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A Novel Approach for Maternal and Fetal R-Peaks Detection

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Abstract: *The electrocardiogram (ECG) signal is one of the new trends techniques for human identification and authentication. So detecting all waves that formed this signal is very important for human identification and authentication. This research work proposes a new algorithm for detecting most of ECG signals like the signals that have positive R-peaks, the signals that have negative R-peaks and the signals that have positive and negative R-peaks. The proposed algorithm is used for detecting R-peaks from maternal and fetal ECG signals. Recently various algorithms addressed this issue. The result of these algorithms show high accuracy for detecting positive R-peaks in case of (maternal ECG) but in case of negative R-peaks (the fetal ECG) show a very low accuracy for detecting this signal. In the proposed technique the ECG signal is treated as an image and the peaks for maternal and fetal ECG are detected with very high accuracy. Scanning and removing method are used to detect the peaks. The result shows that our proposed approach produces better results as compared to existing methods on typical fetal ECG database, in case of positive and negative R-peaks.*
Keywords: *Scanned ECG image, Removing ECG image, Maternal ECG, fetal ECG, RR interval.*

I. Introduction

The electrocardiogram (ECG) signal is one of the novel biometrics behavior that can used for human identification. ECG measures electrical activity all over the heart which usually appears on a long scroll of paper that displays the activity on a computer screen. The electrical activity consists of five deflections recurrent which are QRS-complex surrounded by P and T waves associated with each beat; P-wave represents atrial depolarization and typically between 0.1 and 0.2 mv amplitude, QRS-complex represents ventricular depolarization and the normal duration between 80 and 100 ms and has an amplitude between 0.5 and 1.0 mv ,and T-wave represents ventricular repolarization and normal duration between 150 and 200 ms and amplitude approximately less than 0.5 mv. The detection of R-peaks were of the QRS complex in an abdominal electrocardiogram signal provides information on the heart rate, so it is an important for identifying abnormalities in the heart activity. The abdominal ECG is measured at two locations: Chest and abdomen. Abdomen signal consisting of the contributions from both the maternal electrocardiogram (MECG) and the fetal electrocardiogram (FECG) while the chest leads contains only MECG.

Different approaches have been proposed and used for detection of the MECG and FECG signals: filtering and threshold methods [1], wavelet based methods [2], [3],[4], [5], [6], [7] and neural networks methods [8], [9] but all of these approaches are threshold dependent.

Recently, a threshold free method was introduced by Algunaidi et al [10] and a second method by Nagarkoti et al [11].The first method uses Algunaidi's algorithm that detect 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. The second method introduces an alternative approach. This method use Nagarkoti's algorithm that using varying length moving interval instead of fixed length RR 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.

Our study introduces a new algorithm for detecting R-peaks in both maternal electrocardiogram (MECG) and the fetal electrocardiogram (FECG). The proposed algorithm uses row by row scan to detect the pixels that represent the peaks in (MECG) or (FECG) image without using any algorithm for reducing the noise that present in the signal. So it is an effective algorithm and achieves impressive results.

The organization of the paper is as follows:
Section 1 provides introduction to the research topic. Section 2 presents methodology, Algunaidi's algorithm [10], Nagarkoti's algorithm [11] and the proposed scan algorithm for detecting R- peaks from the signals. In section 3 results are discussed in terms of the sensitivity and positive predictivity and conclusion is drawn in Section 4.

II. Methodology

This section describes Algunaidi's algorithm [10] and Nagarkoti's algorithm [11] in order to compare with our proposed approach.

2.1 Data Acquisition

The abdominal electrocardiogram (AECG) signals, which are used in our testing algorithm were obtained from the PhysioNet [12]. Noninvasive fetal ECG database is available on the website. This database was taken from 25 recorded signals between 21 to 40 weeks of pregnancy. The signals were digitized at 1000 Hz with 16 bits resolution. All algorithms and our proposed approach were implemented in MATLAB.

