A Novel Approach for Detecting QRS Complex of ECG signal

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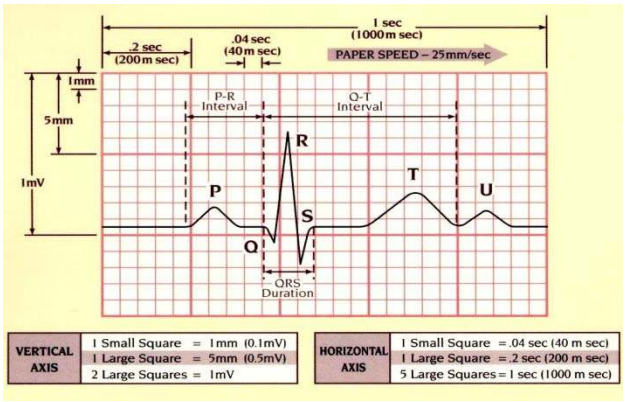
Abstract

In this study, an automatic approach for detecting QRS complexes and evaluating related R-R intervals of ECG signals (PNDM) is proposed. It reliably recognizes QRS complexes based on the deflection occurred between R & S waves as a large positive and negative interval with respect to other ECG signal waves. The proposed detection method follows new fast direct algorithm applied to the entire ECG record itself without additional transformation like discrete wavelet transform (DWT) or any filtering sequence. Mostly used records in the online ECG database (MIT-BIH Arrhythmia) have been used to evaluate the new technique. Moreover it was compared to seven existing techniques; the results show that PNDM has much detection performances according to 99.95% sensitivity and 99.97% specificity. It is also quickest than comparable methods.

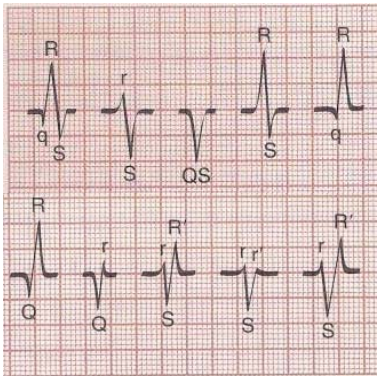
Keywords: *Electrocardiogram (ECG), QRS complex detection, R-R intervals, positive-negative deflection*

1. Introduction

The electrocardiogram (ECG OR EKG) is a graphic record of the direction and magnitude of electrical activity of the heart that is generated by polarization and depolarization of the atria and ventricles [1]. ECG machines record changes in electrical activity by drawing a trace on a moving paper strip. ECG machines run at a standard rate of 25 mm/s and use paper with standard-sized squares. Each large square (5 mm) represents 0.2 seconds (s), i.e. 200 milliseconds (ms). Therefore, there are five large squares per second, and 300 per minute and an ECG event such as a QRS complex occurs once per large square. The heart rate can be calculated rapidly as the length of paper between R waves, so the distance between the different parts of the P-QRS- T complex. All six ECG signal waves are shown in fig.1-a. Three of these waves form a complex and between these waves, there are two intervals and one segment [2]. The duration of the QRS complex shows how long excitation takes spread through the ventricles. The QRS duration is normally 120 ms (represented by three small squares) or less [3][4], but any conduction abnormality takes longer, and causes widened QRS complexes. Remember that the QRS complex represents depolarization, not contraction of the ventricles while contraction proceeds during the ECG's ST segment [5].



(a)



(b)

Fig.1. (a) ECG waveforms and intervals, (b) Common QRS Complexes

Many of the previous works present different techniques for detecting QRS complex from an ECG signal. A simple mathematical based method along with the concept of data structure is used to obtain the complex [6]. A real time QRS detection algorithm based upon adjusting thresholds and parameters periodically to adapt an ECG changes as a QRS morphology and heart rate [7][8]. In [9] the proposed algorithm (called PT method) which recognizes QRS complexes by analyzing positions and magnitude of sharp waves also uses special (BPF) to reduce the false detection of ECG signals. Another paper

[10] proposes a new method for QRS complex detection using the wavelet transforms (termed as WT) by the multi-scale feature of Wavelet Transform WT. The QRS complex can be fixed from high P or T waves, noise, and baseline drift. Moreover, [11][12][13][14] studies proposed a method to detect R-R intervals also QRS complex using WT based on extracting features from a different multi-scale resolution resulting from WT after pre-processing the entire ECG signal to remove Baseline Drift (De-trending) and noise (De-noising) from the source signal. Finally, study [15] proposes a simple and reliable method termed as "The Difference Operation Method (DOM) to detect the QRS complex of ECG signal" which detects QRS complex within two stages. The first-stage finds R by difference equation and the second-stage looks for the points Q and S based on the point R pre-detected.

In this study, a simple and fast intelligent algorithm, termed "Large Positive and Negative Deflection Method (PNDM)" for detecting the QRS complexes of ECG signal is proposed. The proposed PNDM contains two main conditions. The first condition extracts total large positive period by fixing start point (deflection from negative to positive) and the end point (deflection from positive to negative) while the second condition extracts large negative period in a reverse manner. As will be seen in the next sections the large positive and negative periods represent the R & S wave of the ECG signal respectively while the preceding negative deflection represents Q wave [16].

