International Journal of the Physical Sciences Vol. 6(21), pp. 4952-4959, 30 September, 2011
Available online at http://www.academicjournals.org/IJPS
DOI: 10.5897/IJPS11.415
ISSN 1992 - 1950 ©2011 Academic Journals

Full Length Research Paper

Comparative analysis of fetal electrocardiogram (ECG) extraction techniques using system simulation

M. M. Sheikh Algunaidi[1], M. A. Mohd Ali[1] and Md. Fokhrul Islam[2]*

[1]Department of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia.
[2]Department of Electrical and Electronic Engineering, Islamic University of Technology, Board Bazar, Gazipur-1704, Bangladesh.

Accepted 2 September, 2011

This paper presents a system simulation to compare between two adaptive filters based on recursive least square (RLS) and normalized least mean square (NLMS), in their use for fetal heart rate (FHR) monitoring. The reference and primary signals are fed simultaneously to the inputs of the RLS and NLMS adaptive filters to extract the fetal signal. Each extracted signal is postprocessed using a newly developed enhancement technique. To evaluate the performance of the electrocardiogram (ECG) extraction, 20 abdominal ECG signals are acquired between the 36th and 38th gestation weeks. The detection sensitivities of 88.6 and 80.4% and positive prediction value of 82.8 and 72.1% were obtained for RLS and NLMS, respectively. The experimental results show that adaptive filtering using RLS algorithm performs better in extracting the fetal ECG signal.

Key words: Adaptive noise cancelation (ANC), recursive least square (RLS), normalized least mean square (NLMS), MQRS window, fetal electrocardiogram (FECG) extraction.

INTRODUCTION

The electrocardiogram (ECG) still is the simplest non-invasive diagnostic method for various heart diseases. Specially, the fetal ECG (FECG) signal reflects the electrical activity of the fetal heart and provides valuable information of its physiological state (Assaleh, 2007). Non-invasive FECG has been used to obtain valuable clinical information about the fetal well being during pregnancy by using skin electrodes placed on the maternal abdomen. However, the abdominal ECG (AECG) is always corrupted with power line interference, maternal ECG (MECG) and electromyogram (EMG), where the FECG signal is influenced by the gestational age, position of the electrodes and the skin impedance (Goodlin, 1979).

Various research efforts have been proposed to extract the FECG from the AECG, such as time-sequenced adaptive filtering (Ferrara and Widrow, 1982), correlation techniques (Abboud et al., 1992), blind source time frequency analysis and complex wavelets (Karvounis et al., 2006), where then depend on the power separation (Lathauwer et al., 1995), EEG based on real time algorithm (Suresh and Puttamadappa, 2008) and spectrum of the signal to eliminate the maternal QRS (MQRS) complex. Adaptive noise cancelation techniques (ANC) have been used to remove the noise signal from the measured signal using a reference signal that is highly correlated with the noise signal, RLS and NLMS adaptive filters for noise cancellation from phonocardiograph signal have been compared (Mittra et al., 2007). In this paper, the two filters are compared when extracting FECG from the AECG. The fetal extracted signals by most of the aforementioned techniques still have maternal residual peaks; hence, an enhancement technique is proposed to scale down the MQRS complex and to adjust its amplitude. The performance of the filters with the enhancement technique is evaluated by using recorded data from the Universiti Kebangsaan Malaysia Medical Center (UKMMC).

MATERIALS AND METHODS

For evaluating and testing the FECG extraction, three channel

*Corresponding author. E-mail: islammdfokhrul@gmail.com.

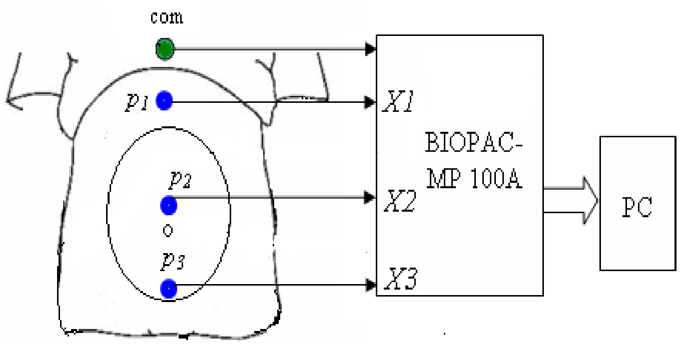

Figure 1. Locations of the abdominal electrodes.

records (four electrodes, p∈ [l, 2, 3] with a single common) are acquired as shown in Figure 1. Twenty AECG signals were recorded from healthy pregnant women with gestational periods between 36 and 38 weeks. Signals were acquired using disposable Ag/AgCl electrodes and amplified with a high gain amplifier (BIOPAC- MP 100A). The AECG signals are digitized at 256 Hz with 12 bit resolution. For comparison purpose, five seconds duration of signals were used.