2.2 Algunaidi's Algorithm

Algunaidi's algorithm [10] consists of three major steps: The pre-processing stage, 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 (max) interval and RR (min) interval are calculated according to an equation that get RR interval with 1000 Hz to the sample frequency. The RR interval is chosen to be more than RR (max) and less than twice of RR (min). The next peaks are detected starting from the last detected peak plus 50 samples after the first peak M(i) detected. The moving interval is updated for detecting the maximum peak between its edges. All of the next peaks are detected according to (1):

$$Mp(m) = Max(Mi(i+50 : 10+1150)) \qquad (1)$$

2.3 Nagarkoti's algorithm

Nagarkoti's algorithm [11] consists of four major steps: a series of pre-processing, band-pass filtering (18 ~ 35 Hz) on the original input signal, QRS peak detection to find the location of the peaks in the filtered signal and updating the length of moving interval. The main task is to correctly detect the first peak in the AECG. Initially, the RR interval is calculated as taken in Algunaidi's method to find the first peak. But before declaring it as first peak, they 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. 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 (2):

$$SE = (RR\ (max) + 2 * RR\ (min)) / 2 \qquad (2)$$

The RR interval is updated to the first peak plus 50 samples to detect the next peak. After the two R-peaks are found the length of RR interval is updated by taking the difference of two R- peaks.

2.4 Proposed Algorithm

The proposed algorithm is divided into two stages the first stage is detecting R-waves from maternal ECG. The second stage is detecting R-waves from fetal ECG.

2.4.1 Detecting R-waves from maternal ECG

The block diagram in "Fig. 1" shows the steps of the algorithm to detect positive R-peaks in case of maternal ECG. First, ECG record signal is converted to an image (Pixels that = 0 are the pixels represent signal and the pixels = 1 represent the pixels of background). Then, the baseline of the signal in the image is determined by calculating all pixels that represent the signal (the baseline is the line which have the maximum number of zero pixels). After detecting the baseline, the scanning method is done to find the peaks by scanning each row from top row to reach the baseline. The first peak is detected by finding the first zero pixel while doing the scan.

After detecting the first peak, its corresponding value on the baseline (fp) is calculated. Then removing method is applied to all the pixels in the area between the row containing the first peak to the baseline and between column (i) to column (j) by setting them to one. Where column (i) is the column containing the first zero pixel after (fp) and column (j) is the column containing the first zero pixel before (fp). Repeat the previous steps on the next peak to reach the baseline. "Fig. 3" shows steps of ECG image matrix update.

Step (A) shows the first detected pixel in the image, step (B) shows the image after apply the removing algorithm by setting each pixels that equal 0 to 1. Repeat these stages to detect the next peak as shown in step

(C) and step (D). The removing algorithm is useful for reducing the noise automatically.

After doing the proposed algorithm on the ECG image all peaks are detected above the baseline as shown in "Fig. 5", but R-peaks need to detect only (positive R-waves) so K-means algorithm is done to cluster the peaks into two groups the first group contain R-peaks and the second group contain the other peaks as shown in "Fig. 6".

2.4.2 **Detecting R-waves from fetal ECG**

In the first stage all peaks above baseline are detected, in this stage all bottoms (negative peaks) below the baseline are detected. The block diagram in "Fig. 2" shows the steps of the algorithm to detect negative R-peaks in case of fetal ECG. First, the scanning method is done to find the negative peaks by scanning each row from the lowest row to reach the baseline. The first negative peak is detected by finding the first zero pixel while doing the scan, its corresponding value on the baseline (fn) is calculated. Then the same removed method is done such as the first stages. This method is applied to all pixels below the baseline to detect all negative peaks. "Fig. 4" shows a steps of ECG image matrix update to detect one negative peaks.

Step (A) shows the first detected bottom pixel in the image, step (B) shows the image after removing algorithm by setting each pixels that equal 0 to 1.

III. Result

The proposed algorithm is worked on 25 recorded signals. The algorithm implemented using MATLAB. According to the proposed algorithm, "Fig. 5" shows the detected peaks of the maternal ECG signal, "Fig. 6" shows the detected maternal ECG after applying K-mean on it and "Fig. 7" shows the detected fetal ECG, and the positive and negative R- peaks on it. To assess the performance of the proposed algorithm, two parameters are used [11]:

- The sensitivity (Se) is the fraction of real events that are correctly detected and defined as (3):

$$Se = TP/ (TP + FN) \quad (3)$$

- The positive predictivity (+P) is the fraction of detections that are real events and defined as (4):

$$+P = TP/ (TP + FP) \quad (4)$$

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.