2. Assessing the QRS Complexes

The QRS complex follows the PR segment and consists of three parts: the Q wave, R wave and S wave fig1-b. The Q wave is the first negative deflection following the PR segment. It is always negative. In some cases it is absent. The amplitude of the Q wave is normally less than 25% of the amplitude of the R wave in that lead. The R wave is the first positive triangular deflection following the Q wave or PR segment. The S wave is the first negative deflection that extends below the baseline in the QRS complex following the R wave. In leads I, II, III, a VL a VF, and V4 to V6 the deflection of the QRS complex is characteristically positive or upright. In leads aVR and V1 to V3, the QRS complex is usually negative or inverted. In leads III and V2 to V4, the QRS complex may also be biphasic. QRS complexes can consist of positive (upright) deflections called R waves and negative (inverted) deflections called Q and S waves.

of ECG data converted from a numeric increasing vector (0 to 650,000) to time series interval (0 to 30 min) with a sampling time (2.7778 millisecond) because the sampling frequency of capturing source ECG data is 360 Hz. The effects of applying smoothing and scaling operations on

One of these waves is sometimes missing. If the R wave is absent, the complex is called a QS complex. Likewise, if the Q wave is absent, the complex is called an RS complex. Waveforms of normal or greater-than-normal amplitude are denoted with uppercase letters, whereas, waveforms of less than 5 mm amplitude are denoted with lowercase letters (e.g., "q," "r," "s") [16].

3. Positive Negative Deflection Method (PNDM)

The main idea behind a new approach is tracking the captured ECG beat and recording each sequentially long deflections (positive to negative and negative to positive) of positive (upright) QRS the first long deflection is from negative to positive which represents the R wave while the second long deflection is from positive to negative which represents the S wave. The short deflection (normal to negative) preceding the first deflection represents Q and of course reverses deflection direction for Q, R and S waves negative or inverted QRS. According the detection of long positive and negative deflection both direction of QRS complex is fixed as well as the length of QRS complex sub-waves (Q, R and S) are evaluated accurately from the deflection period recorded. The proposed algorithm (PNDM) for detecting QRS complex and evaluating related R-R intervals contains four steps and each step is discussed in more detail in the next text and then all steps are capsulated in single diagram using a standard form of writing algorithm.

A) Step 0: [Initialization Step]

In this step three operations will be implemented: the first operation reads the ECG data from the source. In this work the data source is the online ECG database (MIT-BIH arrhythmia database [17]) which will be discussed in more detail in the next section. The second operation is smoothing the reading data by factor (fc) using moving average filter with filter coefficients equal to the reciprocal of the span and the third operation scaling the smoothing data by a specific factor which is evaluated according to the scaling factors listed in (*detailinfo* text file from the MIT-BIH Arrhythmia database). An evaluation scaling equation (1) converts the ECG data read from raw units to the physical units (the same as the real ECG data). The important criteria here is the x-index

Record 122 from MIT-BIH arrhythmia database are shown in fig.2 (a, b).

$$X_i = \frac{X_i - base}{Gain} \quad (1)$$

Where

X_i: ECG Sample

Base: Baseline value equal to 1024.

Gain: Gain factor equal to 200.

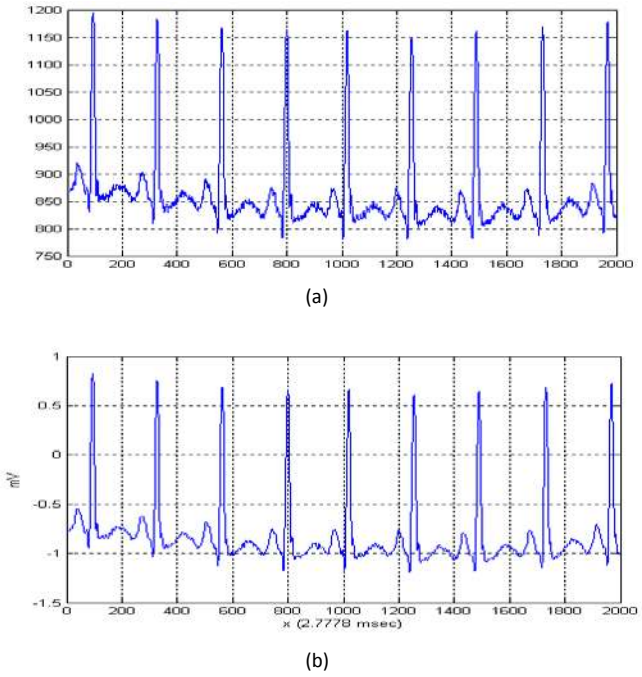


Fig.2. (a) Original ECG signal from MIT-BIH arrhythmia database Record [122]; (b) The ECG signal after smoothing and scaling.

B) Step 1: [Basic Iteration Step]

This step represents the main algorithm loop cycle. It repeats with N (complete number of ECG beats read from the source) times and starts from 2 because some conditions inside the algorithm check each current sample with the previous one.

