An Improved Threshold Free Algorithm for Maternal and Fetal Heart Rate Detection

Shashi Kala Nagarkoti
Dept. of Electrical and Electronics Engineering
G. B. Pant Engineering College, Pauri Garhwal
Uttarakhand, India

Balraj Singh
Dept. of Electrical and Electronics Engineering
G. B. Pant Engineering College, Pauri Garhwal
Uttarakhand, India

B. K. Kaushik
Dept. of Electronics and Computer Engineering
Indian Institute of Technology Roorkee
Uttarakhand, India

ABSTRACT

This research work proposes an improved algorithm to extract maternal and fetal heart rate from an ECG measured of the mother’s abdomen. Recently various research efforts have been devoted to this field. The most recent ones include filtering and threshold methods, wavelet methods, neural networks and others. Each of these methods has different effectiveness and weaknesses. In spite of the fact that their performance is quite apt, the main weakness is that these methods are threshold dependent. Recent developments resulted in threshold free detection of heart rate that involves fixed length RR moving interval, calculated on the basis of normal maximum and minimum heart rate. In the proposed algorithm, we update the length of RR moving interval every time a peak is detected, based on the average maternal heart rate. The effectiveness of this algorithm lies in the fact that it uses optimized RR interval length, which is more capable of detecting a peak towards the end of the ECG which was left undetected using fixed length RR interval algorithm. This algorithm is implemented using MATLAB. The results showed that our proposed approach performs better compared to the fixed length RR interval approach.

General Terms

Abdominal ECG, threshold free algorithm, LMS

Keywords

Maternal ECG, fetal ECG, heart rate, RR interval.

1. INTRODUCTION

The ECG describes the electrical activity of the heart. An ECG during a cardiac cycle consists of P, QRS and T waves. The detection of R-peaks and consequently were of the QRS complex in an abdominal electrocardiogram signal provides information on the heart rate and thus it is an important tool for the physician for identifying abnormalities in the heart activity. This ECG is commonly measured at two locations: chest and abdomen. The abdominal leads pick up a composite signal, consisting of the contributions from both the maternal electrocardiogram (MECG) and the fetal electrocardiogram (FECG) while the chest leads contains only MECG.

Like the standard ECG, which reflects cardiac and metabolic activity, the FECG yields information about the condition of child during pregnancy. Fetal ECG signals are generally much weaker than maternal ECG signals while the fetal heart rate is usually higher than the maternal heart rate [1]. FECG signal is contaminated by various sources of interference. These sources include the maternal ECG, the maternal electromyogram EMG, 50 Hz power line interference, baseline wander and random electronic noise. The EMG noise can also be reduced but not necessarily eliminated with the use of low pass filtering techniques. Therefore, it is safe to eliminate the maternal ECG component in the composite signal, to get an estimate of the FECG signal.

A complete overview of various approaches can be found in [2]. Various research efforts have been proposed in the literature including algorithms based on filtering and threshold methods, the most well known one being the Pan and Tompkins algorithm for peak detection but it requires an initial pre-determined peak detection threshold [3]. Most recent ones include wavelet methods [4]-[9], neural networks [10]-[12] and others, but all are threshold dependent. Recently, a threshold free method was introduced by M. Sheikh M. Algunaidi [13]-[14]. As claimed, Algunaidi's algorithm has facilitated the detection of the maternal peaks without pre-determined thresholds, using fixed length RR moving interval to detect the R peaks, calculated based on the normal maximum and minimum heart rate. This algorithm is able to detect the QRS peaks at different levels of threshold, without respecting threshold value. Since the moving interval requires enough samples for its second edge, some peaks are left undetected towards the end [13]. This study introduces an alternative approach. Instead of using fixed length RR interval, we use varying length moving interval to obtain all the maternal QRS peaks present in the abdominal electrocardiogram (AECG) data so that undetected peaks are not left in the given number of samples.

This paper is organized as follows. Section II describes the algorithm of the threshold free detection method [13], the proposed moving interval approach, and the maternal heart rate (MHR) and fetal heart rate (FHR) evaluation process. Results are shown in Section III in terms of the sensitivity and positive predictivity and conclusion is drawn in Section IV.