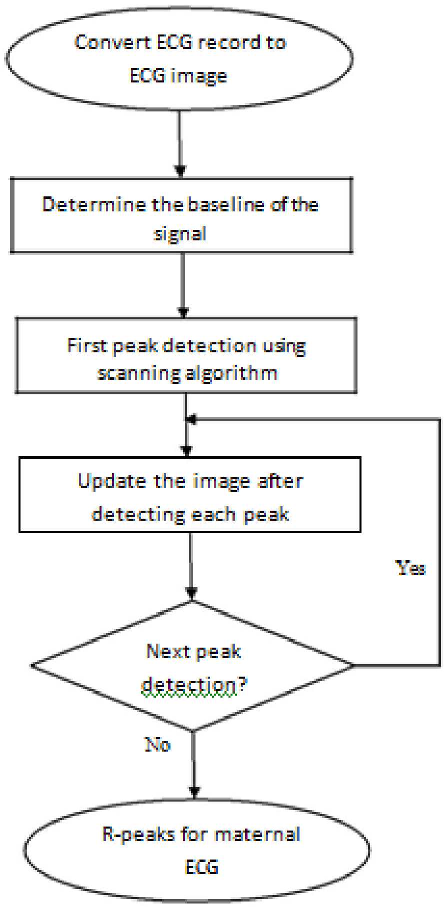
In case of maternal ECG, the average Sensitivity (Se) of the Nagarkoti's algorithm [11] is 99.95 % and its Positive Predictivity (+ P) is 100%. Most of the (FN) QRS complexes were found in record 368. Algunaidi's algorithm [10] has been tested on 25 recorded data. The average sensitivity and positive predictivity, according to this algorithm is 98.22% and 100% respectively. In our proposed algorithm the average Sensitivity (Se) is 100% and the Positive Predictivity (+ P) is 99.98%. It is noted that in case of maternal the two algorithms reach up to 95% detected R-peaks but the proposed algorithm has the highest accuracy "Table 1" summarizes the performance of the detection scheme of maternal R-peaks on the 25 recorded AECG signals according to Algunaidi's algorithm, Nagarkoti's algorithm and the proposed algorithm. But in detecting the fetal ECG, the two algorithms show low accuracy comparing with our algorithm.

"Table 2" shows the Comparison of performance for fetal R- peaks detection between the two algorithms and the proposed algorithm. In this case, as shown in the table, the average Sensitivity (Se) of the Nagarkoti's algorithm is 86.68 % and its Positive Predictivity (+ P) is 81.88. The average sensitivity and positive predictivity, according to Algunaidi's algorithm is 72.80% and 79.25% respectively. The average Sensitivity (Se) of the proposed algorithm is 100% and its Positive Predictivity (+P) is 96.78%. The result shows big different in detecting FECG between our algorithm and the other two algorithms.

IV. Conclusion

A new algorithm is implemented to detect maternal and fetal R-peaks from ECG image. This algorithm has been implemented using MATLAB platform. This algorithm has many advantages that it works on ECG images and can work also on ECG signals after convert it to ECG images, this algorithm also can detect R-peaks from different ECG signal types in case of (normal and abnormal). Another advantage, this algorithm is used on the real signal and get the actual values of the R-peaks that is useful for using this algorithm to make a system for human identification or human authentication using ECG images or ECG signals. Testing on 25 recorded data produces a performance of average sensitivity and average positive predictivity of 100% and 99.98% respectively in case of maternal ECG. In case of fetal ECG average sensitivity and average positive predictivity is 100% and 96.78% respectively. This algorithm can be enhanced to over comes the little errors in the result for detecting fetal ECG by using image processing algorithms on the FECG image such as morphological algorithm to make the result more accurately. After doing this the result of fetal ECG average sensitivity and average positive predictivity is 100% and 99.95% 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 and Nagarkoti's algorithm.