C) Step 2: [Read ECG sample Xi]

This step is special for reading ECG samples one by one (one sample per each loop cycle) from the source (online ECG database in this study) and is then transferred directly to the next step for processing and makes the correct decision is taken. In other words reading ECG samples one by one and processing it directly denotes that suggested method follows a straight forward strategy data analysis and no transformation is needed to analyze the data entry group.

D) Step 3: [Detecting QRS waves]

This step includes all the operations to detect QRS complex after splitting its main components Q, R and S waves, therefore it is the most important part in the suggested algorithm. This step follows the verification of one condition from two; either the first condition when the ECG signal comes up (raising direction) or the second condition when the ECG signal comes down (falling direction) and the detecting of QRS complex start to check after sequential verification of two conditions to ensure that complete QRS complex is probably occurring. In the following text each of three parts will be discussed in more detail with complete flow chart for this step:

Step3-1 [Counting Next S-Wave from raising direction and Detects Current R-Wave]:

This step starts after each ECG signal deflection from a falling to a rising direction, therefore when the deflection occurs the time of current ECG sample will be recorded as a start of interval (RK) while the end of this interval will be recorded when reverse deflection in the same ECG signal occurs again (in the next part). The time event will be recorded as (NK) and the total count of this interval records as (SM).

The previous interval may be S-wave or not and the final decision is token the next part while the final decision about R-wave is taken here if the interval $|XNK - XRM+NK| >$ specific threshold (Rth) which represent the R-Wave limits and can be evaluated using an adaptive technique on the general ECG data read. The position of deflection point (NK, RK) and the time intervals for counting R & S-Waves are shown in fig.3 which contains one complete ECG frame of record (103) from the MIT-BIH arrhythmia database.

PNDM Algorithm for Detecting ECG QRS complex and evaluating related R-R intervals)

Step 0: [Initialize]: **Read** ECG data from the source ;smoothing reading data by factor f_c (using moving average filter with filter coefficients equal to the reciprocal of the span.) and scaling smoothing data by fixed known factor to convert reading ECG data to a standard form of read ECG data.
Set SM←0; RM←0 (SM, RM are the rising and falling intervals respectively)
Set FG←0; PFG←0 (FG, PFG are the current & previous status of direction, +1 for rising and -1 for falling direction)
Set RSIG←0; (RSIG is flag detection of R-wave)

Step 1: [Basic Iteration]:
For I←2 **to** N **do** through step 3 **od** (N are the total No. of ECG beats within 30 min, for MIT-BIH Arrhythmia ,N is equal to 650000 where the ECG sampling time used is 2.7778ms)

Step 2: [Read ECG data]:
Read Current ECG sample X_i

Step 3: [Counting next S-Wave from falling direction and Detect current R-Wave]:
if ($X_{i+1} < X_i$) **then** SM←SM+1; FG=-1
if FG≠CFG **then** RK←I; **fi**
if (RM >2) **then**
if ($|X_{NK} - X_{RM+NK}| \geq R_{th}$ **then**
Fixing interval (X_{NK}, X_{RM+NK}) as R-Wave.
RSIG←1; **fi** RM←0; **fi**

[Counting next R-Wave from raising direction and Detect current S-Wave]:
if ($X_{i+1} > X_i$) **then** RM←RM+1; FG=+1
if FG≠CFG **then** NK←I; **fi**
if (SM >2) **then**
if ($|X_{RK} - X_{SM+RK}| \geq S_{th}$ **then**
Fixing interval (X_{RK}, X_{SM+RK}) as S-Wave.
[Check Occurring of QRS Complex from sequential R&S Waves]:
if RSIG=1 **then**
if $|Time(X_{RK} - X_{NK-SM})|$ <TDF **then**
Fixing (X_{NK}, $Max[X_{NK-SM}, X_{RK}]$, X_{SM+RK}) as QRS Complex interval; Record time event of QRS $_{peak}$ in RiR matrix
fi RSIG=0; **fi** SM←0; **fi fi fi**

Step 4: [Evaluate related R-R intervals]:
For K←1 **to** Sizeof (RiR) **do**
if (k=1) **then** $RR_k \leftarrow RiR_k$
else $RR_k \leftarrow RiR_k - RiR_{k-1}$
fi ; od : and STOP

