

*Full Length Research Paper*

# Evaluation of an improved algorithm for fetal QRS detection

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**In the area of fetal heart rate (FHR) monitoring, different sizes and multifunctional ultrasound based systems are used. All these systems are invasive but cannot be use for long term monitoring applications. The objective of this paper is to evaluate a fetal peak detection algorithm which is applied to all the abdominal channels without threshold (amplitude threshold free) that is threshold independent detection. The proposed algorithm detects fetal R peaks from pregnant abdominal non-invasive records. Fetal signals were extracted using recursive least square (RLS) adaptive filter. Subsequently an enhancement technique based on maternal QRS (MQRS) window was applied to the residual signal, then the signal smoothed by attenuating other component around one Hz using IIR notch filter. MQRS peaks were adjusted in order to make it shorter than fetal QRS (FQRS) peaks. Therefore, peak position correction is also performed to correct false detections (overlapped peaks) using correction technique based on the window signal. Thirty recorded signals (each of 60 seconds) were acquired from pregnant women (from 36 to 38 weeks of gestation) in order to evaluate the proposed algorithm. A sensitivity of 79.8% and a positive prediction value of 77.5% were obtained. The error rate of the proposed algorithm is in the range of 0.7 to 4.9% compare with the ultrasound measurements.**

**Key words:** FHR, RLS, MQRS window and threshold independent.

## INTRODUCTION

Fetal heart rate (FHR) monitoring is one of the methodologies to test fetal well being and diagnose for possible abnormalities. FECG can be derived from the abdominal ECG (AECG) which recorded by placing several leads on the abdomen of the mother.

Fetal monitoring throughout the pregnancy enables the clinician to diagnose and recognize the pathologic condition especially asphyxia (Freeman et al., 2003). Although Doppler ultrasound device is currently used for FHR monitoring, it is not suitable for long term monitoring due to its sensitivity to movement and its safety for long term exposure, which is yet to be established (Friesen et

al., 1990). Besides ultrasound, non-invasive electrocardiography has been used to obtain valuable clinical information about the fetal well-being during pregnancy. On the other hand, the AECG offers several advantages over Doppler ultrasound; lightweight electrodes are used and it is simple to operate even by the mothers themselves.

The extraction of FECG from the mixed (mother and fetus) signal can be reframed in a well-organized manner using various signal processing techniques. However, the AECG is always corrupted with power line interference, maternal ECG (MECG) and the artifacts of muscular contractions electromyogram (EMG) where its variability is influenced by the gestational age, position of the electrodes and the skin impedance (Goodlin, 1979). Therefore, appropriate signal processing techniques are

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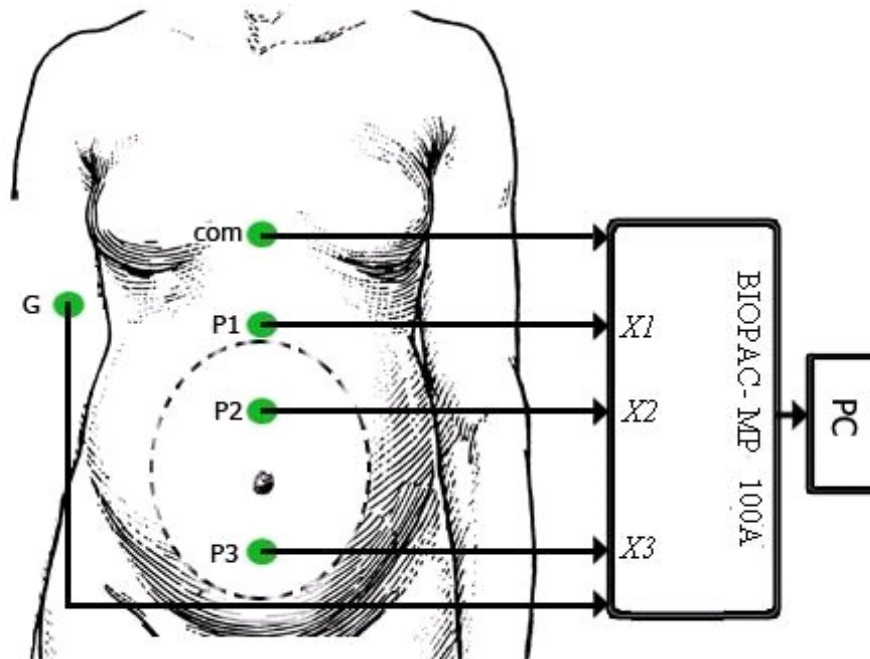


