

# Detection of Qrs Complexes in Ecg Signal Using K-Means Algorithm

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**Abstract:** This paper implements a simple method using K-means clustering algorithm for the detection of QRS-complexes in ECG signal. Butterworth digital filters are designed and implemented to remove the power line interference and baseline wander present in the ECG signal. To detect QRS and non-QRS-regions in the ECG signal, K-means algorithm is used. The performance of the algorithm is validated using MIT-BIH Database. The efficiency of QRS detection is evaluated based on two parameters namely sensitivity and detection rate.

**Keywords—** ECG, MIT-BIH database, K-Means algorithm, detection rate

## I. INTRODUCTION

Electrocardiogram (ECG) signals are used to analyze the cardiovascular activity in the human body and have a primary role in the diagnosis of several heart diseases. The QRS complex is the most important and distinguishable component in the ECG because of its spiked nature and high amplitude. Since it reflects the electrical activity within the heart during the ventricular contraction, the time of its occurrence as well as its shape provides much information about the current state of heart. The ECG recordings in MIT-BIH Database[4] may contain various challenging problems such as segment with high noise content, sudden change in QRS amplitude and morphology, or muscle and electrode artifacts which are not often detected correctly. Hence reliable and correct detection of QRS complexes, under various backgrounds, is very important in any algorithm used for ECG analysis. The correct performance of these systems depends on several important factors such as quality of ECG signal, the applied detection rule, the learning and testing dataset used. Once the positions of the QRS-complexes are found, the locations of other components of ECG like P, T waves and ST segment, etc. are found relative to the position of QRS, in order to analyze the complete cardiac period. In this sense, QRS-detection provides the fundamental for almost all automated ECG analysis algorithms. Mostly QRS detectors consist of two stages: preprocessing stage, including linear filtering followed by nonlinear transformation and decision rule[7]. Automatic detection and delineation of the QRS complex in ECG is of extreme importance for computer aided diagnosis of cardiac disorder. The aim of the present work is to detect the QRS wave from electrocardiogram (ECG) signals.

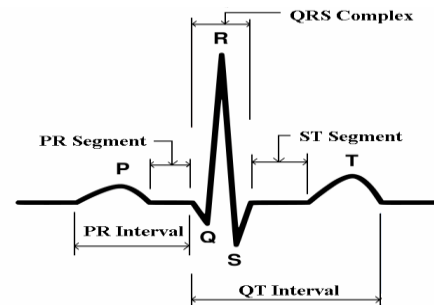


Fig 1. An ECG signal

## II. K-MEANS ALGORITHM

This section describes an outline of K-means algorithm used for the generation of feature signal[3]. When a number of samples are given and it is required to group them into K number of clusters, K-means algorithm can be used. It is based on the minimization of performance index, which is defined as the sum of squared distances from all points in a cluster domain to the cluster center. The various procedural steps of the K-means algorithm[3] are as follows.

Step 1: Choose initially K cluster centers  $Z_1(1), Z_2(1), \dots, Z_K(1)$ . These are arbitrary and are usually selected as the first K samples of the given samples set X and  $Z_{l+1}(1) \neq Z_l(1)$ , for  $l = 1, 2, \dots, K-1$ .

Step 2: At the  $k^{\text{th}}$  iterative step, distribute the samples X among the K cluster domain, using the following relation.

$$X \in S_j(k) \text{ if } \|X - Z_j(k)\| < \|X - Z_i(k)\| \quad (1)$$

For all  $i = 1, 2, \dots, K, i \neq j$ , where  $S_j(k)$  denotes the set of samples whose cluster center is  $Z_j(k)$ .

Step 3: from the results of step 2, compute the new cluster centers  $Z_j(k+1), j = 1, 2, \dots, K$ , such that the sum of the squared distances from all the points in  $S_j(k)$  to the new cluster center is minimized. In other words, the new center  $Z_j(k+1)$  is computed so that the performance index,

$$J_j = \sum_{X \in S_j(k)} \|X - Z_j(k+1)\|^2$$

$$j = 1, 2, \dots, K \text{ is minimized.} \quad (2)$$

The  $Z_j(k+1)$ , which minimizes this performance index is simply the sample mean of  $S_j(k)$ . Therefore, the new cluster

center is given by,

$$Z_j(k+1) = \frac{1}{N_j} \sum_{X \in S_j(k)} X, j = 1, 2, \dots, K \quad (3)$$

where,  $N_j$  is the number of samples in  $S_j(k)$ . The name “K means” is obviously derived from the manner in which cluster are sequentially updated.

Step 4: if  $Z_j(k+1) = Z_j(k)$  for  $j=1, 2, \dots, K$ , the algorithm has converged and the procedure is terminated. The behavior of K-means algorithm is influenced by the number of cluster centers specified, the choice of initial cluster, the order in which the sample are taken and the geometrical properties of data.