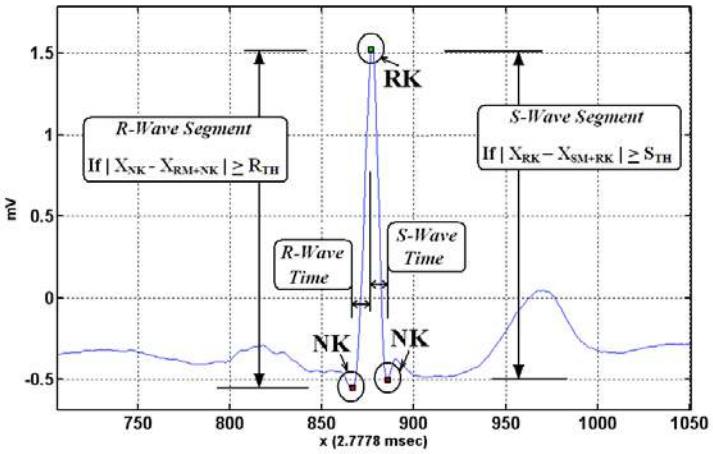


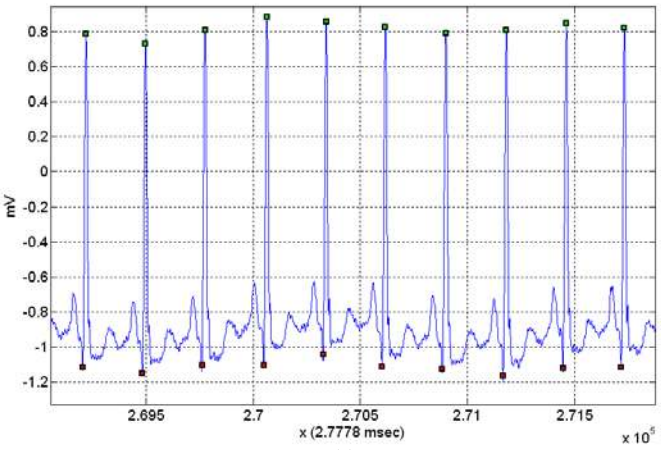
Fig.3. the relation between positions of deflection Points (NK and RK) and fixing R & S waves

Step3-2 [Counting Next R-Wave from raising direction and Detects Current S-Wave]:

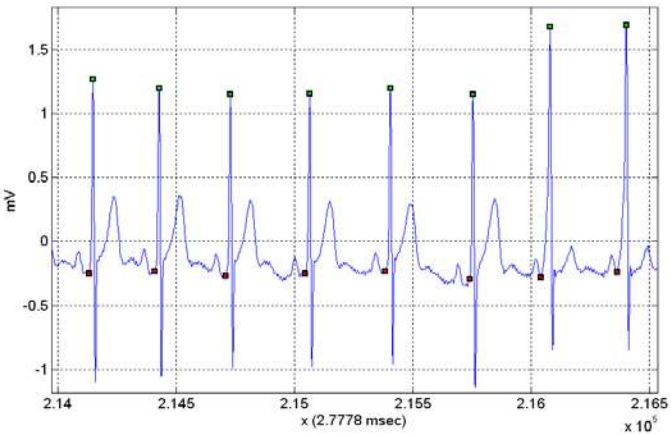
In the same manner followed above, this step counting R-wave also detects S-wave. The operation inside this part starts to count R-wave when deflections in the ECG signal from rising to falling direction. In the opposite way from the previous part the start of interval is (RK) and (NK) is ended (start of the next deflection) and the count of this interval is (RM). The decision about representing this interval as R-wave or not is already taken in previous step while in this step the decision about S-wave if the interval counted in the previous step verifies the condition ($|XRK- XSM+RK| >$ specific threshold (Sth) which is the limit of S-wave.

From the discussion of the two the previous steps (3-1 & 3-2), an important criteria in the suggested algorithm can be concluded here, that these steps work in interference mode (each step counting one interval and a final decision for the interval counting in other step is taken). The final decision for each interval (R or S-wave) counting must be taken when the tested interval finishes, however at this time the ECG transfers to a different direction of deflection (falling to rising or rising to falling) and this is the reason behind the interference between these two steps .

As discussed in the previous text the QRS complex resulted from a sequential R-wave and S-wave. This means that the operation of QRS detection does not start to be checked even though jointed R & S-waves are detected in step3-1 and step 3-2 respectively. In fig.4 (a, b, c, d, e, f) six different ECG samples from MIT-BIH arrhythmia database are tested by the previous two steps according to the PNDM algorithm and the start and end of each interval detected (R or S wave) are marked with different colors.



(a)



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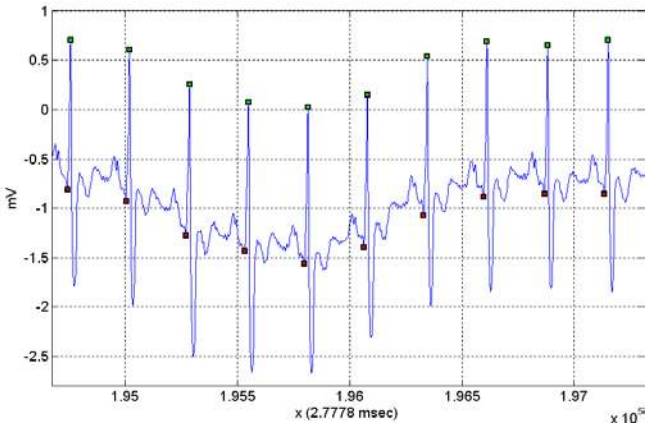