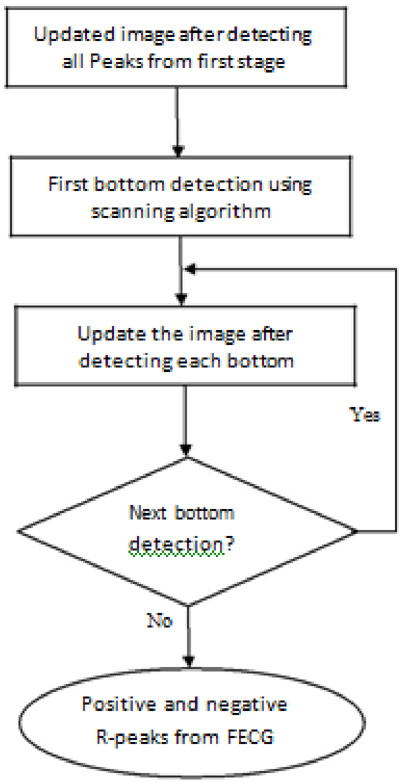


Figure 2: Block diagram of proposed algorithm to detect fetal ECG

Figure 1: Block diagram of proposed algorithm to detect maternal ECG

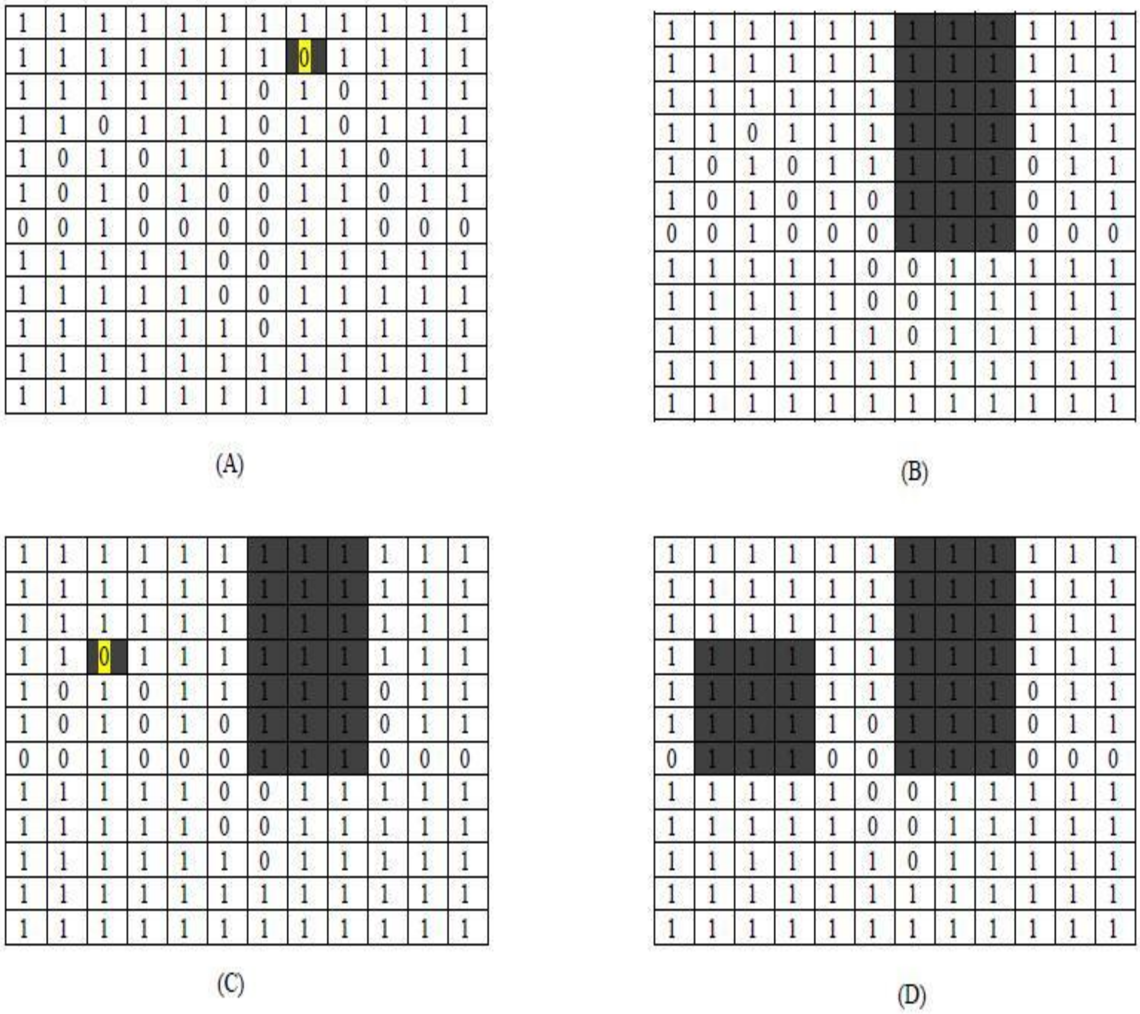
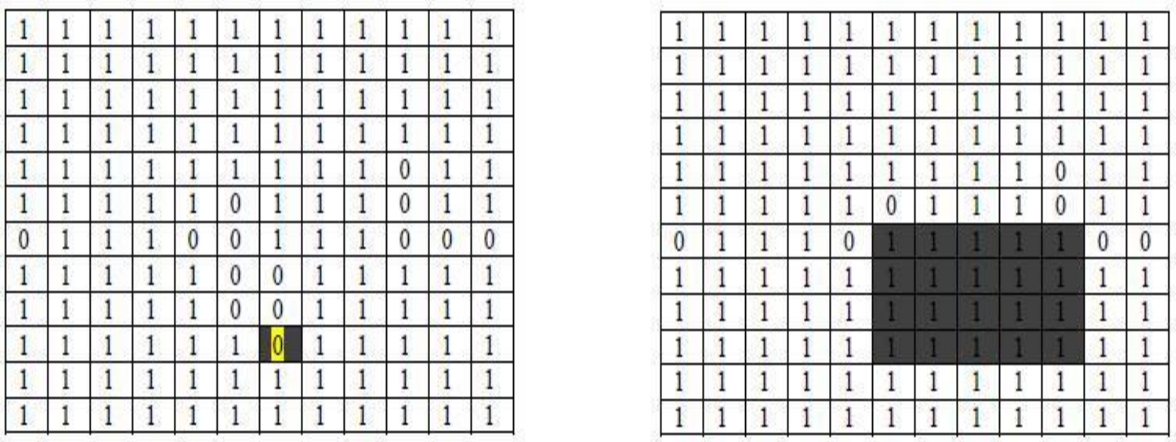


Figure 3: steps (A, B, C and D) of ECG image matrix update to detect two peaks



(A) **(B)**