Figure 1. Locations of the abdominal electrodes.

required to reveal the FECG from the AECG. The FECG can be derived from the AECG and can be used for the extraction of FHR which is a marker for the cardiac condition of the fetus (Symond et al., 2001). Various research efforts have been proposed to extract the FECG from the AECG such as adaptive filtering (Ferrara and Widrow, 1982), correlation techniques (Abboud et al., 1992), blind source separation (Lathauwer et al., 1995), combination of wavelet analysis and blind source separation method (Maria and Jonathon, 2005) and time domain analysis (Ibrahimy et al., 2003). However, the extracted FECG is still corrupted by the residual peaks of MECG (especially its QRS complexes) hence the FECG detection remains difficult.

FHR can be obtained by determining the R-R intervals from the extracted FECG. Pan and Willis have proposed a well known algorithm for QRS peak detection based on signal derivatives, but it requires a pre-determined peak's threshold (Jiapu and Tompkins, 1985). Algorithm based on digital filter is described in (Hamilton and Tompkins, 1986), algorithm based on wavelet transform is discussed in (Li et al., 1995) and algorithm based on neural network is investigated in (Guerrero-Martinez et al., 2006). Another development of fetal R peak detection in noninvasive records is described in (Karvounis et al., 2006). Adaptive threshold window based on complex wavelets is another algorithm for peak detection (Sheikh and Mohd Ali, 2009). Since the amplitude of the extracted FECG is always fluctuated, these algorithms are not able to detect all R peaks correctly due to threshold dependency. In addition the detection of FQRS complex

on surface records is not an easy task due to the overlapping of the mother signal.

In this paper, a newly developed threshold free algorithm to detect the overlapping peaks is presented. Adaptive noise canceller (ANC) is used to extract the FECG from the AECG and the developed maternal QRS window (MQRSW) signal is used to scale down the maternal residual complex in the extracted FECG. All MQRS complexes are adjusted to be shorter than FQRS in order to detect the overlapped peak. The performance of the proposed algorithm is evaluated by using recorded data from the Universiti Kebangsaan Malaysia Medical Center (PPUKM).

## MATERIALS AND METHODS

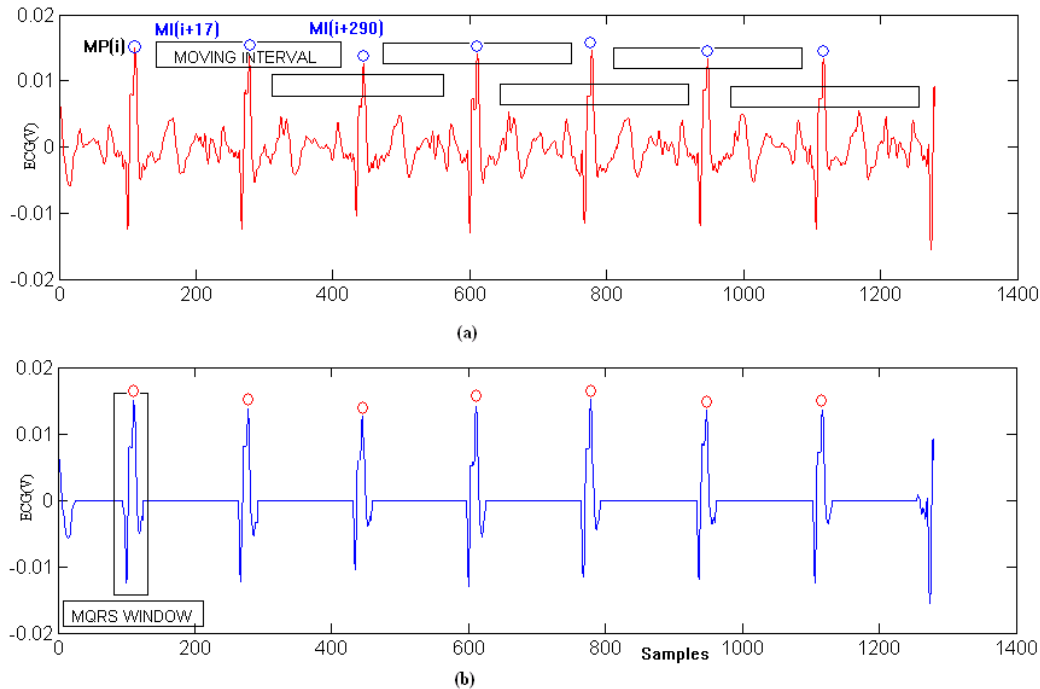
For evaluating and testing the fetal peak detection algorithm, 3 channel records (four electrodes,  $p_e$  [1, 2, 3], with a single common) were acquired as shown in Figure 1.