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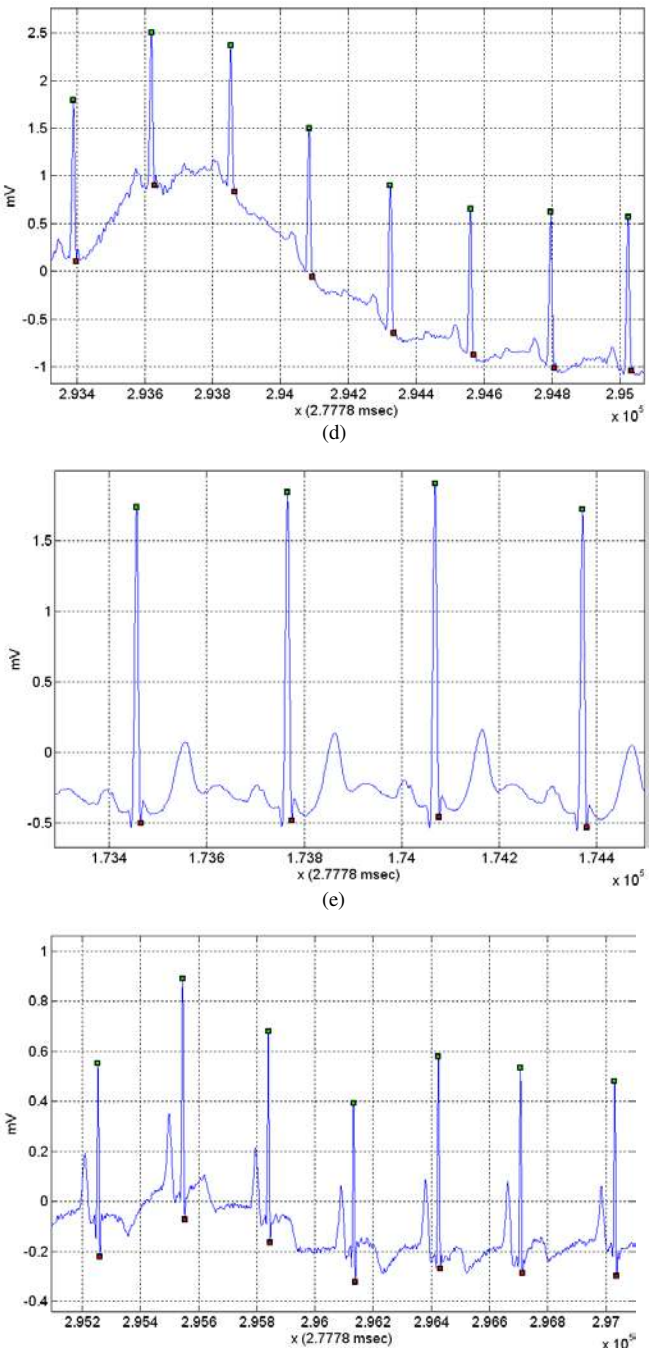

(d)

(e)

(f)

Fig.4. R-waves detected in (a) record [122], (b) record [230], (c) record [118] and S-wave detected in (d) record [103], (e) record [234] , (f) record [222] from ECG MIT-BIH arrhythmia database

Step3-3 Detecting QRS Complex Interval

This step of suggested algorithm checks occurring of QRS complex interval, therefore this step achieves the main goal of this research. The detection process starts automatically after each jointed sequential R & S-waves which was checked by the previous two steps (3-1 & 3-2) because of course no checking is needed without the two components of the QRS complex (R- & S-waves). As was seen in the previous two steps, the detection of (R & S waves) done individually in a single part but one criterion remains floated (if two intervals R & S-waves detected are jointed or not) which remains true if and only if the main condition (2) can be verified.

$$\left| \text{Time}\,(X_{RK} - X_{NK\text{-}SM}) \right| < \text{TDF} \qquad (2)$$

Where

TDF*: A desired minimum distance between the end of the R-wave and the start of the S-wave interval (in most cases may be zero or very small value).*

The previous condition checks the connection validity between two detected intervals but even if it is true, other conditions must be verified which is the correct order of two detected intervals (i.e. R-wave first and S-wave second). This issue is resolved in the suggested algorithm using a specific flag called (RSIG) which resets to **zero** initially and then sets to **one** when each R-wave is detected. The status of RSIG will be checked mainly before the condition of the QRS complex to insure that the current S-wave is preceded by R-wave. The results for detecting QRS complexes of some ECG samples from MIT-BIH arrhythmia database are shown in fig 5(a, b, c, d).

Step3-4 Evaluate related R-R intervals

The last part of the suggested algorithm evaluates normally the R-R intervals which are fixed from the QRS_{peak} resulted from the previous steps. The strategy followed here is recording the peak event for successive QRS complexes detected using (3). This equation fixes the R peak either from the end of R interval or the start of S interval by taking maximum values between it. The results for fixing R-R interval from QRS_{peak} of some ECG samples from MIT-BIH arrhythmia database are shown in fig 5(b, c, d).

$$\text{Max}\,[X_{NK\text{-}SM}, X_{RK}] \qquad (3)$$

Where

$X_{NK\text{-}SM}$: *The Start of S-Wave resulting from subtracting second deflection point NK (falling to rising) from the total length of S-interval (SM).*

