ECG signal analysis for detection of Cardiovascular abnormalities and Ischemic episodes

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***Abstract*—Electrocardiogram (ECG) is generally used for diagnosis of cardiovascular abnormalities and heart disorders. An efficient method for analyzing the ECG signal towards the detection of cardiovascular abnormalities and ischemic episodes follows mainly five stages: pre-processing, feature extraction,cardiac abnormality detection, beat classification and ischemic episode recognition.The detection of cardiovascular abnormalities like bradycardia and tachycardia is based on the calculation of heart rate(HR) from the extracted ECG features.The extracted ST-segment and T-wave features are used for detection of ischemic episodes.The ability of the method was tested on European ST-T database. The performance of ischemic episode detection shows 88.08% sensitivity (Se) and 92.42% positive predictive accuracy (PPA).**

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

I. 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 abnormalities and disorders. 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 key to Ischemic episodes detection is ST-segment deviation and T-wave.The normal ST-segment and T-wave duration is 80-120ms and 120-160ms respectively [2].

Bradycardia, Tachycardia, Bundle Branch Block, Premature Ventricular Contraction, Wolff-Parkinson-White syndrome (WPW), etc., are the most common cardiovascular abnormalities [3].The cardiovascular abnormalities like bradycardia and tachycardia can be identified by calculating the heart rate (HR). The HR is calculated from the extracted features of ECG signal. The HR value is compared with the normal range of HR i.e.60-120BPM [3]to detect cardiovascular abnormalities.

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 analyzed 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 cardiovascular abnormalities and ischemic episodes 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 to identify various cardiovascular abnormalities.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.

Rest of the paper is organized as follows. Section II explains proposed methodology. Section III provides the experimental result using the European Society of Cardiology (ESC) ST-T database, Section IV provides conclusion.

II. PROPOSED METHODOLOGY

The methodology basically describes two different processes.First is the detection of cardiovascular abnormalities and then the detection of ischemic episodes.The block diagram for the proposed method is shown in Fig.1.

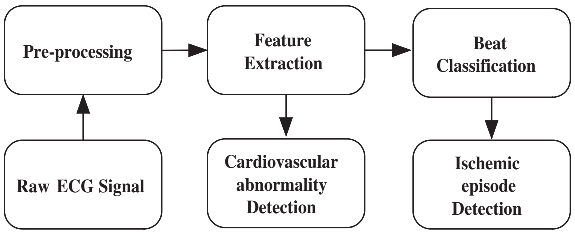

Fig. 1. Block diagram of ischemic episode detection

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.

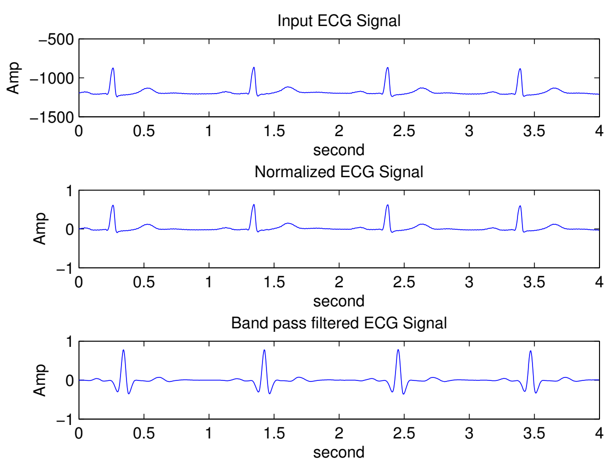

Fig. 2. ECG signal after normalization and filtering

B. Feature Extraction

The variations in ECG features like QRS-complex morphology and ST-segment deviation and T-wave alternation can be used for the detection of ischemic episodes. First feature towards the ischemic episode detection process is the determination of QRS-complex. The tallest peak i.e. R-peak 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.

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].

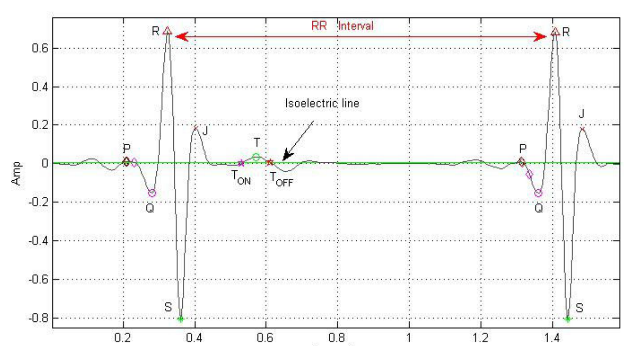

Fig. 3. ECG signal extracted wave peaks and points with baseline

C. Cardiovascular abnormalities detection

The cardiovascular abnormalities detection is based on heart rate (HR) calculation. The HR is calculated from the extracted features of ECG signal 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)and 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 HR value is compared with normal range to detect the cardiovascular abnormalities like bradycardia and tachycardia. The fast and slow heart rate value determines these abnormalities. The HR values less than 60BPM is termed as bradycardia (slow HR) and greater than 120BPM is called as tachycardia (fast HR)[3].The cardiovascular abnormality detection algorithm is as follows.

Algorithm 1 Cardiovascular abnormality detection

```
if (HR ≤ 60 BPM) then
    It is Bradycardia
end if
if (HR ≥120 BPM) then
    It is Tachycardia
end if
```

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.