Thirty AECG signals were recorded from healthy pregnant women between 36 and 38 weeks of gestation. Signals were amplified with a high gain amplifier (BIOPAC - MP 100A), the AECG signals were digitized at 256 Hz with 12 bit resolution, the total recording time during each session is 60 s. Each of the stages of the proposed method is described below.

### Maternal QRS window signal

In Figure 2(a) the moving interval is developed to detect the MQRS peaks (Sheikh and Ali, 2009). The marks of the maternal R peaks are used to design the MQRSW.

Every MQRS complex is captured within a MQRSW which is



**Figure 2.** (a) The moving interval principal, (b) the window signal.

defined by taking 13 samples before and after every peak found in the primary signal. The window signal created by the MQRSW consists of all QRS complexes captured within a MQRSW and all samples that do not fall within this window are zero padded as depicted in Figure 2(b). The window signal is used to scale down the QRS residues in the fetal extracted signal according to the window signal. The QRS peaks should be adjusted in order to keep all the amplitudes shorter than the FQRS peaks in the extracted signal. The first step is to get the maximum value (MV) between adjacent maternal peaks. Once the MV has been detected, the maternal peaks in the extracted signal are adjusted to be  $0.75 * MV$ .

### Fetal QRS detection

One of the main applications of the adaptive filters is the noise cancellation. Adaptive noise canceller (ANC) is a method of estimating a fetal signal  $FECG_P$ , contaminated by additive noise, maternal signal  $MECG_P$ ,  $p \in [2, 3]$  with the primary input to the ANC becoming  $Y_p$  using a reference input,  $MECG_r \cong Y_r$ . In the present work robust recursive least square (RLS) is used for removal of unwanted noise from the FECG that is due to its ability in removing the noise comparing with another extracting technique (Ibrahimy et al., 2003). The basic block diagram of the adaptive filter for this particular application is shown in Figure 3.

Since the amplitude of the extracted FECG is always fluctuated, many algorithms are not able to detect all the R peaks correctly due to threshold dependency. In this work a developed detection algorithm is presented, which try to introduce new solution in order to firstly, overcome the difficulty of the amplitude threshold and secondly to detect the overlapped peaks. The principle of the fetal peak detection is based on the normal fetal heart beat, fetal RR interval and the sampling frequency. The FHR of interest is in

between 93 to 180 bpm. Therefore the maximum normal RR interval is about 164 samples (its double is 328 samples) and the minimum is about 85 samples (its double is 170 samples). Figure 4 illustrated the moving interval (MI) which is used to develop the threshold free algorithm.