The experimental protocol was approved by the UKMMC Research and Ethical Committee prior to commencement of the study. The first electrode (com in Figure 1) is placed at the sternum, and considered as common to the three input channels. The second electrode (p1 in Figure 1) is placed in such a way that it will acquire only the MECG signals, and considered as the reference. The other electrode (p2 or p3 in Figure 1) is considered as primary acquiring a mixture of MECG and FECG. The recorded signals are transferred and stored in a personal computer as *.mat files.

Description of extractor

The FECG signal extraction consists of four stages. The first stage is the preprocessing, which involves with the removal of the DC signal and the baseline wander using zero mean and band-pass filter, respectively. The second stage is the maternal signal peak detection and the creation of the MQRS window (MQRSW) signal. The third stage is to extract the fetal signal using ANC based on the RLS and NLMS techniques. In the fourth stage, the postprocessing technique scales down the MQRS complexes in the extracted signal by applying the window signal created in the second stage. The proposed technique is illustrated in Figure 2 and discussed in details as follows.

Preprocessing

The preprocessing stage consists of the removal of the DC signal, baseline wander and the power line interference. The observation signals X_1, X_2 and X_3 are acquired from the maternal abdomen as shown in Figure 1. They are then made zero mean by subtracting the mean as follows:

$$X(k) = X(k) - mean(X(k)) \quad (1)$$

The signals are then passed through a finite impulse response (FIR) hamming band-pass filter with cutoffs at 40 and 4 Hz within the bandwidth of interest for FECG monitoring.

MQRSW creation

In order to create the MQRSW, the maternal signal peaks should first be detected. For this purpose, a threshold free peak detection algorithm based on moving interval (MI) is used to detect the MQRS peaks from the filtered (Y1) signal (Sheikh and Mohd Ali, 2009). The implementation of the detection algorithm depends on the normal maternal heart rate (MHR), its RR interval and sampling frequency. As depicted in Figure 3, the maximum normal MHR is assumed 100 beats per min (BPM) and the minimum 60 BPM. The sampling frequency is chosen to be 256 Hz in this work. The RR interval and its double can be calculated as follows:

$$RR \cong (1/HR) \times 256 \times 60 \quad (2)$$

Therefore, the maximum normal RR interval is about 250 samples (its double is 500 samples) and the minimum is about 150 samples (its double is 300 samples). The RR intervals are ranged between 150 and 250 samples, and the range of double RR interval is between 300 and 500 samples. In Figure 3, the maximum RR interval is shown at the top, the minimum RR interval at the bottom and between them, is an example of medium RR interval.

Let the three cases start at the same starting peak MP (i) at index i, then the starting point of the moving interval (SMI) is chosen to be $MI(i+17)$ to account for the QRS complex after the detected peak by 17 samples. The end point of the moving interval (EMI) must be in a location that is greater than the location of the peak (A) of the maximum RR interval and smaller than double the minimum RR interval or before peak (B). Thus, the EMI is chosen to be equal to $MI(i+290)$. Within these limits, only one peak (A, C or D) can be detected in every moving interval (MI) as shown in Figure 3. Detecting the peak in the MI is executed by taking the maximum:

$$Mp(i_m) = MAX(MI(i+17 : i+290)) \quad (3)$$

Once the peak is detected, the MI will be shifted forward after the detected peak by 17 samples for SMI and by 290 samples for EMI in order to detect the next peak. The principle of the peak detection is illustrated in Figure 4a. This principle does not require any previous knowledge about the peak threshold making the detection of low computational complexity and robust.

After the maternal signal peak detection, the MQRSW is created. Every MQRS complex is captured within a window which is defined by taking 13 samples before and after the MQRS peaks found in the reference signal (Y1) (Sheikh et al., 2011). All the samples between two MQRSW are zero padded. The signal resulting from this process is known as the window signal as shown in Figure 4b.

FECG extraction

Adaptive filters track the dynamic nature of a system and eliminate the noise from the signal. These filters minimize the difference between the output signal and the desired signal by altering their filter coefficients assuming the noise on the input port remains correlated to the noise on the desired port. One of the main applications of the adaptive filters is the noise removal using ANC as shown in Figure 5.

ANC estimates a fetal signal $FECG_p$, contaminated by additive noise, maternal signal $MECG_p$, p∈ [2, 3] with the primary input