2. METHODOLOGY

2.1 Data Acquisition

The abdominal ECG (AECG) signals used were taken from the

PhysioNet Non-invasive fetal ECG database. These signals are of a single subject between 21 to 40 weeks of pregnancy and the duration of each signal is 10 seconds. The signals were digitized at 1000 Hz with 16 bit resolution. Both Algunaidi's [13] and our proposed approach were implemented in MATLAB.

2.2 Algunaidi's Algorithm

The Algunaidi's algorithm [11] was employed in order to calculate MHR and compare with our proposed approach. The algorithm consists of three major steps. A series of pre-processing, band-pass filtering (18 ~ 35 Hz) on the original input signal and QRS peak detection to find the location of the peaks in the filtered signal. The RR interval depends on the normal heart rate (HR), where the maximum and minimum heart rate is 100 and 60 beats per minute respectively. The sample frequency is chosen 1000 Hz and RR interval can be calculated as

$$RR \approx \frac{1000*60}{HR} \qquad (1)$$

The RR (max) interval and RR (min) interval calculated according to (1) and come out to be 1000 and 600 respectively. The next step is to choose RR interval such that the person with minimum heart rate could not acquire more than one peak whereas the peak should not be left undetected in case of person having maximum heart rate. Therefore, the RR interval is chosen to be more than RR (max) and less than twice of RR (min). After the first peak M (i) detected by taking the maximum in the RR interval, the moving interval updated automatically. The next peaks detected starting from the last detected peak plus 50 samples. The moving interval updated for detecting the maximum peak between its edges. All the next peaks are detected according to (2).

$$Mp(m) = Max(Mi(i+50 : i+1150) \qquad (2)$$

2.3 Proposed Algorithm

The block diagram in Fig. 1 shows the steps of the algorithm [13]. An alternative approach presented here to obtain all the peaks available in the AECG data. Instead of having a fixed RR interval, which may leave the peaks undetected at the boundary, we deliberately update the length of our interval. It is noticeable that the RR interval would contain only one peak if properly placed after the previously detected peak. Therefore, the main task is to correctly detect the first peak in the AECG. Initially, we take the RR interval as taken in Algunaidi's method to find the first peak. But before declaring it as first peak, we look for another peak before the maximum value, which is more than 60% of the maximum value. If such peak exists, it is declared as first peak. Now the first edge of the moving interval is chosen to be Mi (i + 50). Then the second edge (SE) of the moving interval is calculated as-

$$SE = \frac{RR_{max} + 2*RR_{min}}{2} \qquad (3)$$

Then the second edge of the moving interval is equal to Mi(i+SE). After first peak detected, we update our RR interval to the first peak plus 50 samples to detect the next peak. As soon as we find the two R peaks, we update the length of our RR interval by taking the difference of two R peaks. As soon as we find the two R peaks, we update the length of our RR interval by taking the difference of two R peaks.