The maximum RR interval is represented at the top of Figure 4 and the minimum RR interval is represented at the bottom, in between the other RR intervals within the frequencies of interest are shown. Assume the first fetal peak  $FP(i)$  and its index ( $i$ ) is used to define the MI. The starting point of the moving interval (SMI) is chosen to be  $MI(i+5)$ , that is after the QRS complex of  $FP(i)$ . 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  $MI(i+167)$ . Within these limits only one peak (A, C, D or E) can be detected. Detecting the peak in the MI is executed by taking the maximum value within the interval as:

$$F_p(t_f) = \text{MAX}(MI(t + 5; t + 167)) \quad (1)$$

After the (A, C, D or E) is detected, by MI. The next peak is detected by using similar MI starting at five samples after the peak. In this way the fetal peaks are detected without using amplitude threshold. Once the peak is detected the MI will be shifted forward after the detected peak by 5 samples as SMI and by 167 samples as EMI in order to detect the next peaks between the edges of every new MI. The positions of the fetal R waves were manually (using Matlab) marked in each preprocessed signal, and these reference marks were compared with the ones detected by the MI. The false detected peaks are marked with FF, overlapped OV and missing peaks MS. The detected peaks are considered false if the difference between the peaks in Figure 5(a) and (b) more than two samples otherwise correct detected.

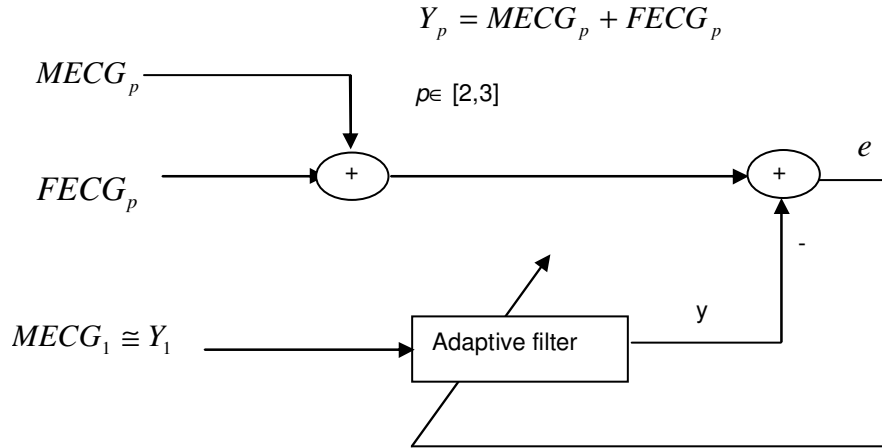


Figure 3. Adaptive noise canceller system.