Figure 4: steps (A and B) of ECG image matrix update to detect one bottom

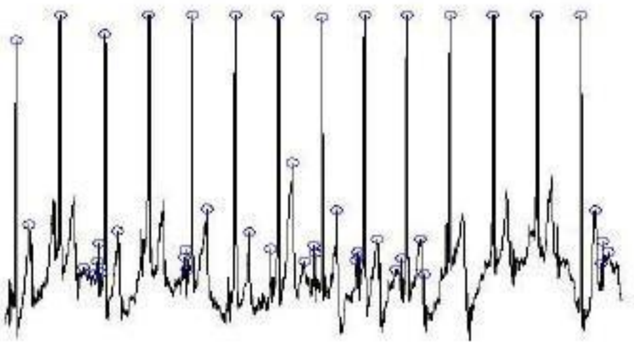


Figure 5: Detected R-peaks in MECG signal according to proposed algorithm

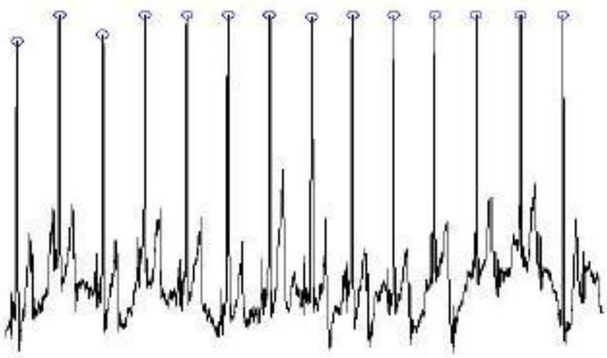


Figure 6: Detected MECG signal after applying K-means

Figure 7: Detected positive and negative R-waves in FECG signal according to proposed algorithm