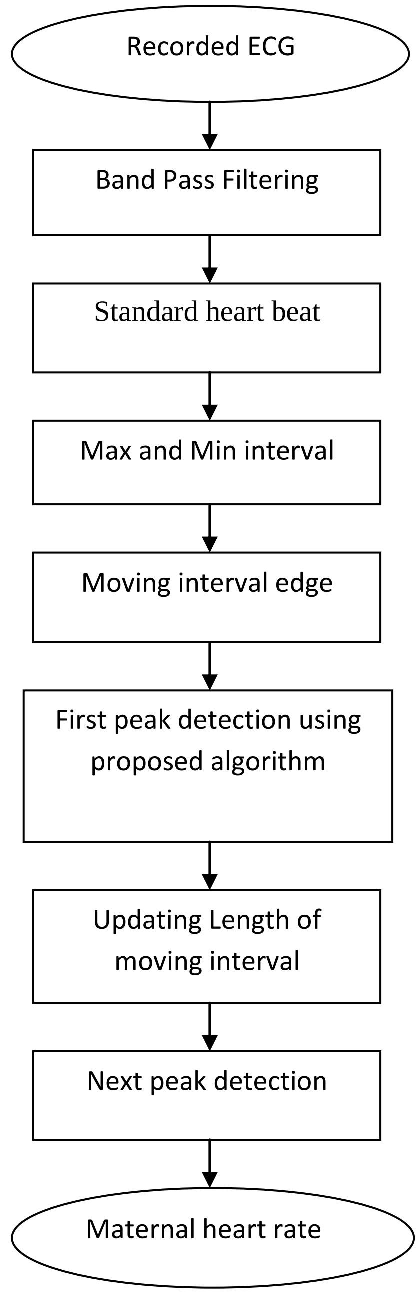

Fig 1: Block diagram of proposed algorithm

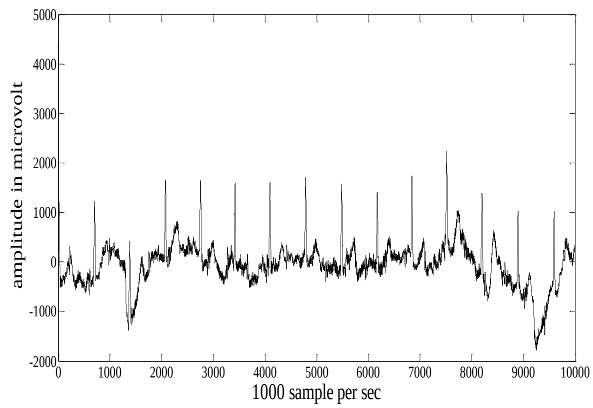

Fig 2: Input signal

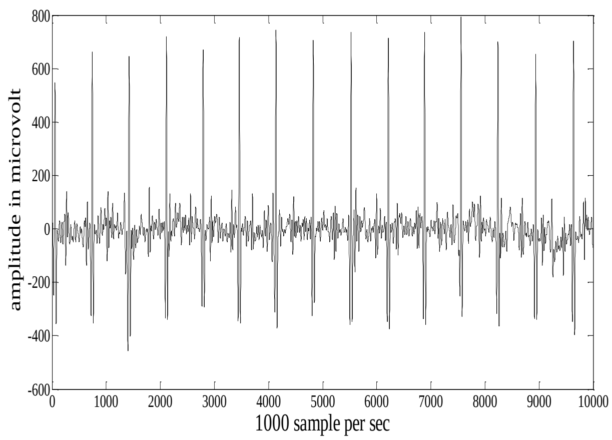

Fig 3: Filtered signal

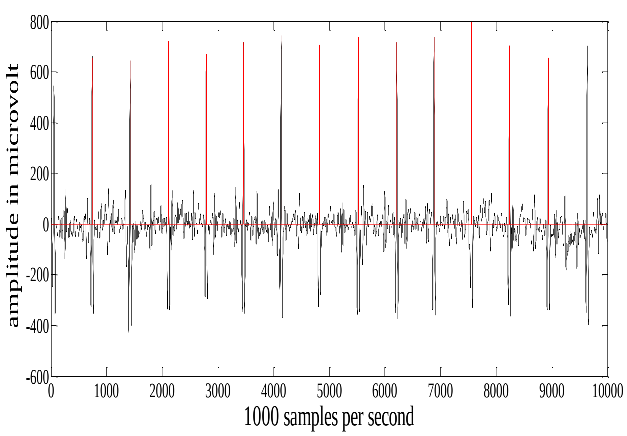

Fig 4: Detected peaks in AECG signal according to Algunaidi's algorithm

As soon as we find the two R peaks, we update the length of our RR interval by taking the difference of two R peaks. Then, as we detect more R peaks, we keep on updating the length of RR interval on the basis of estimated average heart rate. After each iteration, the length of RR interval updated and extracts a new length for rest of the peak in AECG signal. After every peak detection the window length is updated automatically and all the maternal peaks presented in the recorded AECG signal are detected. Besides selecting the length of RR interval and detecting first peak, the processing of the signal is identical to the Algunaidi's method.