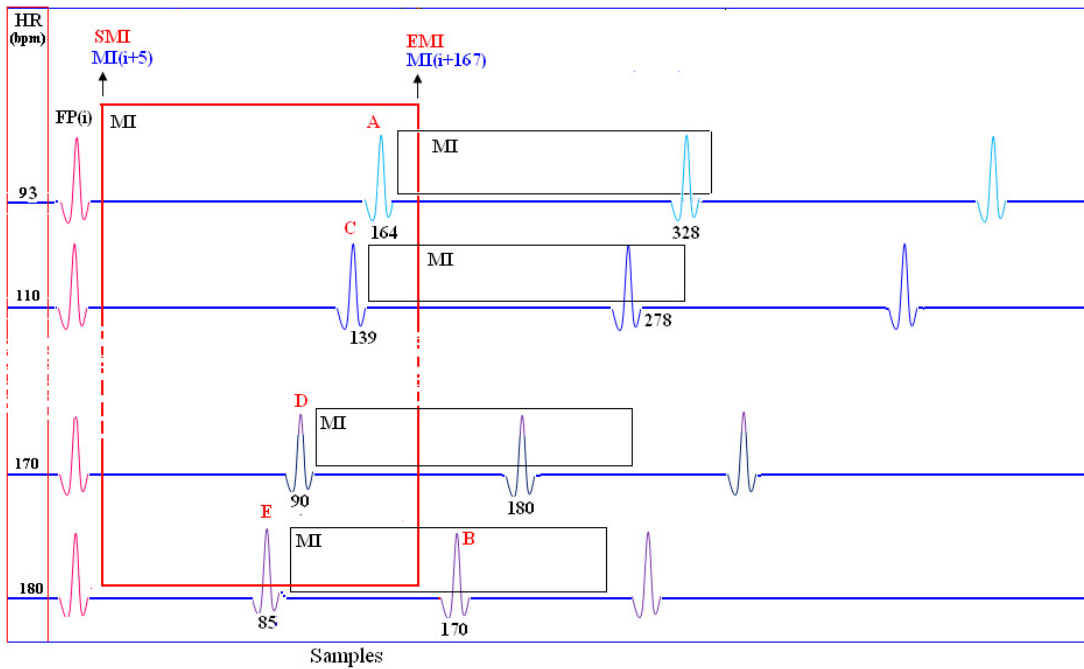


Figure 4. The principal of the peak detection moving interval.

Finally, peak position correction about amplitude and backward search are settled to correct false detections (overlapped peaks) using window signal. The fetal extracted overlapped peak is usually shifted around the original peak due to the effect of the MQRS complex overlapped with the FQRS complex. After peaks detection, overlapped peaks which are shifted from there locations are corrected. In the correction technique, the value index of the fetal peak detected in Figure 6(b) is the same index in Figure 6(a). If the index value of the fetal detected peak in Figure 6(b) has zero value for the same index in Figure 6(a), then all these peaks are equal to ( $x=2$ ) value in Figure 6(c). If the index value of the fetal detected peaks in Figure 6(b) has value different of zero for the same index

in Figure 6(a), then all these peaks (overlapped peaks) are equal to ( $y=1.45$ ) value in Figure 6(c). In the last step of the correction technique, the indexes of all value equal to ( $y$ ) are corrected if the difference between RR interval before ( $y$ ) and RR interval after ( $y$ ) more than two samples, otherwise the indexes remain the same, as shown in Figure 6(b) and (c).

**Overall system simulation**

An enhancement technique using MQRSW has applied to scale down the residual MQRS complex in the extracted signal.