Algorithm 2 Ischemic beat classification

```
if (ST-segment ≤ 0.08mV) (or) (ST-segment ≥ 0.08mV)
(or) (T inverted or T→ 0mV) then
    The beat is ischemic
else The beat is normal
end if
```

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 summarized below.

Algorithm 3 Ischemic episode detection

```
if ([(No. of Ischemic beats) /(All beats)] ≥ 0.75) then
    The window is ischemic
else The window is normal
end if
if (No. of consecutive ischemic window ≥ 2) then
    Ischemic episode is identified
end if
```

The complete flowchart of Cardiovascular abnormality and Ischemic episode detection process is given in Fig. 4.

III. 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 250Hz. The cardiovascular abnormalities i.e. bradycardia and tachycardia are detected by comparing the calculated HR value with the normal range of heart rate.The ischemic episode detection performance is measured in terms of sensitivity (Se) and positive predictive accuracy (PPA). The sensitivity parameter measures the ability to detect ischemic episode whereas positive predictive accuracy provides the estimation likelihood that the 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 for ischemic episodes detection 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 cardiovascular abnormalities are also detected using above specified data base as given in Table 1.

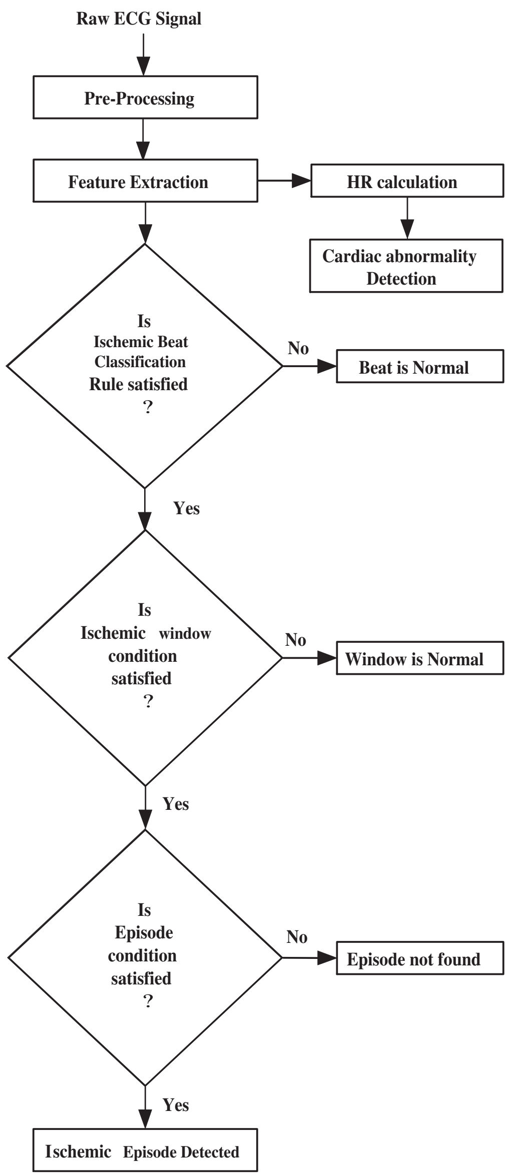

Fig. 4. Flowchart for cardiovascular abnormality and Ischemic episode detection

TABLE I

ECG Data	No. of 30s Windows	No. of Ischemic Windows	No. of Ischemic ST Episodes	TP	FP	FN	% Se	% PPA	HR	Cardiovascular abnormality
e0105	3693	694	8	11	0	3	78.6	100	56	Bradycardia
e0112	3672	36	6	5	1	0	100	83.33	55	Bradycardia
e0122	6245	2077	3	2	1	0	100	66.67	94	Normal HR
e0127	5053	316	6	7	0	1	87.5	100	76	Normal HR
e0207	3815	14	3	6	0	3	66.67	100	58	Bradycardia
e0404	3884	30	3	5	0	2	71.43	100	59	Bradycardia
e0417	5188	31	3	3	0	0	100	100	78	Normal HR
e0606	4415	4381	3	2	1	0	100	66.67	67	Normal HR
e0613	4097	465	5	11	0	6	64.7	100	62	Normal HR
e0615	3832	3811	3	3	0	0	100	100	58	Bradycardia
e0704	5376	5368	3	3	0	0	100	100	81	Normal HR
						Average	88.08	92.42		

IV. Conclusion

In this paper, an efficient method for the detection of cardiovascular abnormalities and ischemic episodes using ECG signal are proposed. The performance of the proposed technique was validated on European ST-T data base. The performances of the proposed method are measured sensitivity (Se) and positive predictive accuracy (PPA) parameters. Experimental results show that average sensitivity and positive predictive accuracy are 88.08 % and 92.42% respectively. As an example, the proposed methodology detects 3693 number of 30s windows, 694 number of ischemic windows and 08 numbers of ST episodes for the ECG recording e0105. The number of available ischemic ST episodes is 11 as per the European ST-T data base. The cardiovascular abnormality i.e. bradycardia is detected using calculated HR value. Some heart rate values are more than 60BPM but less than 120BPM which comes under normal HR range. The detection of tachycardia (HR>120BPM) is not found for the chosen ECG records. This technique can also be extended to detect other cardiovascular abnormalities like Bundle Branch Block, Wolff-Parkinson-White syndrome, Premature Ventricular Contraction, etc.

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