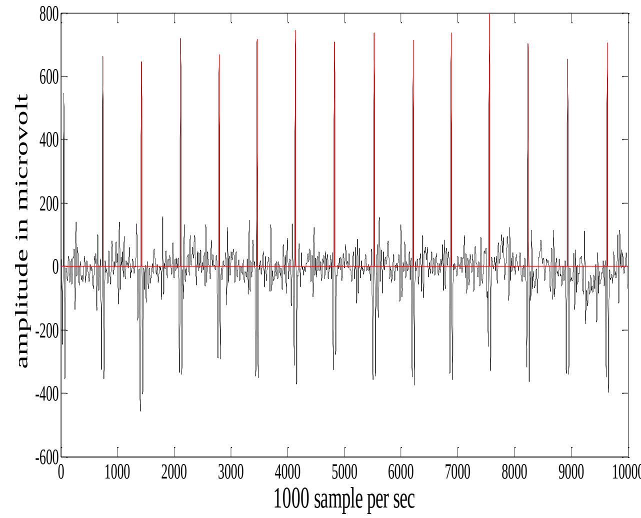

Fig 5: Detected peaks in AECG signal according to proposed algorithm

2.4 Fetal ECG Extraction

2.4.1 Maternal QRS Window Signal

The marks of the maternal R peaks (Fig 5) are used to design the maternal QRS window (MQRSW). Every MQRS complex is captured within a MQRSW which is defined by taking 50 samples before and after every peak found in the maternal ECG signal. The window signal consists of all MQRS complexes captured within a MQRSW and all samples that do not fall within this window are zero padded as depicted in Fig. 6 and Fig. 7. The window signal is used to scale down the MQRS residues in the fetal extracted signal [14].

2.4.2 Fetal QRS Detection

The fetal ECG signal is extracted from AECG signal using adaptive noise canceller (ANC) method [14]. Since the maternal residual peaks are still observed in the FECG signal, it can be eliminated after applying the maternal QRS removal window signal [14]. Fig. 8 and Fig. 9 show the extracted fetal ECG signal according to Algunaidi’s algorithm and our proposed algorithm respectively.

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. So a threshold free detection algorithm is used here to detect all fetal R peaks presented in AECG signal. The principle of the fetal peak detection is also based on the normal fetal heart beat, fetal RR interval and the sampling frequency, where the maximum rate is around 180 beats per minute and the minimum rate is around 90 beats per minute. The sampling frequency is chosen to 1000 Hz. Now the fetal peaks are detected according to Algunaidi’s algorithm (sec. 2.2) and our proposed algorithm (sec. 2.3).