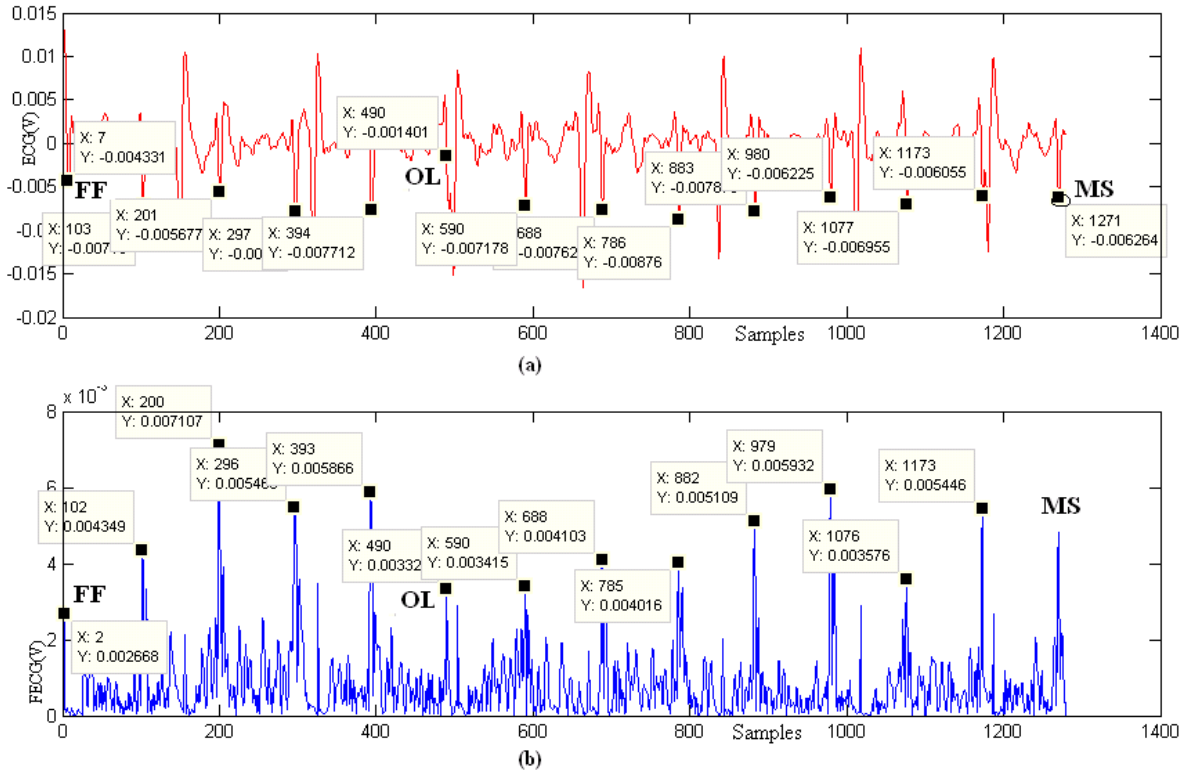


Figure 5. (a) Labeled fetal peaks after preprocessing, (b) labeled fetal detected peaks.

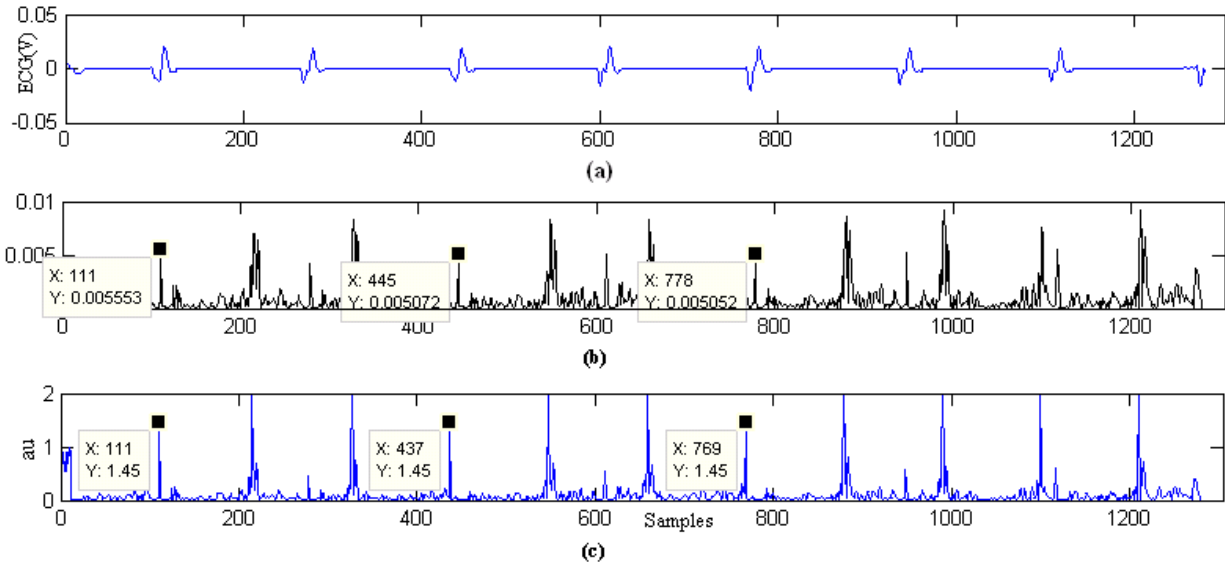


Figure 6. (a) The window signal, (b) fetal signal after adjustment, (c) fetal signal after correction.