X_{RK} : *The end of R-interval.*

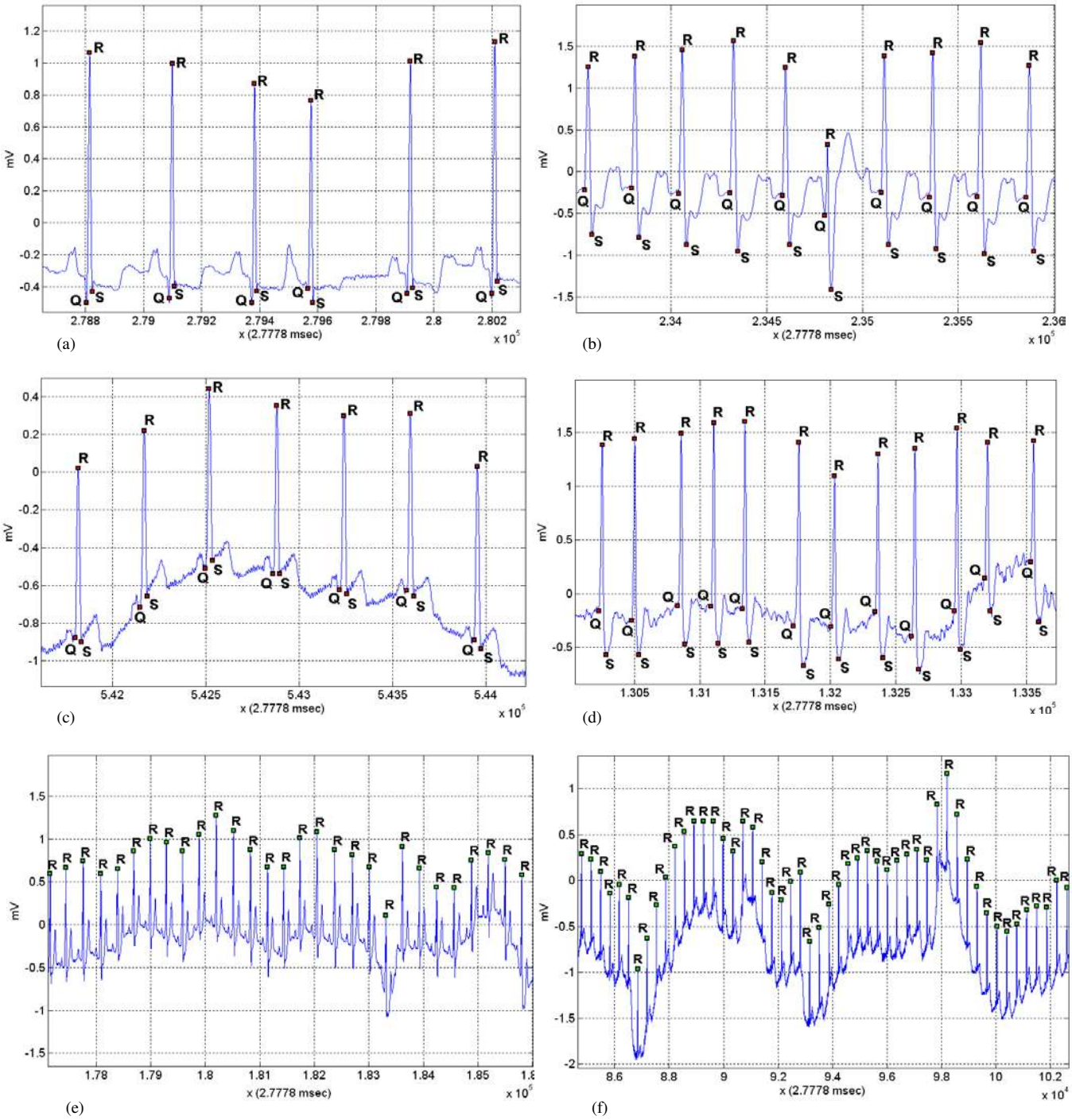

Fig.5. Implementation Results of PNDM on MIT-BIH arrhythmia database: QRS complex detection of

(a) record[100], (b) record[109], (c) record[121], (d) record[203] ; Fixing R-R intervals of (e) record [111], (b) record [121]

4. Implementation of (PNDM) algorithm

The ECG samples used in the previous sections are taken from the MIT-BIH arrhythmia database [17]. This database is used to evaluate the effectiveness of the suggested algorithm (PNDM); it contains 48 ECG records with 30 min recording time, 360Hz sampling frequency and 11bits resolution along 10mV range. Like other studies in this field, some criteria must be evaluated to improve the validity and correct behavior of

the new method. The first criterion is a group of three statistical parameters: the first one is FP (failed positive) which is the number of ECG beats detected when no beat is present, second is FN (failed negative) which is the number of real beats that were not detected and third is Fd (failed detection) which is the percentage of detection failure [18][19]. The Fd percentage is computed according to (FP, FN) with respect to the total number of ECG beats tested (TP) using (4). The results of (FP, FN and Fd) after the implementation of (PNDM) on the MIT-BIH arrhythmia database are listed in table.1 which also contains the same parameters set results of other detection methods ([9][10][15] to compare the overall accuracy of the results.

$$F_d = \frac{FP + FN}{TP} \qquad (4)$$

The second criterion is two percentage (Se, Sp) which is a measure of sensitivity and specificity respectively [19]. The Se percentage defined in (5) denotes detection sensitivity according to the FN value while the Sp percentage defined in (6) denotes the positive specificity.