### III. MIT-BIH ARRHYTHMIA DATABASE

In this paper, ECG signals are taken from MIT-BIH database for QRS detection and arrhythmia classification. MIT (Massachusetts Institute of Technology) and Beth Israel Hospital (now the Beth Israel Deaconess Medical Center) have together put forward this database[4]. This was formed from 48 half an hour excerpts of two-channel ambulatory ECG recordings, obtained from 47 subjects studied at the laboratories of Beth Israel Hospital. The 360 samples per second digitized recordings have 11-bit resolution over a 10 mV range. In this paper recordings of 10 seconds duration have taken.

The analog outputs of the playback unit were filtered to limit analog-to-digital converter (ADC) saturation and for anti-aliasing, using a passband from 0.1 to 100 Hz relative to real time, well beyond the lowest and highest frequencies recoverable from the recordings. The bandpass-filtered signals were digitized at 360 Hz per signal relative to real time using hardware constructed at the MIT Biomedical Engineering Center and at the BIH Biomedical Engineering Laboratory. The sampling frequency was chosen to facilitate implementations of 60 Hz (mains frequency) digital notch filters in arrhythmia detectors. Since the recorders were battery-powered, most of the 60 Hz noise present in the database arose during playback. In those records that were digitized at twice real time, this noise appears at 30 Hz (and multiples of 30 Hz) relative to real time.

### IV. IMPLEMENTATION OF QRS DETECTION METHOD

This section consists of two sub sections namely implementation of digital filters (IV-A) and implementation of k-means algorithm (IV-B). Sub section IV-A describes the implementation of digital filters whereas sub section IV-B describes the implementation of K-Means algorithm.

#### IV-A. IMPLEMENTATION OF DIGITAL FILTERS

This subsection describes filter design and implementation required for removal of power line interference and baseline wander. A raw ECG signal from MIT-BIH database is selected. Fig. 2(a) shows raw ECG signal selected from database (Record No. 101). As we know that this ECG signal is often contaminated by power line interference of 60 Hz, therefore to get rid of this interference, a Butterworth digital notch filter of 60 Hz frequency is designed and implemented in MATLAB. The output of notch filter is shown in Fig. 2(b).

To get rid of baseline wander which is generally found in the range of 0 to 0.5 Hz, a digital low pass Butterworth filter of cut-off frequency 0.5 Hz is designed and implemented in MATLAB. The output of notch filter (Fig. 2(b)) is further passed through this low pass digital Butterworth filter to remove the baseline wander. Fig. 2(c) displays the resultant signal after removal of baseline drift.

#### IV-B. IMPLEMENTATION OF K-MEANS ALGORITHM

This section implements an algorithm developed for the detection and delineation of QRS-complexes in single lead ECG signal.

Step1: The absolute slope i.e. absolute value of the difference between two consecutive samples is calculated to enhance the signal in the region of QRS-complex. The absolute value of slope of the ECG signal is used as an important discriminating feature because absolute slope of the signal is much more in the QRS-region than in the rest of the region. Fig. 2(d) shows the absolute slope of the filtered ECG signal. To enhance this absolute slope this paper uses moving average criteria. Due to this it is observed that the smoother version of QRS complex is obtained, which is shown in Fig. 2(e).

These absolute slope values are then normalized to reduce the burden of the classifier to form the complicated decision boundary.

Step 2: The various steps of K-means algorithm as described in section 2 are followed in order to find the two cluster centers namely the QRS-cluster center and the non-QRS-cluster center.

Step 3: After finding two cluster centers using K-means algorithm, the slope curve shown in Fig. 2(e) is scanned. The membership of slope, at a given sampling instant, is found. An output is 1 if a sample belongs to a QRS-cluster and output is 0 if it belongs to a non-QRS-cluster. Thus, a continuous train of 1's is obtained in the QRS-region and 0's is obtained in the non-QRS region. Fig. 3 shows the output of K-Means algorithm. It is seen that, K-means algorithm not only detects the QRS complexes of ECG, but also delineate them accurately.