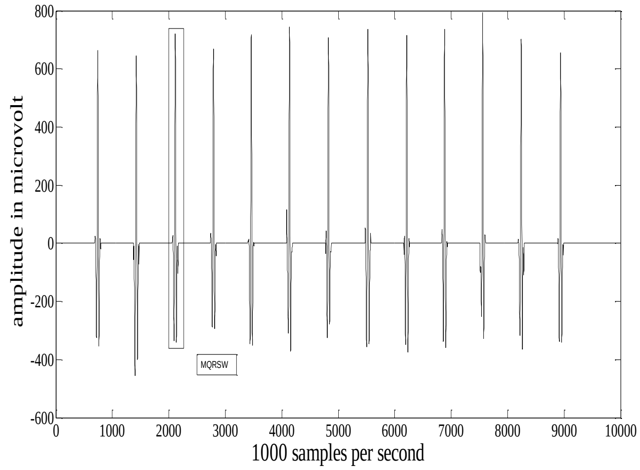

Fig 6: MQRS window signal according to Algunaidi's algorithm

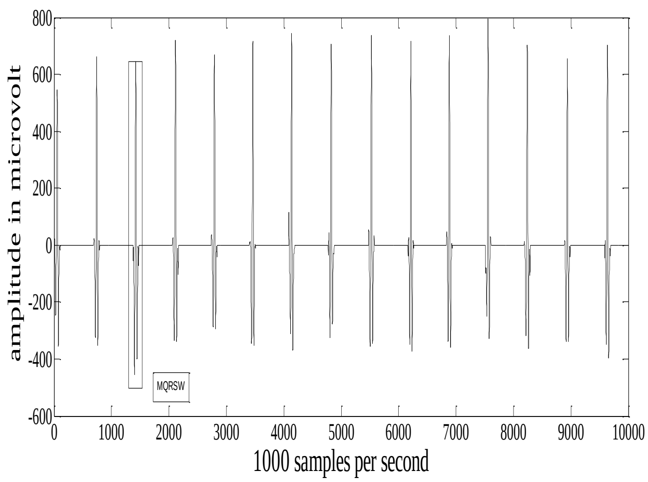

Fig 7: MQRS window signal according to proposed algorithm

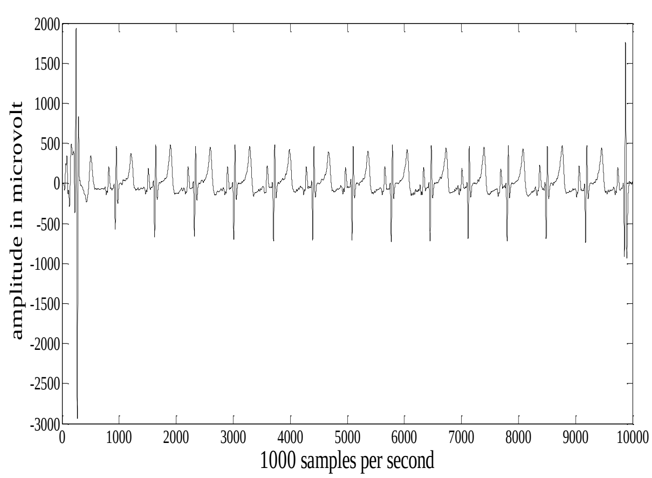

Fig 8: Fetal ECG signal according to Algunaidi's algorithm

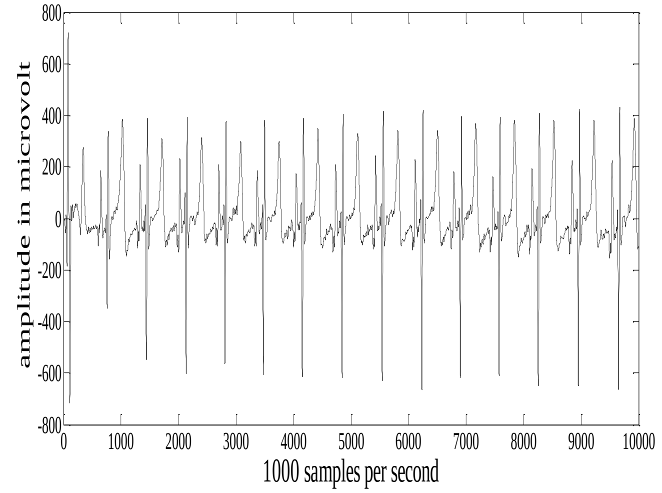

Fig 9: Fetal ECG signal according to proposed algorithm

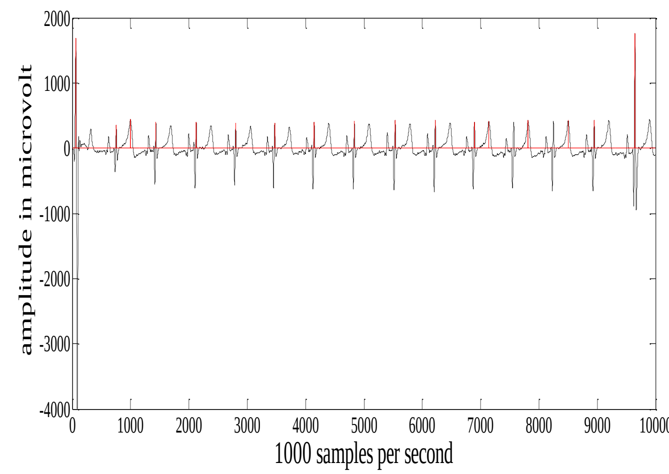

Fig 10: Detected fetal peaks in AECG signal according to Algunaidi's algorithm

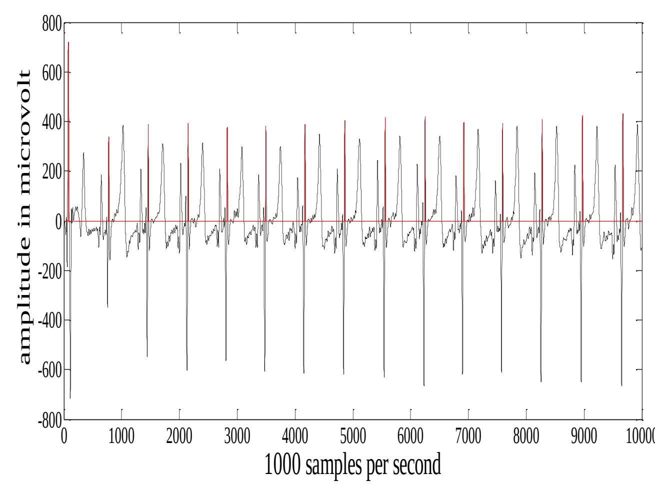

Fig 11: Detected fetal peaks according to proposed algorithm

The detected fetal peaks in the AECG data are shown in Fig. 10 and Fig. 11 respectively according to Algunaidi's algorithm [14] and our proposed algorithm.