Subsequently IIR notch filter of one Hz followed by MQRS peak adjustment are applied to the FECG signal. Finally, the developed fetal R peak detection algorithm is applied to detect the peaks in the FECG, where the false peak are corrected using the peak position

correction. Various filters with different cut off frequencies are used for removing the baseline wander, in this stage the acquired signals are fed to an interpolated finite impulse response (FIR) hamming band-pass filter with low-frequency and high-frequency cut-offs at 4

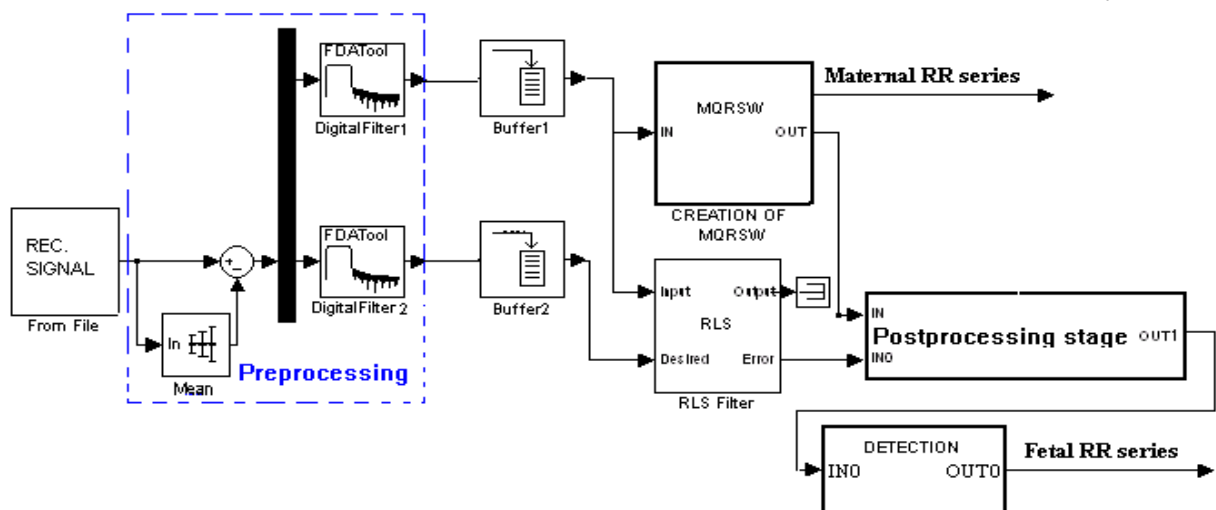


Figure 7. Computer simulation for fetal peak detection.

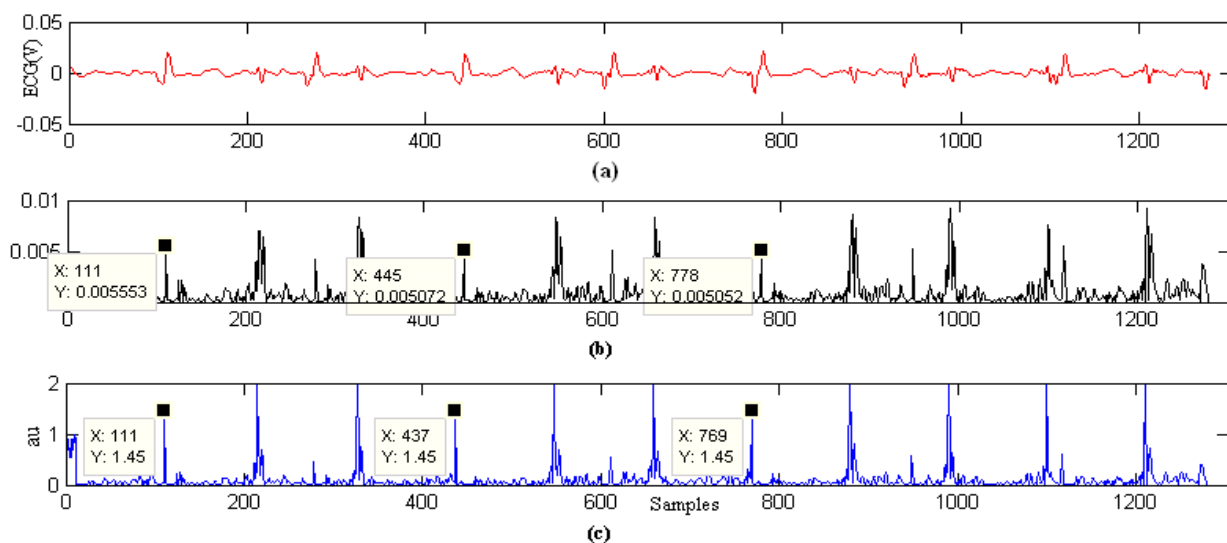


Figure 8. (a) Preprocessed AECG signal, (b) fetal signal after adjustment, (c) corrected fetal signal.

