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ECG signal analysis for detection of Heart Rate and Ischemic Episodes

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Abstract

Electrocardiogram (ECG) is generally used for diagnosis of cardiovascular abnormalities and disorders. An efficient method for analysing the ECG signal towards the detection of heart rate (HR) and ischemic episodes follows mainly five stages: pre-processing, feature extraction, heart rate detection, beat classification and ischemic episode recognition. The heart rate is calculated using the extracted features of the ECG signal. The calculated HR value can be analysed for the detection of various cardiovascular abnormalities. The ability of the method was validated on European ST-T database. The performance of ischemic episode detection shows 88.08% sensitivity (Se) and 92.42% positive predictive accuracy (PPA).

Keywords

ECG, Pre-processing, QRS-complex, Heart rate (HR), ST-segment deviation, Ischemic episode detection.

1. Introduction

The electrocardiogram (ECG) is a graphical recording of the electrical signals generated by the heart [1]. A typical ECG recording consists of P-wave, QRS-complex, T-wave and U-wave. The amplitude and interval of different waves provides a measure for detection of various cardiac conditions. The most important interval used for determination of cardiovascular abnormality condition is RR-interval (distance between two R-peaks). The normal RR-interval is 600-1200ms. The normal ST-segment and T-wave duration is 80-120ms and 120-160ms respectively [2] which are useful for ischemia detection. The heart rate (HR) is calculated from the extracted features of ECG signal. The heart rate can be useful to identify various cardiac abnormalities like Bradycardia, Tachycardia, Bundle Branch Block, Premature Ventricular Contraction, Wolff-Parkinson-White syndrome (WPW), etc., [3]

Ischemia (heart stroke) is a cardiovascular disorder which affects the heart and the blood vessels. The coronary arteries become narrowed by atherosclerosis which restricts the flow of blood and oxygen to the heart and brain. This makes brain cells to die which creates cardiac disorder known as ischemia [4]. The detection process takes more time if analysed by doctor using long duration ECG data. So an automatic technique is necessary for early detection of ischemia. The ECG beat classification is essential for automatic detection and diagnosis of ischemic episodes in a long duration electrocardiogram. The key to ischemic episodes detection is the ST-segment deviation and T-wave amplitude changes [5].

Most importantly the parameter, ST-segment deviation is expressed as polarity change relative to isoelectric line. The isoelectric line is the baseline, typically measured between the T-wave offset and the preceding P-wave onset of electrocardiogram. Isoelectric line is used as a reference for measurement of ST-segment deviation [6]. Abnormal T-wave, usually very tall or inverted, appears corresponding to the elevation or depression in ST-segment. The ST-segment is considered as elevated if the segment is 0.08mV or more above the isoelectric line. The T-wave inversion or flattening is measured using first 30s of the ECG recording [7].

The methodology followed to detect ischemic episode basically consists of five stages. In first stage the ECG recording is pre-processed to achieve noise removal. In the next stage, ECG feature extraction is carried out to locate the changes in QRS-complex, ST-segment and T-wave. Thereafter Heart rate is calculated from the extracted features. In the next stage beat is classified as normal or ischemic using some rule based on medical knowledge and the final stage provides the identification of ischemic episode which is based on the detection of two or more consecutive ischemic windows using first 30s of each ECG recording. The performance of the ischemic episode detection technique is evaluated in terms of sensitivity and positive predictive accuracy.

The paper is organized as follows: Section 2 explains proposed methodology. Section 3 provides the experimental result using the European Society of Cardiology (ESC) ST–T database. Finally section 4 concludes the topic.

2. Proposed Methodology

The methodology basically describes two different processes. First is the heart rate (HR) calculation process and then ischemic episode detection. The HR is calculated using the extracted ECG features from the second stage of the detection process. The calculated HR value can be used for cardiovascular abnormalities identification. The block diagram for the detection of heart rate and ischemic episode is shown in Fig.1.