3. RESULT

The accuracy of the proposed algorithm tested by applying it to 25 recorded signals. Each of these signals is about 10 seconds in duration. The algorithm implemented using MATLAB. Table 1 summarizes the performance of the detection scheme on the 25 recorded AECG signals. Fig. 2 and Fig. 3 show the recorded signal obtained from PhysioNet database and filtered signal respectively. Fig. 4 and Fig. 5 show detected maternal peaks in AECG signal according to Algunaidi's algorithm and proposed algorithm respectively. Fig.6 and Fig. 7 show the maternal QRS removal window signal. Fetal ECG signal after applying maternal QRS removal window is shown in Fig.8 and Fig. 9. Fig. 10 and Fig. 11 show detected fetal peaks according to Algunaidi's algorithm and proposed algorithm respectively.
To assess the performance two parameters should be used.

The sensitivity (Se) is the fraction of real events that are correctly detected and defined as,

$$Se = \frac{TP}{TP + FN} \tag{4}$$

The positive predictivity (+P) is the fraction of detections that are real events and defined as,

$$+P = \frac{TP}{TP + FP} \tag{5}$$

Where false negative (FN) denotes the number of missed detections, false positives (FP) represents number of extra detections and true positives (TP) is the number of correctly detected QRS complexes.

In case of maternal ECG, the average Sensitivity (Se) of the proposed algorithm is 99.95 % and its Positive Predictivity (+ P) is 100%. Most of the (FN) QRS complexes were found in record 368. Algunaidi's algorithm has been tested on our 25 recorded data. The average sensitivity and positive predictivity, according to this algorithm is 98.22% and 100% respectively. In case of fetal ECG, the average Sensitivity (Se) of the proposed algorithm is 86.68 % and its Positive Predictivity (+ P) is 81.88 % and according to Algunaidi's algorithm, average sensitivity and positive predictivity is 72.80 % and 79.25 % respectively. Table 1 shows the performance for maternal R peak detection according to Algunaidi's algorithm and our proposed algorithm. Table 2 summarizes the performance of the detection scheme of fetal R peaks on the 25 recorded AECG signals according to Algunaidi's algorithm and our proposed algorithm.

4. CONCLUSION

An improved approach is proposed as an alternative to the existing Algunaidi's threshold free algorithm for heart rate detection. This algorithm has been implemented using MATLAB platform. This algorithm has facilitated the detection of all the R peaks, based on normal maximum and minimum heart rate. No undetected peaks are left using this algorithm. Testing on 25 recorded data produces a performance of average sensitivity and average positive predictivity of 99.95% and 100% respectively in case of maternal ECG. In case of fetal ECG average sensitivity and average positive predictivity is 86.68% and 81.88% respectively.

A variety of experiments showed that the proposed method achieved higher sensitivity in case of MECG and higher sensitivity and positive predictivity in case of FECG than the Algunaidi's algorithm.

Table 1. Comparison of performance for maternal R peak detection

Records	Performance For Maternal R Peak Detection			
	According to Algunaidi's algorithm		According to proposed algorithm	
	TP	Se(%)	TP	Se(%)
102	13	97.5	15	100
115	15	98.9	16	100
127	14	97.7	16	100
154	13	98.7	14	100
192	13	98.7	14	100
244	14	100	14	100
252	15	98.9	16	100
274	14	98.8	15	100
300	14	98.8	15	100
308	14	100	14	100
323	14	98.8	15	100
368	14	98.8	16	98.9
384	15	100	15	100
392	15	98.9	16	100
410	14	98.8	15	100
416	15	98.9	16	100
436	14	97.7	16	100
444	16	98.9	17	100
445	13	97.5	15	100
515	14	97.7	16	100
571	14	97.7	16	100
585	13	97.5	15	100
595	14	98.8	15	100
597	14	98.8	15	100
621	15	98.9	16	100
Total/ Average	353	98.22	383	99.95