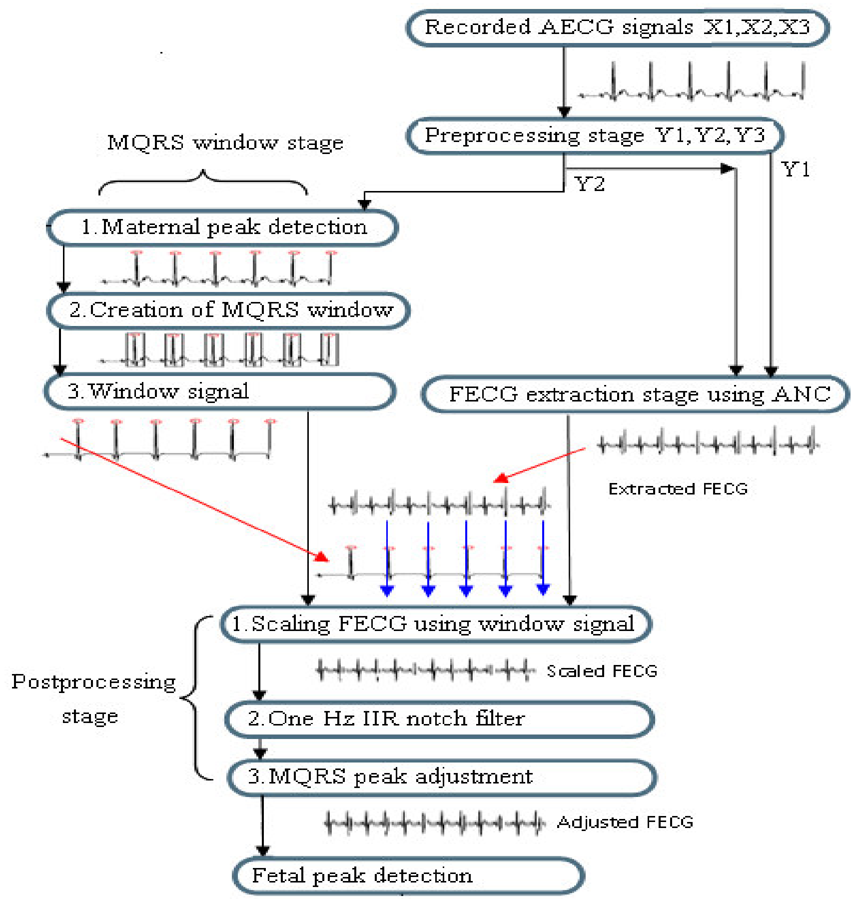

Figure 2. The block diagram of the proposed technique.

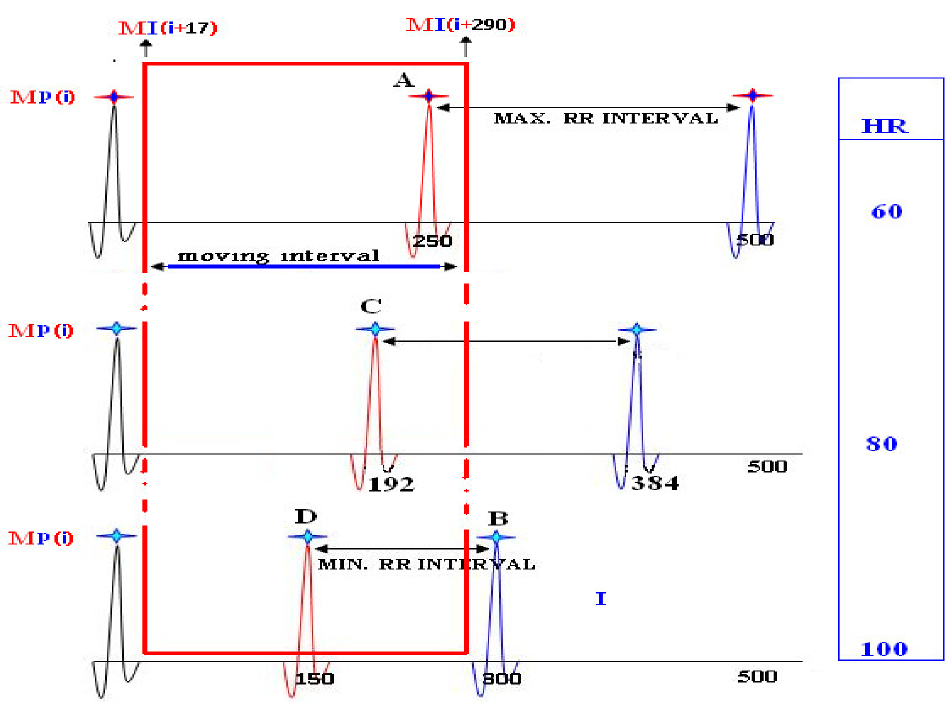

Figure 3. Moving interval for peak detection.