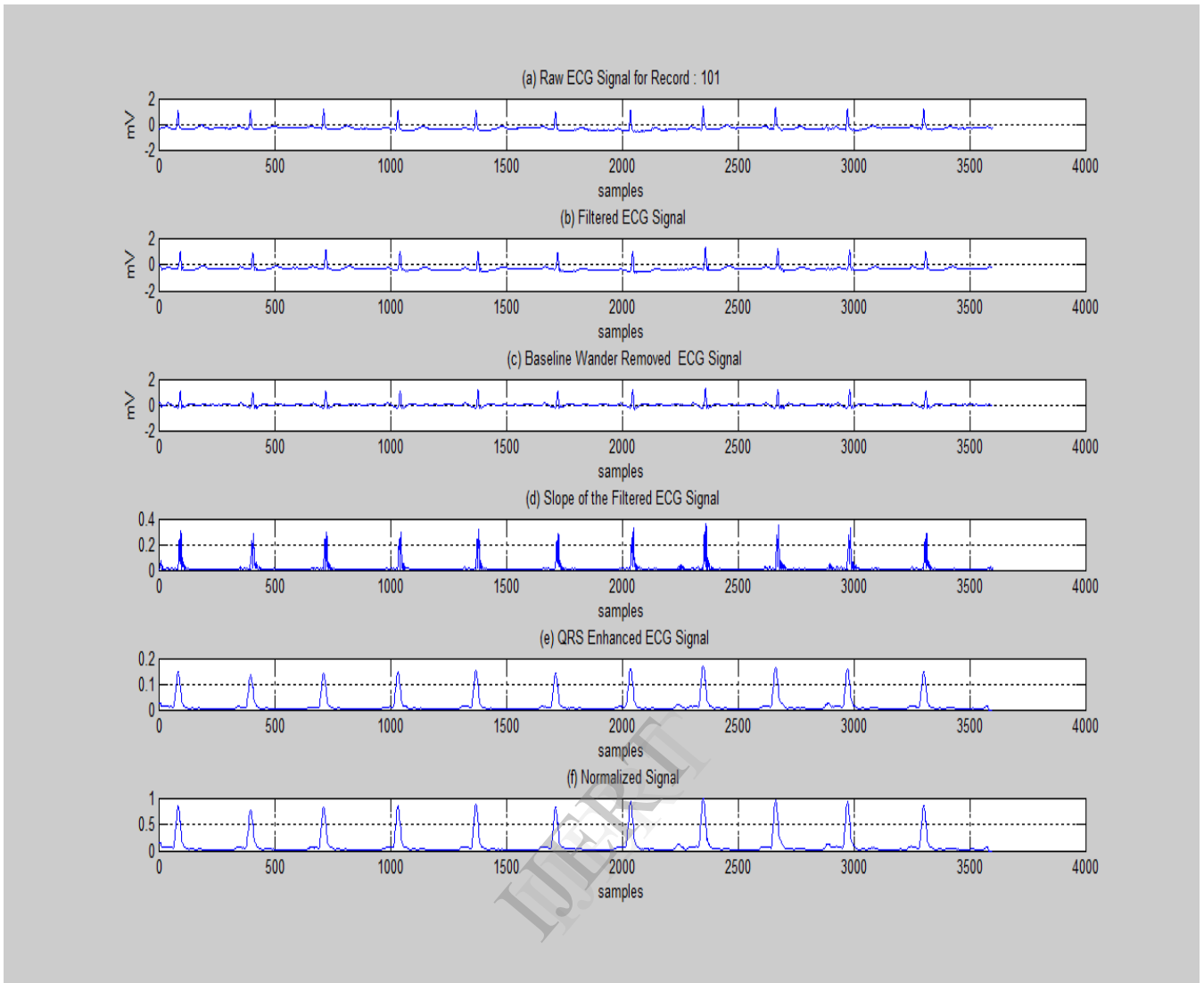


Fig 2.Steps involved in k-means algorithm: (a) raw ECG signal, (b) notch filtered ECG signal, (c)baseline wander removed ECG signal (d) absolute slope curve, (e) QRS enhanced signal (f) normalized signal

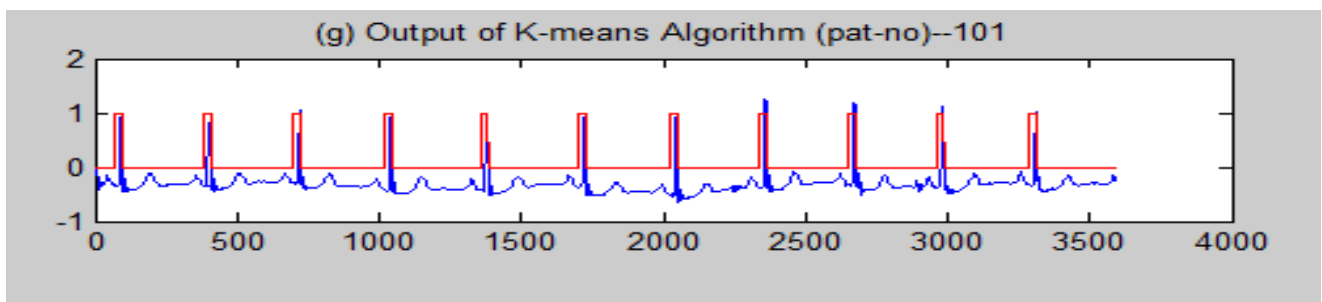


Fig 3. Output of K-means algorithm

## V. RESULTS AND DISCUSSIONS

Detection is said to be true positive (TP) if the algorithm correctly identifies the QRS-complex and it is said to be false negative (FN) if the algorithm fails to detect the QRS-complex. False positive (FP) detections are obtained if non-QRS-wave is detected as a QRS-complex.