The experimental results of (Se, Sp) after implementing (PNDM) on 48 ECG records of MIT-BIH arrhythmia database are shown in table.2, this table also contains the results of (Se, Sp) for the same ECG records with seven different methods, PT, WT,DOM methods [9][10][15] and EMD, Christov's method (Algorithm 1, 2), [19][20][21], thus the proposed detection method compares with three such methods in table 1. It gives the best results among these methods. The QRS detection methods listed in table 2 used the same ECG database (48 records 30 min MIT-BIH arrhythmia database) which are used in the implementation of PDNM. The results in table 2 indicate that PNDM is the best among the seven methods.

$$Se = 1 - \frac{FN}{TP + FN} = \frac{TP}{TP + FN} \qquad (5)$$

$$Sp = 1 - \frac{FP}{TP + FP} = \frac{TP}{TP + FP} \qquad (6)$$

All the previous results obtained by implementing the PNDM method using MATLAB software in a personal computer with 2.8 GHz Intel CPU, and the average execution time of PNDM is about (4.15 seconds) to process 30 minutes long ECG records while in (DOM, WT) [15] the average time of handling (10 minutes) are (30sec,60 sec) respectively.

The last part of the suggested algorithm computes the RR interval which is the interval between two consecutive QRS complexes. The RR intervals computed along the ECG signal can be used mainly to find heart rate [2]. The MIT- BIH arrhythmia database which is used in this implementation contains all the ECG beats data, the detailed information about RR intervals for all records found also inside the database. There are (31) records from total in (48) records in table.1 which refer to zero values of FN, FP and denote the success of PNDM in detecting all QRS complexes in ECG signals.

The NMSE between RR intervals of the successive records computed by PNDM and the intervals already stored inside the database listed also in table.1. The smallest values of NMSE computed denote very high accuracy in calculations of RR intervals in comparison with the stored intervals. It is also observed the values of NMSE evaluated reflect completely the accuracy of PNDM in detecting QRS complex and fixing R wave's peak, and evaluating of RR intervals comes from the difference between two sequential R waves in sequential QRS complexes.

5. Conclusions

Many existing studies have shown QRS detection already achieves high sensitivity and specificity using one or more stages of filtering and specific type of transformation like (Wavelet, Cosine, Fourier, …etc) also some other studies present a hardware real time system for processing entire ECG data. In this study a direct, simple, accurate and very fast PNDM is proposed for QRS complexes detection of ECG signal. The new method is very easy to implement and does not need any additional transformation, it is applied directly on the ECG data itself. The average time for processing one 30 minutes ECG record from MIT-BIH arrhythmia database is about 4.15 sec depending on the special real time functions inside the MATLAB package. The last part of this study contains a statistical comparison between the results of PNDM and the other seven QRS detection methods, the comparison refers that PNDM has a faster average processing time and also the lowest percentage of failure detection Fd (0.08%) and the maximum percentage of sensitivity (99.95%) and specificity (99.97)%. It can be concluded depending on the average processing time and accuracy that PNDM is extremely suitable for the real time detection of QRS complexes in the ECG signal.

Table 1: The results of proposed method (PNDM) and other three methods for all ECG signals in MIT-BIH Arrhythmia Database