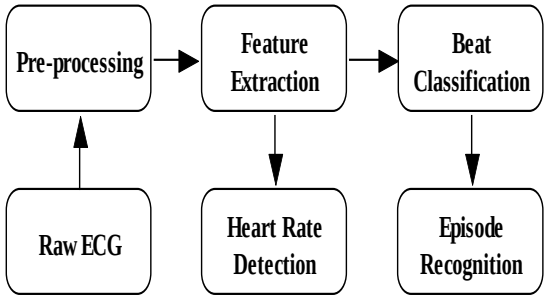

Fig.1: Block diagram of detection process

A. pre-processing

The pre-processing of raw ECG signal is required for removal of noises such as muscle noise, 60Hz interference, baseline wander and T-wave interference, etc. [8]. Pre-processing stage involves normalization and filtering. In the normalization process the amplitude of the signal is normalized first and then it is passed through band pass filter. The function of band pass filter is noise rejection. The desirable pass band to maximize the QRS energy is approximately 5-15 Hz [9]. The raw ECG signal, the signal after normalization and the normalized signal after passing through band pass filtering are shown in Fig. 2.

B. Feature Extraction

The variations in ECG features like QRS-complex morphology, ST-segment deviation and T-wave alternation can be used for ischemic episode detection. First feature towards the ischemic episode detection process is the determination of QRS-complex. The R-peak which has the tallest peak in ECG signal is first determined in QRS-complex. Then the lowest peak 'S' is determined followed by Q-peak. The suitable method used for finding QRS-complex is based on J. Pan and J. Tompkins algorithm [9]. Other features like P-wave location, J-point location, T-wave, T_{ON} and T_{OFF} locations, isoelectric line and ST-segment location were detected using the previously located Q-, R- and S-wave peaks.

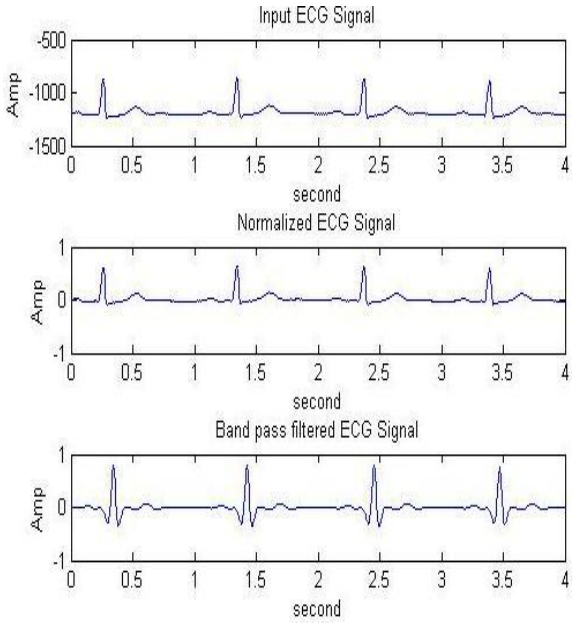

Fig. 2: Normalized and filtered ECG signal

1) P-Wave Location:

A threshold level is used with reference to the normal range of ECG segments to locate P-wave. The normal PR-interval ranges from 120-200ms whereas the amplitude and duration of P-wave are 0.25mV and 80ms respectively. Also P-wave is the first positive peak on the left of tall R-peak location [1].

2) J-point Location:

The J-point is the junction between the QRS-complex and the ST-segment of ECG signals [6]. Also it is the first point where the waveform flattens out to the right after QRS-complex. The J-point location is normally at the end of QRS-complex which has the normal range of 80-120ms [2].

3) T-Wave, T_{ON} and T_{OFF} Location:

After knowing the location of R-peak and J-point, the peak of T-wave is estimated as maximum elevation between R-peak + 400ms and J-point + 80ms. T_{ON} and T_{OFF} is then estimated by considering 35ms duration from left and right of the T-wave peak respectively [1].

4) Isoelectric Line and ST segment Location:

Isoelectric line is the baseline or almost zero amplitude level. The base line is chosen as the flat line between P-wave and Q-wave. The location for isoelectric line was estimated by finding the start and end point of all zero amplitude ECG level. Two points are identified by considering start and end location of zero amplitude points from peak location of P-wave respectively. A flat line is drawn between these two points called as isoelectric line. All the extracted ECG features are as shown in Fig. 3. ST-segment is located at 80ms after J-point when cardiac rhythm is less than 120BPM and 60ms after J-point when the cardiac rhythm is more than 120BPM [10].

