients are varying in time according to the change of channel, and try to eliminate ISI and additive noise at each time. The implicit assumption of adaptive equalizers is that the channel is varying slowly.

In telecommunications, equalizers are used to render the frequency response. When a channel has been "equalized", the frequency domain attributes of the signal at the input are faithfully reproduced at the output. Telephones, DSL lines and television cables use equalizers to prepare data signals for transmission.
6.2 IMPORTANT FEATURES OF ADAPTIVE EQUALIZER

The purpose of using adaptive equalizer is for compensating the channel distortion so that the detected signal will be reliable. The working principle of adaptive equalizer is shown in Figure 6.2.

![Figure 6.2 General block diagram of an adaptive equalizer](image)

In this method, the received signal is applied to receive filter. The receive filter is a low pass filter that rejects all out of band noise. The output of the receive filter is sampled at the symbol rate or twice the symbol rate. Sampled signal is applied to transversal filter equalizer. The aim is to adapt the coefficients to minimize the noise and interferences at the output. The adaptation of the equalizer is driven by an error signal.

Adaptive equalizers are working under training mode and Decision directed mode. Training mode is used to make equalizer suitable in the initial acquisition duration. In this mode of operation, the transmitter generates a data symbol sequence known to the receiver. The receiver therefore, substitutes this known training signal in place of the slicer output. Once an agreed time has elapsed, the slicer output is substituted and the actual data transmission begins.
In decision directed mode, the receiver decisions are used to generate the error signal. This error signal gives more information about the channel. This error signal is used to adjust the coefficients of the equalizer. After this training process is done, the adaptive equalizer can be continuously adjusted in the decision directed mode. The error signal is got from the final receiver estimate. The output of the adaptive equalizer is sent to the decision device receiver to get the estimate. The error signal estimate is used to adjust the coefficients of the adaptive equalizer. Decision directed equalizer adjustment is effective in tracking slow variations in the channel and other variations in the system. However, this approach is not effective during initial acquisition.

6.3 THE CHANNEL EQUALIZER

The performance of a fetal ECG signal extraction is limited by MECG signal interference and additive noise. MECG signal interference is usually a result of multipath distortion in the channel through which the signal is passed through. Such channels may be characterized by a FIR digital filter and an additive noise source.

The observed MECG signal sequence \{y(k)\}, at the receiver in response to the input MECG signal sequence \{I(k)\} is

\[
y(k) = \sum_{n=0}^{N_h-1} h(n)I(k - n) + \eta(k)
\]

\[
= h(0)I(k) + \sum_{n=0}^{N_h-1} h(n)I(k - n) + \eta(k)
\]

(6.1)

Where \(N_h\) is the length of the channel impulse response and \(\eta(k)\) is the additive noise. In the above equation, the first term represents the scaled version of the desired signal and second and third terms represent the effects of MECG signal interference and other noises respectively. To reduce the
effects of MECG signal interference and other noises, the observed signal sequence \{y(k)\} is applied to an equalizer of order \(m\).

It consists of tapped delay line with tap spacing equal to the signal interval \(T\). So, at each time instant \(k\), the input to the equalizer is a vector containing \(m\) most recent samples of the received MECG signal \(y(k)\). The equalizer performs some complex computations over this input vector in order to reduce the noises mixed up with the desired fetal ECG signal.

A block diagram of the channel equalizer is shown in Figure 6.3. The input to the equalizer is the observed MECG signal vector \(y(k) = \{y(k) y(k-1) \ldots y(k-m+1)\}\) corrupted by dispersive nature of the channel through which the signal is passed through and the additive noise such as power line interference, muscle artifacts and random Gaussian noise corresponding to the transmitted MECG signal \(I(k)\) and \(\hat{I}(k)\) at the output of the equalizer is an estimate of the MECG signal \(I(k)\). The parameters of equalizer are optimized using hybrid learning algorithm to minimize the error \(e(k)\) between the abdominal signal \(a(k)\) and the estimated MECG signal.

![Figure 6.3 Block diagram for channel equalizer](image-url)
The error signal which has FECG signal and noise is used to alter the weights of the equalizer till the desired FECG signal is obtained.

6.4 SIMULATION RESULTS

In this study, various combinations of ANFIS and equalizer is presented to optimize the extracted fetal ECG. The advantages of these methods are it requires only one abdominal signal and one thoracic signal for ECG extraction.

6.4.1 FECG Extraction using Equalizer

In this method, the simulated maternal ECG signal passed through FIR filter at first and the output is given to equalizer to give the estimated MECG signal. Then the estimated MECG signal gets subtracted from the abdominal signal to get the desired fetal ECG signal. The MSE and PSNR for the extracted FECG is obtained and the simulation results are shown in Figure 6.4.

![Figure 6.4 FECG extraction using equalizer](image)

Figure 6.4 FECG extraction using equalizer
6.4.2 FECG Extraction using Equalizer Post-processing

In this method, non-linearities between the thoracic ECG and abdominal ECG is removed at first by passing signals through ANFIS and the estimated output from ANFIS is passed through equalizer to extract fetal ECG as shown in Figure 6.5.

![Block diagram for equalizer post-processing](image)

**Figure 6.5** Block diagram for equalizer post-processing

![Signal extraction](image)

**Figure 6.6** FECG signal extraction using equalizer post-processing
6.4.3 **FECG Extraction using Equalizer Pre-processing**

In this method, MECG signal estimation is done by passing through an adaptive equalizer and the output is given to ANFIS network for further tuning. The thoracic signal is also given as a second input to ANFIS network and the signal subtraction will give extracted fetal ECG as shown in Figure 6.7.

**Figure 6.7** FECG extraction using equalizer pre-processing
6.5 COMPARISON STUDIES OF EQUALIZER, EQUALIZER PRE-PROCESSING AND EQUALIZER POST-PROCESSING METHODS

The table 6.1 shows the PSNR comparison of Equalizer, Equalizer pre-processing followed by ANFIS and ANFIS followed by Equalizer post-processing. It is evident from the result that the equalizer pre-processing followed by ANFIS minimizes the error rate and thereby improves the PSNR better than other methods. The graphical representation of the result is shown in Figure 6.8.

Table 6.1 PSNR Comparison of Equalizer, Equalizer pre-processing and post-processing methods

<table>
<thead>
<tr>
<th>Methods adopted</th>
<th>PSNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equalizer</td>
<td>81.4200</td>
</tr>
<tr>
<td>Equalizer Pre-processing</td>
<td>88.872</td>
</tr>
<tr>
<td>Equalizer Post-processing</td>
<td>73.7314</td>
</tr>
</tbody>
</table>

Figure 6.8 Comparison studies of Equalizer, Equalizer pre-processing and Equalizer post-processing Methods
6.5 CONCLUSION

In this chapter, the implementation of adaptive equalizer along with ANFIS is presented and have been analyzed for the quality of extracted FECG. The parameters used to assess the quality of the FECG are peak signal to noise ratio (PSNR) and mean square error (MSE). The results of performance evaluation for Equalizer, ANFIS followed by Equalizer post-processing and Equalizer pre-processing followed by ANFIS are compared. Upon comparison, de-noising using Equalizer pre-processing followed by ANFIS achieved the best results and can be concluded as the better of the three methods.