The ECG signals used for analysis and detection in this work are a part of MIT-BIH Arrhythmia Database given on the website of MIT-BIH [4].

The said algorithm is applied on total of 48 records from database. It is observed that, in the case of normal beats (i.e. for Record numbers 100, 101, 102, 103, 104, 105, 106, 107, 112, 113, 115, 117, 119, 121, 122, 123, 201, 202, 209, 212, 213, 215, 217, 219, 220, 221, 222, 223, 228, 230, 231, 232, 234) and right bundle branch block (i.e. for record numbers 118,124), the results are encouraging and almost all the beats were detected successfully. Similarly, in the case of left bundle branch block also (i.e. for record numbers 111, 207, 214), the total number of complexes detected are accurate and percentage range of  $Se$  and  $P^+$  is satisfactory.

As the algorithm has been implemented in MATLAB working environment, therefore the part of the whole signal of each data set has been operated.

In order to evaluate the accuracy of detection of QRS complex, two essential parameters: sensitivity  $Se$  and the positive predictivity  $P^+$  (detection rate), are used. These parameters describe the overall performance of the detector and their values are calculated as follows:

$$Se = TP / (TP + FN)$$

$$P^+ = TP / (TP + FP)$$

Using these expressions, the average detection rate obtained for all 48 records is 97% also the percentage of false positive detection and false negative detection for all records are 4.06% and 0.00% respectively, as listed in Table 1.

Therefore, from the table, it is observed that, the results obtained (listed in Table1) from the implemented algorithm provide satisfying accuracy level.

Out of analysed 48 records, for record numbers 109, 200, 203, 210 and 233 it is seen that, the predictivity is not 100% and instances of False Positive detection are seen. This may be because of slope of non QRS regions of these five ECG records falling in the range of absolute slope values chosen for detection of QRS region.

Table 1: QRS detected in ECG signal

RECORD NO.	TOTAL BEATS	TP	FN	FP	%Se	P+
100	13	13	0	0	100	100%
101	11	11	0	0	100	100%
102	12	12	0	0	100	100%
103	11	11	0	0	100	100%
104	13	13	0	0	100	100%
105	14	14	0	0	100	100%
106	10	10	0	0	100	100%
107	11	11	0	0	100	100%
109	17	15	0	2	100	70.58%
111	12	12	0	0	100	100%
112	15	15	0	0	100	100%
113	9	9	0	0	100	100%
114	9	9	0	0	100	100%
115	10	10	0	0	100	100%
116	14	14	0	0	100	100%
117	9	9	0	0	100	100%
118	12	12	0	0	100	100%
119	10	10	0	0	100	100%
121	11	11	0	0	100	100%
122	16	16	0	0	100	100%
123	8	8	0	0	100	100%
124	9	9	0	0	100	100%
200	16	16	0	7	100	53.34%
201	14	14	0	0	100	100%
202	9	9	0	0	100	100%
203	28	15	0	10	100	60%
205	14	14	0	0	100	100%
207	10	10	0	0	100	100%
208	16	16	0	0	100	100%
209	15	15	0	0	100	100%
210	16	15	0	1	100	93%
212	15	15	0	0	100	100%
213	18	18	0	0	100	100%
214	12	12	0	0	100	100%
215	18	18	0	0	100	100%
217	12	12	0	0	100	100%
219	13	13	0	0	100	100%
220	12	12	0	0	100	100%
221	13	13	0	0	100	100%
222	13	13	0	0	100	100%
223	14	14	0	0	100	100%
228	12	12	0	0	100	100%
230	14	14	0	0	100	100%
231	10	10	0	0	100	100%
232	8	8	0	0	100	100%
233	17	13	0	4	100	76%
234	15	15	0	0	100	100%
<b>TOTAL</b>	<b>286</b>	<b>284</b>	<b>0</b>	<b>9</b>	<b>100</b>	<b>97%</b>
		96.56%	0.00%	4.06%	100%	97%

## VI. CONCLUSION

K-means clustering algorithm is implemented and simulated in this paper using MATLAB. It is observed that this algorithm simultaneously detects and delineates the QRS-complexes present in the ECG signal. This paper also designs and implements digital notch and low pass Butterworth filters required for removal of power line interference and baseline wander respectively. A detection rate of 97% is obtained for MIT-BIH database[4], which seems to be significant. It is observed that the information

obtained through this algorithm is very useful for ECG classification and diagnosis. It is also possible to extend this method for automatic ECG signal analysis and diagnosis.

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