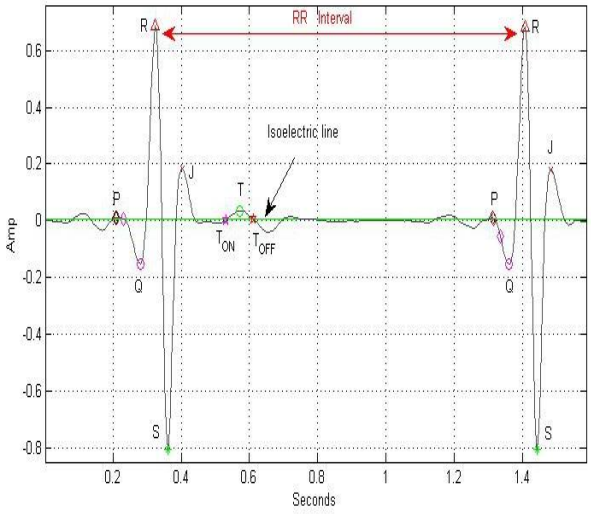

Fig. 3: Extracted wave peaks in ECG signal

C. Heart rate calculation

The heart rate (HR) is calculated from the above extracted features of ECG signal. The HR is determined by finding the inverse of RR-interval which is the time difference between two consecutive R-peaks present in every QRS complex [11]. HR is expressed in beats per minute (BPM). The normal range of HR is 60-120BPM [3]. The formula used to calculate heart rate (HR) is Heart Rate = [360/ (RR-interval in samples)] * 60 beats/min [1]. The calculated heart rate (HR) value can be used to detect the cardiovascular abnormalities.

D. Beat Classification

The ST-segment and T-wave are the two features generally used by cardiologist for ischemic beat classification [12]. The beat classification is based on some clinical rules. The rules considered as the beat is ischemic when ST deviation is more than 0.08mV above or below the isoelectric line and the beat is ischemic when T-wave is inverted or flattened [7]. The rules defined and followed for locating T-wave inversion and ST–episode deviation uses first 30s duration ECG [13]. T-wave inversion is measured considering T-wave amplitude variation (positive or negative) and ST-segment deviation is measured relative to the reference isoelectric line for. The ischemic beat classification method in [7] is used without considering the angle of deviation (in degree) as follows.

Ischemic beat classification

IF (ST- segment ≤ 0.08 mV) **OR**
(ST- segment ≥ 0.08 mV) **OR**
(T inverted or T→ 0 mV)
THEN beat is ischemic
ELSE beat is normal

E. Episode Recognition

As per the recommendation of ESC (European Society of cardiology) the ischemic episode detection procedure considers minimum 30s duration of signal [14]. A sliding window technique is used which searches the sequences of ischemic beats exist for 30s or more. The first sliding window includes first 30s of the signal and the technique proceeds moving the window one beat at a time keeping window duration of 30s. The ischemic window is detected if the 30s window contains more or equal to 75% of ischemic beats. The recognition of ischemic episode determines the existence of a series of consecutive windows which satisfies both 30s duration and 75% of ischemic beats [7]. Here the ischemic episode is calculated for the presence of at least two or more number of consecutive ischemic windows. The ischemic window identification and ischemic episode recognition process is summarised below.

Ischemic episode detection

IF [(No. of Ischemic beats)/ (All beats)] ≥ 0.75
THEN The Window is Ischemic
ELSE The Window is Normal
IF No. of consecutive ischemic window ≥ 2
THEN Ischemic episode is identified

The flow chart for heart rate and Ischemic episode detection process is as given in Fig. 4.