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Record	Performance For maternal R Peak Detection					
	According to Algunaidi's algorithm		According to Nagarkoti's algorithm		According to proposed algorithm	
	TP	Se (%)	TP	Se (%)	TP	Se (%)
102	13	97.5	15	100	15	100
115	15	98.9	16	100	18	100
127	14	97.7	16	100	16	100
154	13	98.7	14	100	16	100
192	13	98.7	14	100	14	100
244	14	100	14	100	14	100
252	15	98.9	16	100	16	100
274	14	98.8	15	100	15	100
300	14	98.8	15	100	15	100
308	14	100	14	100	13	100
323	14	98.8	15	100	15	100
368	14	98.8	16	98.9	15	100
384	15	100	15	100	15	100
392	15	98.9	16	100	16	100
410	14	98.8	15	100	15	100
416	15	98.9	16	100	15	100
436	14	97.7	16	100	16	100
444	16	98.9	17	100	16	100
445	13	97.5	15	100	15	100
515	14	97.7	16	100	16	100
571	14	97.7	16	100	15	100
585	13	97.5	15	100	15	100
595	14	98.8	15	100	15	100
597	14	98.8	15	100	15	100
621	15	98.9	16	100	16	100
Total/ Average	353	98.22	383	99.95	382	100

Table 1. Comparison of performance for maternal R peak detection

Record	Performance For Fetal R Peak Detection								
	According to Algunaidi's algorithm			According to Nagarkoti's algorithm			According to proposed algorithm		
	TP	Se (%)	Pe (%)	TP	Se (%)	Pe (%)	TP	Se (%)	Pe (%)
102	17	89.47	80.95	29	90.62	90.62	29	100	100
115	19	79.16	100	33	100	100	33	100	97
127	20	74.07	68.96	34	75.56	69.38	32	100	100
154	16	69.56	69.56	36	85.71	73.46	29	100	96.6
192	17	94.44	100	38	86.36	73.07	29	100	96.6
244	15	65.21	75	29	69.04	69.04	28	100	100
252	19	59.37	59.37	36	92.30	85.71	32	100	96.9
274	20	66.67	80	25	83.34	100	31	100	100
300	17	56.67	56.67	31	70.45	70.45	31	100	96.8
308	18	72	85.71	29	69.04	69.04	29	100	93.5
323	18	100	100	33	100	100	31	100	96.8
368	17	94.44	80.95	31	70.45	67.39	30	100	93.7
384	18	78.26	72	33	75	70.21	30	100	96.7
392	16	55.17	61.53	33	89.18	86.84	33	100	97
410	18	64.28	69.23	31	72.09	70.45	31	100	93.9
416	18	60	60	33	100	100	34	100	94.4
436	20	76.92	58.82	34	97.14	91.89	32	100	100
444	17	89.47	89.47	31	86.11	88.57	32	100	91.4
445	16	64	94.11	36	80.00	70.58	29	100	96.6
515	16	94.11	100	31	88.57	83.78	31	100	100
571	17	100	100	41	95.34	87.23	31	100	96.8
585	17	85	100	44	100	81.48	30	100	100
595	18	90	78.26	43	97.72	82.69	31	100	91.17
597	17	77.27	89.47	41	95.34	83.67	31	100	96.8
621	16	51.61	51.61	44	97.78	81.48	32	100	96.9
Total/ Average	437	72.80	79.25	823	86.68	81.88	771	100	96.78

Table 2. Comparison of performance for fetal R peak detection