and 40 Hz respectively, which has been used to cancel baseline wander and power line interference, then for DC removal each observation signal is made zero mean by subtracting its mean from the input signal as:

$$X_n = X_n - \text{mean}(X_n) \quad (2)$$

In this work, peak detection is performed under Matlab®/Simulink® platform. The model is developed for system simulation towards realizing real time FHR, which is built by connecting the embedded Matlab function blocks and the available required blocks in the software library. The parameters of the blocks are entered while designing them for simulation. Thirty recorded data which were between 36 and 38th week of singleton pregnancy are used to test for fetal QRS detection. Recorded signals were transferred to a

personal computer and stored in "From file" block, as \*.mat file. Then these signals were, used as input signals as shown in Figure 7.

## RESULTS AND DISCUSSION

The preprocessed AECG is shown in Figure 8(a). After the fetal signal extraction, the maternal residual peaks were attenuated in the fetal extracted signals using the window signal, and smoothed using the notch filter the resulted signals is illustrated in Figure 8(b). The final signal in Figure 8(c) is the signal with corrected overlapped peaks. The obtained results from thirty

**Table 1.** Algorithm performance for fetal R peak detection.

Weeks of gestation	No. of signals	ANC method	
		<i>Se</i>	+ <i>P</i> (%)
36	12	83.3	81.0
37	8	84.3	82.4
38	10	71.9	69.4
Overall average		79.8	77.5

**Table 2.** Performance of peak detection algorithm with US.

Signal No.	Lead system protocols	Measured FHR by ultrasound	usm	Estimated FHR by proposed algorithm	Error rate (%)
36_1		156		143	1.4
36_2	F	130	141	148	4.9
36_3		138		146	3.5
37_1		139		136	2.3
37_2	F	128	133	132	0.8
37_3		133		135	1.5
37_1		130		135	1.5
37_2	G	139	133	132	0.7
37_3		128		134	0.7
37_4		133		138	3.8

recorded data each of 60 seconds are summarized in Table 1. The average values of sensitivity (*Se*) and positive prediction (+*P*) are 79.8 and 77.5% respectively. The new correction technique introduces a new solution to the cases of overlapping between maternal and fetal QRS able to overcome this difficulty compared to the other algorithms.

In Table 2, 10 estimated FECGs each of 60 seconds were used to calculate the FHR. The FHR was measured before each recording one time using ultrasound. The FHR average of these signals detected by the proposed algorithm was compared with the average of estimated FHR by ultrasound M mode. As can be seen in the Table 2, the result of this comparison shows the robust where the estimated FHR by the proposed algorithm is close to the ultrasound estimated FHR. The error rate of comparing the proposed algorithm to the usm ranged between 0.7 to 4.9%. As a result, the robust of the fetal QRS peaks detection ability is reflected from this result.

**CONCLUSIONS**

This paper has demonstrated a fetal peak detection algorithm which is applied to all the abdominal channels without threshold (amplitude threshold free) that is threshold independent detection toward realizing FHR monitoring. A Simulink model using the blocks from

Simulink Library and the blocks embedded with Matlab function was presented to evaluate the performance of the algorithm. It was obtained a 79.8% of sensitivity and a 77.5% of positive prediction value. The error rate of the proposed algorithm is in the range of 0.7 to 4.9% compare with the ultrasound measurements. In addition the enhancement technique which able to attenuate the unwanted component in the extracted signal is also presented.

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