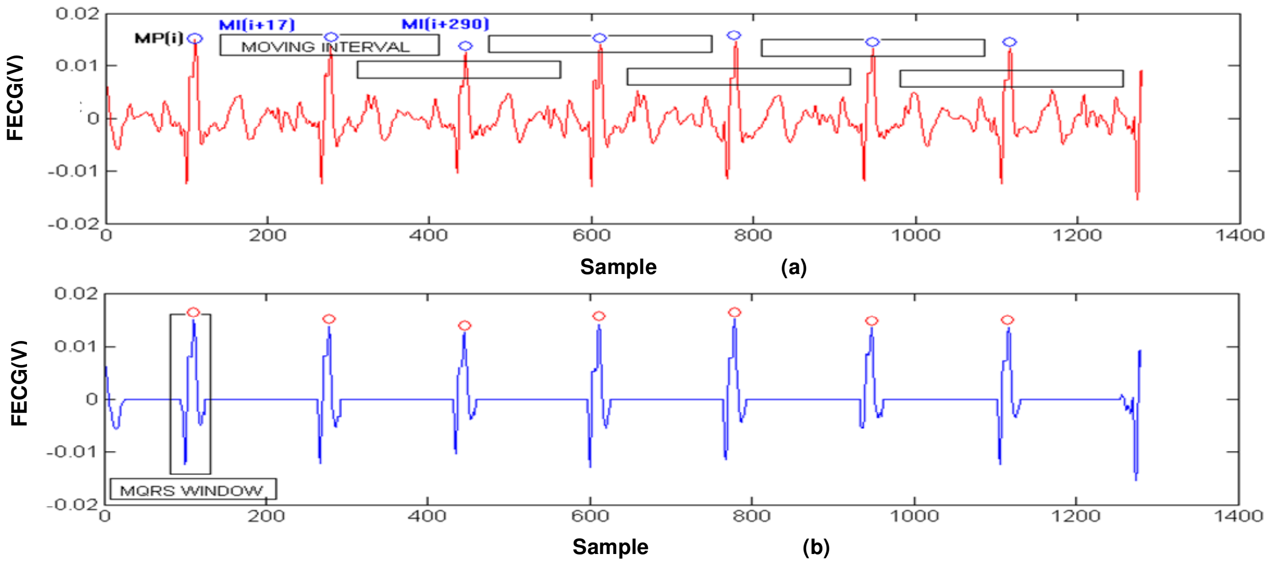

Figure 4. (a) Peak detection using MI, (b) window signal consisting of seven MQRS windows.

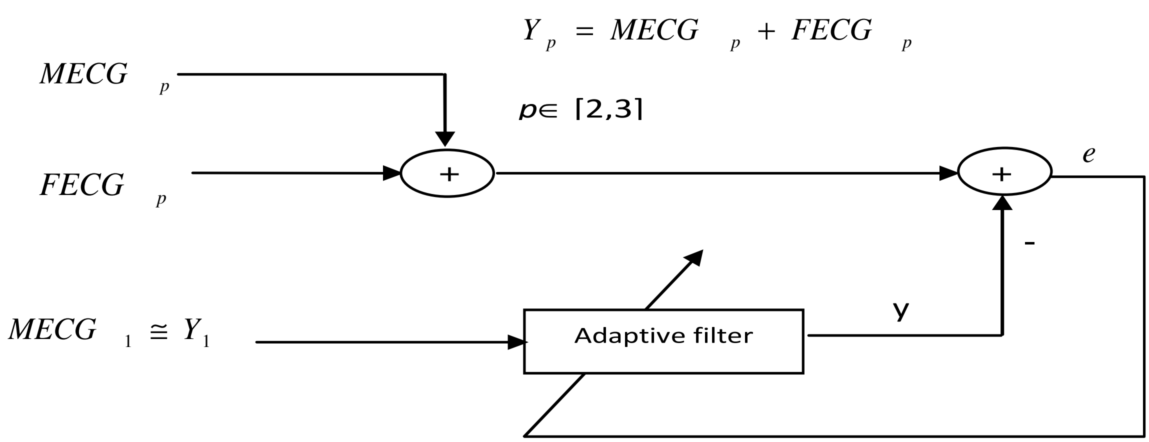

Figure 5. Adaptive noise canceller system.

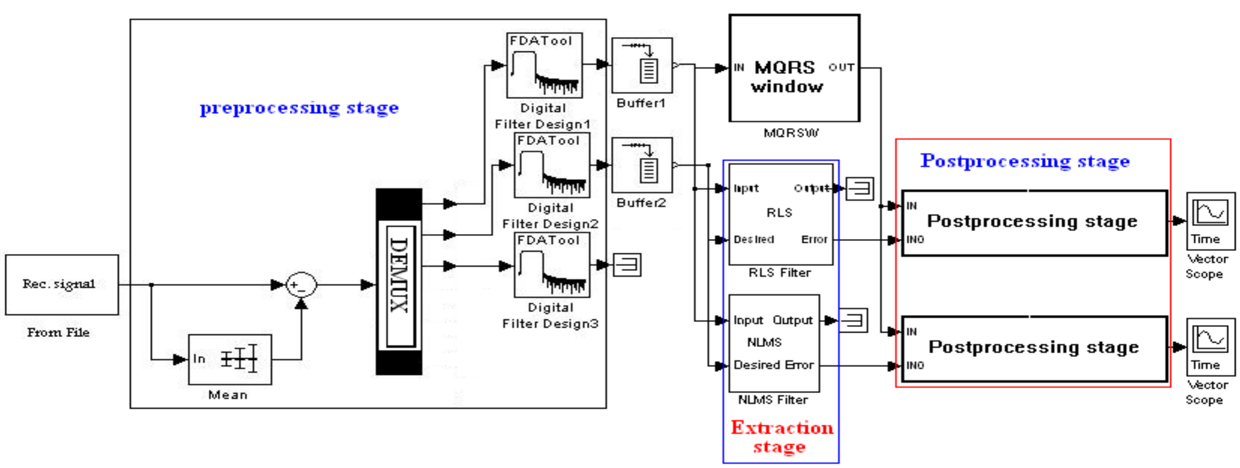

Figure 6. Computer simulation for FECG extraction using RLS and NLMS filters.