Record #	Total (No of Beats)	PNDM method					DOM method [15]			PT method [9]			WT method [10]		
		FP beats	FN beats	Fd (%)	Pro.Time (sec)	NMSE of RR	FP beats	FN beats	Fd (%)	FP beats	FN beats	Fd (%)	FP beats	FN beats	Fd (%)
100	2273	0	0	0.00	4.39	9.7e-6	0	1	0.04	0	0	0.00	0	0	0.00
101	1865	0	0	0.00	4.33	3.5e-3	0	1	0.05	5	3	0.43	1	0	0.00
102	2187	0	0	0.00	4.14	1.3e-3	0	1	0.05	0	0	0.00	0	0	0.11
103	2084	0	0	0.00	3.83	1.4e-3	0	0	0.00	0	0	0.00	0	0	0.00
104	2230	4	0	0.18	4.33	x	2	0	0.09	1	0	0.04	8	2	0.45
105	2572	0	9	0.35	3.90	x	0	17	0.66	67	22	3.46	15	13	1.09
106	2027	2	2	0.20	4.36	x	0	6	0.30	5	2	0.35	2	3	0.25
107	2137	0	0	0.00	3.86	2.6e-4	0	3	0.14	0	2	0.09	0	0	0.00
108	1763	5	2	0.40	3.64	x	6	0	0.34	199	22	12.54	13	15	1.59
109	2532	0	0	0.00	4.40	7.2e-3	0	3	0.12	0	1	0.04	0	0	0.00
111	2124	0	0	0.00	4.25	3.1e-4	0	1	0.05	1	0	0.05	1	1	0.09
112	2539	0	0	0.00	3.82	1.4e-3	1	0	0.04	0	1	0.04	2	1	0.12
113	1795	0	0	0.00	4.28	3.3e-6	9	0	0.50	0	0	0.00	2	0	0.11
114	1879	0	0	0.00	4.24	4.2e-3	0	1	0.05	3	17	1.06	3	0	0.16
115	1953	0	0	0.00	3.40	1.2e-6	0	0	0.00	0	0	0.00	0	0	0.00
116	2412	0	6	0.25	4.35	x	0	17	0.70	3	22	1.04	0	1	0.04
117	1535	0	0	0.00	4.23	9.3e-4	2	0	0.13	1	1	0.13	1	0	0.07
118	2275	0	0	0.00	4.26	2.4e-3	10	0	0.44	1	0	0.04	1	0	0.04
119	1987	0	0	0.00	3.85	1.1e-5	0	0	0.00	1	0	0.05	1	0	0.05
121	1863	0	0	0.00	4.23	3.5e-4	0	2	0.11	4	7	0.59	2	1	0.16
122	2476	0	0	0.00	3.40	7.3e-6	0	0	0.00	1	1	0.08	0	0	0.00
123	1518	0	0	0.00	4.06	8.7e-3	0	0	0.00	0	0	0.00	0	0	0.00
124	1619	0	0	0.00	4.21	5.2e-3	1	0	0.06	0	0	0.00	0	0	0.00
200	2601	6	4	0.38	3.95	x	5	0	0.19	6	3	0.35	0	1	0.04
201	1963	3	7	0.51	4.34	x	0	20	1.02	0	10	0.51	1	12	0.66
202	2136	0	0	0.00	4.35	3.4e-3	1	0	0.05	o·	4	0.19	0	1	0.05
203	2982	2	9	0.37	4.44	x	16	2	0.60	53	30	2.78	2	24	0.87
205	2656	0	6	0.23	4.11	x	0	16	0.60	0	2	0.08	0	1	0.04
207	1862	1	2	0.16	4.33	x	0	1	0.05	4	4	0.43	2	3	0.27
208	2956	0	1	0.03	4.12	x	0	14	0.47	4	14	0.60	0	4	0.14
209	3004	0	0	0.00	4.30	7.1e-3	1	0	0.03	3	0	0.10	0	0	0.00
210	2647	3	4	0.26	4.19	x	0	14	0.53	2	8	0.38	3	3	0.23
212	2748	0	0	0.00	4.30	1.2e-3	1	0	0.04	0	0	0.00	0	0	0.00
213	3251	0	0	0.00	4.50	4.0e-3	0	3	0.09	1	2	0.09	0	0	0.00
214	2262	1	2	0.13	3.90	x	0	4	0.18	2	4	0.26	x	x	x
215	3363	0	0	0.00	4.44	5.1e-5	0	4	0.12	0	1	0.03	x	x	x
217	2208	1	3	0.18	3.88	x	0	2	0.09	4	6	0.45	1	1	0.09
219	2154	0	0	0.00	3.90	3.5e-5	0	0	0.00	0	0	0.00	0	0	0.00
220	2048	0	0	0.00	4.24	2.9e-6	0	0	0.00	0	0	0.00	0	0	0.00
221	2427	0	0	0.00	3.87	1.2e-3	0	1	0.04	2	0	0.08	0	7	0.29
222	2484	0	0	0.00	4.35	1.7e-4	0	5	0.20	101	81	7.33	1	9	0.40
223	2605	3	0	0.12	4.21	x	1	0	0.04	1	0	0.04	0	2	0.08
228	2053	0	3	0.15	4.10	x	0	2	0.10	25	5	1.46	3	7	0.49
230	2256	0	0	0.00	4.34	2.6e-3	2	0	0.09	1	0	0.04	0	0	0.00
231	1886	0	0	0.00	4.28	2.3e-6	0	15	0.80	0	0	0.00	0	0	0.00
232	1780	0	0	0.00	4.34	1.6e-4	0	0	0.00	6	1	0.39	0	0	0.00
233	3079	0	4	0.13	4.55	x	0	9	0.29	0	1	0.03	0	0	0.00
234	2753	0	0	0.00	4.10	6.1e-6	0	1	0.04	0	0	0.00	0	0	0.00
Total	116137	31	64	0.08	4.15		58	166	0.19	507	277	0.68	65	112	0.15
Average Time for Processing (Time Segment) ECG Data		4.15 sec (30 min)					30 sec (10 min)			x			60 sec (10 min)		

Table 2: The FP beats, FN beats and (FD, Se, Sp) % comparison results with seven different QRS detection methods

Method	Total beats	FP beats	FN beats	Failed Detection Fd (%)	Sensitivity Se (%)	Specificity Sp (%)
PNDM	**116,137**	**31 (0.03%)**	**64 (0.06%)**	**0.08**	**99.95**	**99.97**
DOM [15]		58 (0.05%)	166 (0.14%)	0.19	99.86	99.95
PT [9]		507 (0.43%)	277 (0.24%)	0.68	99.76	99.57
WT [10]		65 (0.06%)	112 (0.10%)	0.15	99.90	99.94
New R-Peak detector [21]		140 (0.12%)	79 (0.07%)	0.19	99.93	99.88
EMD [19]	**110,050**	84 (0.08%)	174 (0.16%)	0.23	99.84	99.92
Christov's method Algo.1 [20]		215 (0.20%)	294 (0.27%)	0.46	99.69	99.65
Christov's method Algo.1 [20]		239 (0.22%)	240 (0.22%)	0.44	99.74	99.65

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