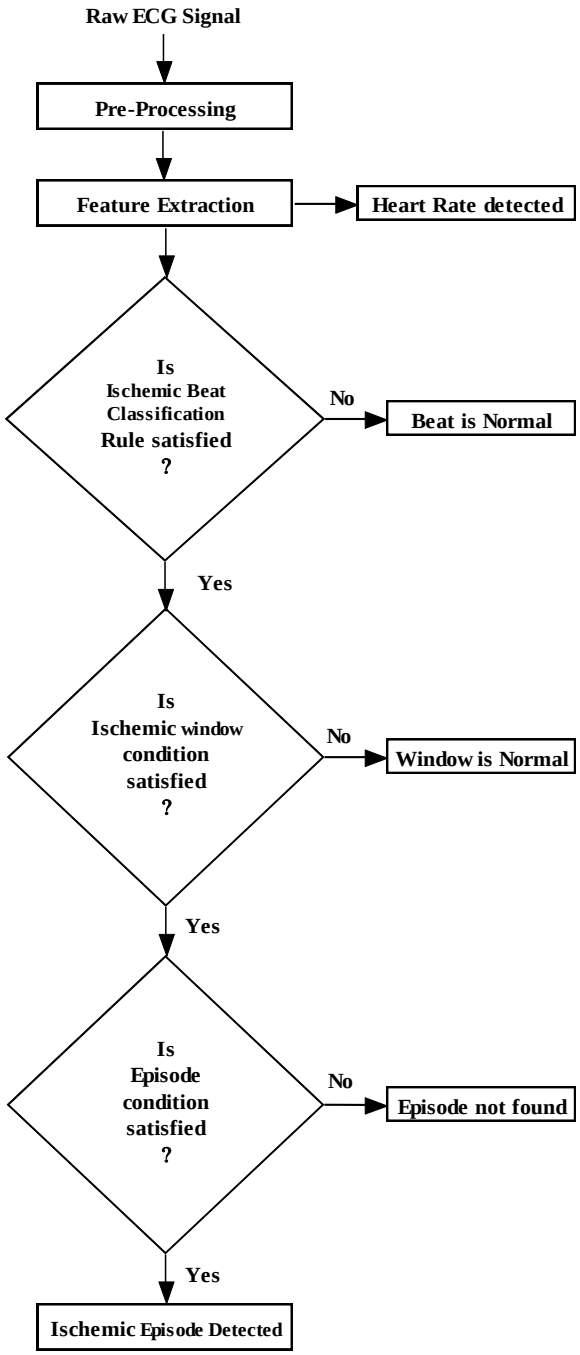

Fig. 4: Flow chart for Heart rate and Ischemic episode detection

3. Experimental Result

The effectiveness of this technique is validated by choosing 10 random ECG records from European ST-T database [15].The database consists of the recordings of 90 double channel 2-hr ECG signal with sampling rate $250s^{-1}$. The performance is measured in terms of sensitivity (Se) and positive predictive accuracy (PPA). The sensitivity measures the ability to detect ischemic episode whereas positive predictive accuracy gives estimation likelihood that a detected episode is a true Ischemic episode [16].

$$Se(\%) = \frac{TP}{TP + FN} \times 100$$

$$PPA(\%) = \frac{TP}{TP + FP} \times 100$$

Where
TP = True Positive (correctly detected event)
FP = False Positive (erroneously detected non-event)
FN = False Negative (erroneously missed event)
The average sensitivity and average positive predictive accuracy were found to be 88.08 % and 92.42 % respectively by randomly choosing ten records from European ST-T data base. The HR value and the corresponding abnormalities are also detected using above specified data base as given in Table 1.

Table 1: HR and Ischemic episode evaluation

ECG Data	30s windows	Ischemic windows	Ischemic ST episodes	TP	FP	FN	% Se	% PPA	HR
e0105	3693	694	8	11	0	3	78.57	100	56
e0112	3672	36	6	5	1	0	100	83.33	55
e0122	6245	2077	3	2	1	0	100	66.67	94
e0127	5053	316	6	7	0	1	87.5	100	76
e0207	3815	14	3	6	0	3	66.67	100	58
e0404	3884	30	3	5	0	2	71.43	100	59
e0417	5188	31	3	3	0	0	100	100	78
e0606	4415	4381	3	2	1	0	100	66.67	67
e0613	4097	465	5	11	0	6	64.71	100	62
e0615	3832	3811	3	3	0	0	100	100	58
e0704	5376	5368	3	3	0	0	100	100	81
						Avg=	88.08	92.42	

4. Conclusion

The performance of the proposed technique was validated on European ST-T data base [15]. This database contains 90 ECG recordings with annotated ischaemic episodes. The performance measurement

parameters, sensitivity (Se) and positive predictive accuracy (PPA) are calculated to detect ischemic ST-episodes. As table 1 indicates, the method provides the average sensitivity and positive predictive accuracy of 88.08% and 92.42% respectively. As per the table 1 some HR values are less than 60BPM and others comes under normal HR range (60-120BPM). The cardiovascular abnormalities can be identified using HR value. This technique can also be extended to detect other abnormalities like Tachycardia, Bundle Branch Block, Wolff-Parkinson-White syndrome, Premature Ventricular Contraction, etc.

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