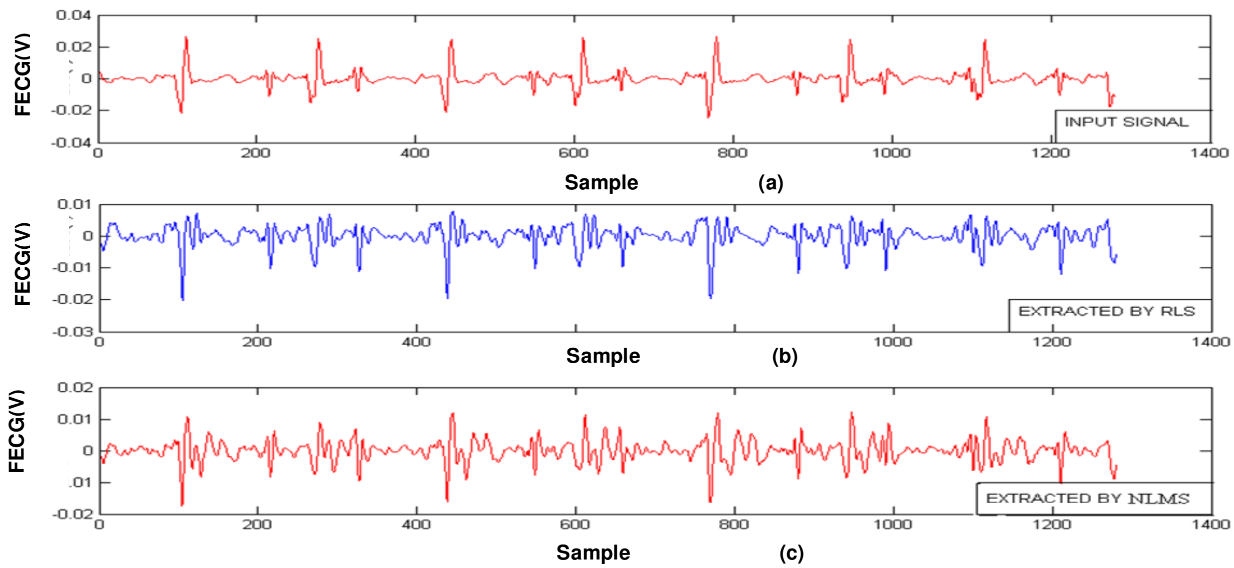

Figure 7. (a) Primary signal after preprocessing stage, (b) fetal extracted signal by RLS filter and (c) fetal extracted signal by NLMS filter.

becoming Y_p using a reference input, $MECG_1 \cong Y_1$ (Widrow et al., 1975). In the present work, this filter is used for removal of external unwanted noise from the FECG. In this stage, two signals Y_1 and Y_p (Y_2 or Y_3) are fed simultaneously to the inputs of the RLS and NLMS filters as reference and primary, respectively to extract the fetal signal $FECG_p$.

After $FECG_p$ extraction using ANC, it is noted that the maternal signal residual peaks are still observed, which means that it is still difficult to detect the fetal peaks. Hence, an effective enhancement technique is required to further enhance the fetal extracted signals by attenuating other interfering components.

Postprocessing

MQRSW is applied to the extracted signal at the output of the ANC in order to scale down the maternal signal residual complexes. After scaling down, the extracted $FECG_p$ signal still has a small amount of baseline wander. Therefore, a second order infinite impulse response (IIR) notch filter centered at 1 Hz is used to attenuate this baseline wander. Finally, the amplitude of the maternal and the overlapped peaks (maternal and fetal) in the extracted signal should be adjusted to keep all the amplitudes of the maternal peaks shorter than the amplitudes of the fetal peaks.

SYSTEM SIMULATION

A Simulink model was created using blocks from the Simulink library and blocks embedded with Matlab functions as shown in Figure 6. The system simulation was performed to compare between the RLS and NLMS adaptive filters for extracting the fetal signal. The recorded signals were stored in the 'From File' block and applied to the input of the preprocessing stage. The 'Mean' block and the add/subtract block performed the function of Equation 1. The output of the zero mean function was connected to the 'DEMUX' block to split the ECG channels to the FIR hamming band-pass filters. This stage is ended by buffering 5 s of each signal. The output of 'Buffer1' are fed simultaneously to the input ports of the 'RLS' and 'NLMS' blocks as reference signal. At the same time, 'Buffer2' fed the desired ports of the 'RLS' and 'NLMS' blocks and the input port (IN) of the 'MQRSW' block. The window signal from the output port (OUT) of the 'MQRSW' block is fed to the (IN) ports of the postprocessing stages. The fetal extracted signals derived from the (Error) ports are fed to the (INO) ports of the postprocessing stages. The resulting extracted signals are shown in Figure 7.