Table 2. Comparison of performance for fetal R peak detection

Records	Performance For Fetal R Peak Detection					
	According to Algunaidi's algorithm			According to proposed algorithm		
	TP	Se(%)	Pe(%)	TP	Se(%)	Pe(%)
102	17	89.47	80.95	29	90.62	90.62
115	19	79.16	100	33	100	100
127	20	74.07	68.96	34	75.56	69.38
154	16	69.56	69.56	36	85.71	73.46
192	17	94.44	100	38	86.36	73.07
244	15	65.21	75	29	69.04	69.04
252	19	59.37	59.37	36	92.30	85.71
274	20	66.67	80	25	83.34	100
300	17	56.67	56.67	31	70.45	70.45
308	18	72	85.71	29	69.04	69.04
323	18	100	100	33	100	100
368	17	94.44	80.95	31	70.45	67.39
384	18	78.26	72	33	75	70.21
392	16	55.17	61.53	33	89.18	86.84
410	18	64.28	69.23	31	72.09	70.45
416	18	60	60	33	100	100
436	20	76.92	58.82	34	97.14	91.89
444	17	89.47	89.47	31	86.11	88.57
445	16	64	94.11	36	80.00	70.58
515	16	94.11	100	31	88.57	83.78
571	17	100	100	41	95.34	87.23
585	17	85	100	44	100	81.48
595	18	90	78.26	43	97.72	82.69
597	17	77.27	89.47	41	95.34	83.67
621	16	51.61	51.61	44	97.78	81.48
Total/ Average	437	72.80	79.25	823	86.68	81.88

5. REFERENCES

[1] Khamene, A., and Negahdaripour, S. "A New Method for the Extraction of Fetal ECG from the Composite Abdominal Signal." IEEE Trans. Biomed. Engineering 47 (2000): 507–516.

[2] B. U. K'ohler, C. Henning and R. Orgelmeister, "The principles of software QRS detection", IEEE Eng. Med. Bioi. Mag. vol. 21, pp. 42-57, Jan/Feb 2002.

[3] Pan and W. I. Tompkins, "A Real-Time QRS Detection Algorithm", IEEE Trans. Biomed. Eng. vol 32, pp. 230-236, 1985.

[4] E.C. Karvounis, C. Papaloukas, D.I. Fotiadis and L.K. Michalis, "Fetal Heart Rate Extraction from Composite Maternal ECG Using Complex Continuous Wavelet Transform", IEEE computer in cardiology. 31:737-740, 2004.

[5] C.W. Li, C.X.Zheng, C.F.Tai, "Detection of ECG Characteristic Points Using Wavelet Transforms", IEEE Transaction on Biomedical Eng.,42.No.1:22-28, January 1995.

[6] J.S.Sahambi, S.N.Tandon, and R.K.P.Bhatt, "Using wavelet transforms for ECG characterization." IEEE Engineering in Medicine and Biology, 1997, 77-83

[7] Qing Chen, Jicheng Liu, Guoliang Li, "QRS wave group detection based on B-Spline wavelet and adaptive threshold", International Conference on Computer, Mechatronics, Control and Electronic Engineering (CMCE), 2010

[8] Faezipour, M. Tiwari, T.M. Saeed, A. Nourani, M. Tamil, L.S, "wavelet based denoising and beat detection of ECG signal," Life Science Systems and Applications Workshop. LiSSA 2009. IEEE/NIH, 100-103,2009

[9] Khaled Daqrouq, Ibrahim N. Abu-Isbeiht and Abdel-Rahman AIQawasmi, "QRS Complex Detection Based on Symmlets Wavelet Function", IEEE 5th International Multi-Conference on Systems. Signals and Devices, 1-5, 2008

[10] M.G. Strintzis, G. Stalidis, X. Magnisalis, and N. Maglaveras, "Use of neural networks for electrocardiogram (ECG) feature extraction, recognition and classification", Neural Net. World, vol. 3, no. 6, pp. 477-484, 1992

[11] Q. Xue, Y.H. Hu, and W.J. Tompkins, "Neural-network-based Adaptive filtering for QRS detection", IEEE Trans. Biomed Eng.voI.39, pp. 317-329, 1992

[12] Ziimray Doh, Tamer Olmez, Erturn1 Yazgan, "ECG waveform classification using the neural network and wavelet transform", The First Joint BMEW/EMBS Conference Serving Humanity, Advancing Technology Od 1316, '99. Atlanta, GA, USA, 1999

[13] M. Sheikh M. Algunaidi, M.A. Mohd Ali, "Threshold-Free Detection of Maternal Heart Rate from Abdominal ECG", IEEE International Conference on Signal and Image Processing Applications, 2009

[14] M. M Sheikh Algunaidi, M. A. Mohd Ali and Md. Fokhrul Islam. "Evaluation of an improved algorithm for fetal QRS detection", International Journal of the Physical Sciences Vol. 6(2), pp. 213-220, 18 January, 2011.