The fetal extracted signals are still corrupted with maternal signal residual peaks and some baseline wander which are scaled down and notch filtered, respectively. In order to detect the fetal peak, the amplitudes of the maternal and the fetal overlapped peaks in the extracted signal need to be adjusted, to keep all amplitudes of the maternal peaks shorter than those of the fetal peaks. The first step is to get the maximum value (mv) between adjacent maternal peaks. Once the maximum has been detected, the amplitude of the adjacent maternal peaks in the extracted signal is adjusted to be 0.75 × mv. Finally, fetal peaks are detected from the enhanced signals at the end of this stage by using similar procedure for the detection of the maternal signal peaks.

RESULTS AND DISCUSSION

The fetal extracted signals by the two adaptive filters are nearly similar, but when the fetal signals cannot be observed or are noisy, the RLS filter has better performance as shown in Figure 8. The maternal signal residual peaks are then attenuated in both extracted signals by using the window signal. The resulting signals are illustrated in Figure 9.

A small amount of baseline wander has also been observed in the extracted signal. Figure 10 shows the resulting signal after the IIR notch filter. The MQRS

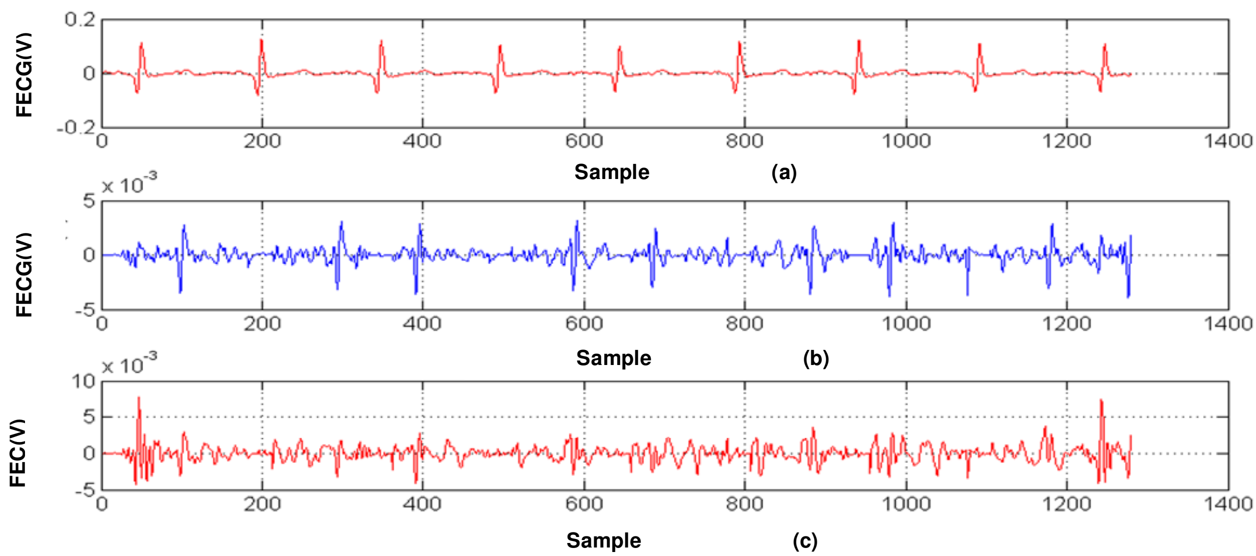

Figure 8. (a) Primary signal after preprocessing stage showing negligible fetal signal, (b) fetal extracted signal by RLS filter, and (c) fetal extracted signal by NLMS filter.

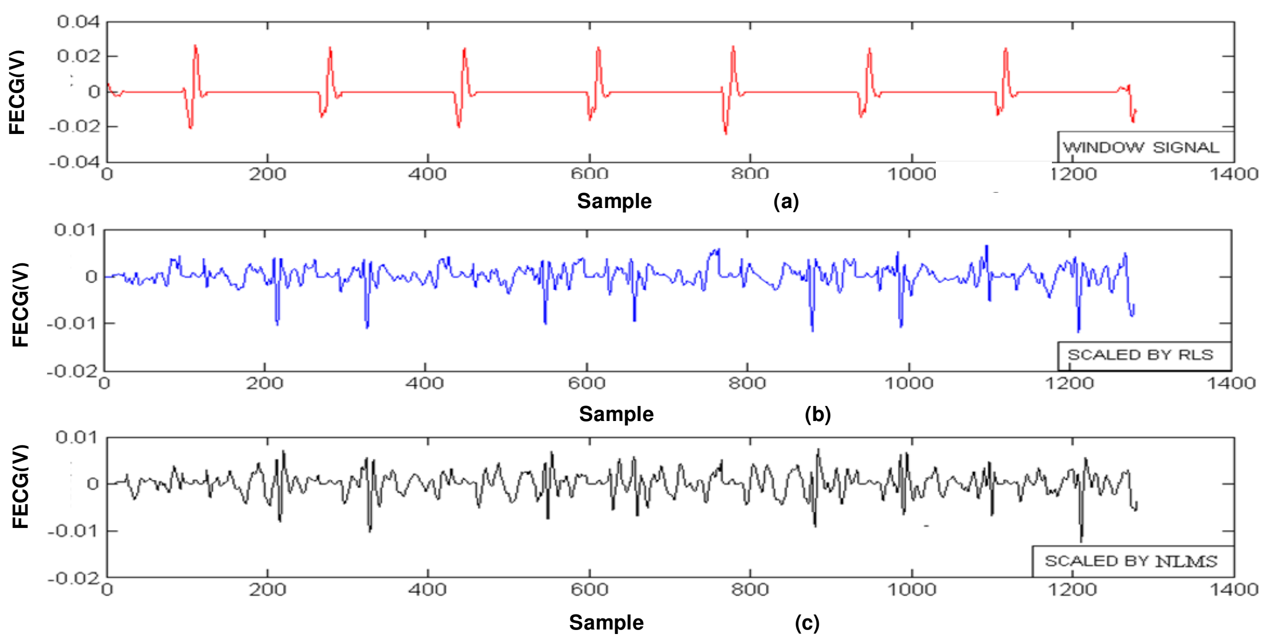

Figure 9. (a) The window signal, (b) scaled fetal extracted signal by RLS filter and (c) scaled fetal extracted signal by NLMS filter.

complex peaks are then adjusted for easier detection of the fetal signal peaks with results as shown in Figure 11.

The results of the fetal signal peaks detection are summarized in Table 1. It shows that the average values of sensitivity (Se) and positive prediction ($+P$) of the RLS based method are 88.6 and 82.8%, respectively as compared to 80.4 and 72.1% of the NLMS based method. The results in Table 1 demonstrate that the RLS adaptive filter is a more robust algorithm in extracting the FECG signal as compared to NLMS adaptive filter.

Conclusions

This paper demonstrates a system simulation to compare the performance of RLS and NLMS adaptive filters, for detecting the FHR. A Simulink model using blocks from

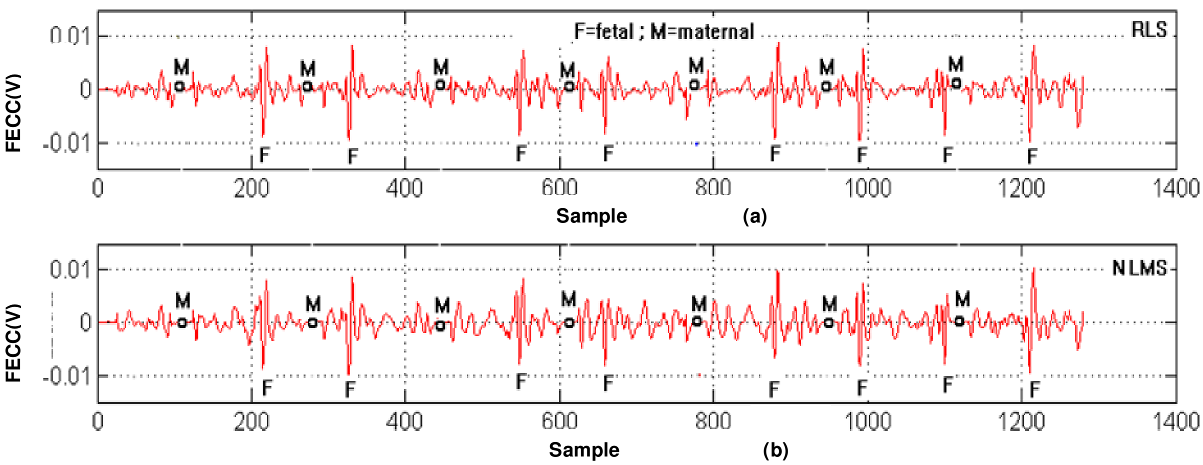

Figure 10. Fetal signal after the IIR notch filter, (a) fetal extracted signal by RLS filter, (b) fetal extracted signal by NLMS filter (M = locations of maternal signal peaks and F = fetal signal peaks).

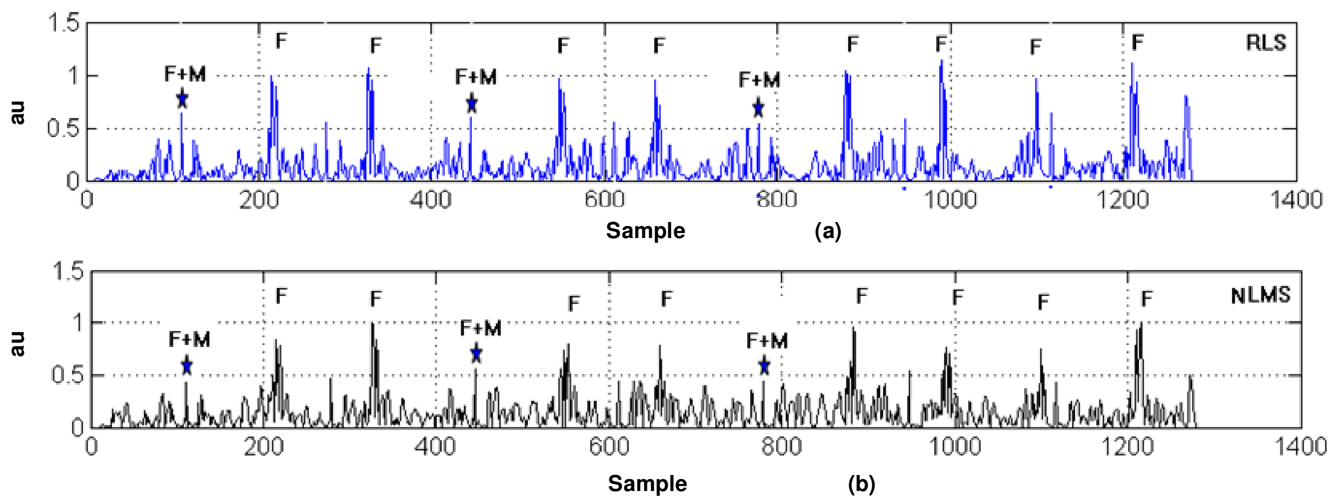

Figure 11. Fetal signal after adjustment, (a) fetal extracted signal by RLS filter, (b) fetal extracted signal by NLMS filter (F = fetal signal peaks and F + M = overlapped peaks).

Table 1. Performance of RLS and NLMS based methods.

Week	Number of signals	RLS method		NLMS method	
		Se (%)	*+P (%)*	*Se (%)*	*+P (%)*
36	9	86.2	82.9	81.9	72.9
37	5	92.4	78.8	74.9	66.7
38	6	89.0	85.9	82.9	75.3
Overall average		88.6	82.8	80.4	72.1

Simulink library and blocks embedded with Matlab functions was presented to evaluate these performances. The average values of sensitivity and positive prediction of the RLS based method are 88.6 and 82.8%, respectively as compared to 80.4 and 72.1% of the NLMS based method. According to the results, the RLS ANC technique gives better results to be used in realizing FHR monitoring. In addition, the MQRSW scale down in the postprocessing stage improves the performance further by enhancing the fetal extracted signal.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Science, Technology and Innovation, Malaysia for supporting this work under the Science Fund Grant 03-01-02-SF0255. The authors would also like to express their gratitude to Professor Dr. Muhamad Abdul Jamil M. Yassin and Associate Professor Dr. Shuhaila Ahmad for their assistance in collecting the clinical data.

REFERENCES

Abboud S, Alaluf A, Einav S, Sadeh D (1992). Real time abdominal fetal ECG recording using hardware correlator. Comput. Biol. Med., 22: 325–335.

Assaleh K (2007). Extraction of feral electrocardiogram using adaptive neuro-fuzzy inference system. IEEE Trans. Biomed. Eng., 54(1): 59-68.

Ferrara ER, Widrow B (1982). Fetal electrocardiogram enhancement by time-sequenced adaptive filtering. IEEE Trans. Biomed. Eng., 29: 458–460.

Goodlin RC (1979). History of fetal monitoring. Am. J. Obstet, Gynecol., 133(3): 323-352.

Karvounis EC, Tsipouras MG, Fotiadis DI, Naka KK (2006). A method for fetal heart rate extraction based on time-frequency analysis. Proceedings of the 19th IEEE Symposium on Computer-Based Medical Systems (CBMS'06), pp. 347-352.

Lathauwer LD, Moor BD, Vandewalle J (1995). Fetal electrocardiogram extraction by source subspace separation. Proc. IEEE SP/ATHOS Workshop HOS., pp. 134–138.

Mittra AK, Shukla A, Zadgaonkar AS (2007). System simulation and comparative analysis of fetal heart sound de-noising techniques for advanced phonocardiography. Int. J. Biomed. Eng. Technol., 1: 73-85.

Sheikh M, Mohd Ali MA (2009). Threshold-free detection of maternal heart rate from abdominal electrocardiogram. IEEE International Conference on Signal and Image Processing Applications (ICSIPA), pp. 455 - 458.

Sheikh M, Mohd Ali MA, Islam MF (2011). Evaluation of an improved algorithm for fetal QRS detection. Int. J. Phy. Sci., 6(2): 213-220.

Suresh MN, Puttamadappa C (2008). Removal OF EMG and ECG artifacts from EEG based on real time recurrent learning algorithm. Int. J. Phy. Sci., 3(5): 120-125.

Widrow B, Glover Jr, McCool JR, Kaunitz JM, Williams J, Hearn CS, Zeidler RH, Eugene JR, Goodlin RC (1975). Adaptive noise cancelling: principles and applications. Proceedings of the IEEE, 63(12): 1692 - 1716.