Identification of Myocardial Ischemic and Infarction Episodes Based on ST Level and Beat Type Re-attribution Method

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ABSTRACT
The objective of this study is to establish an efficient and effective recognition system for myocardial ischemic and myocardial infarction episodes in ECG. We first applied a preprocessing algorithm to reduce noise and baseline wander. Then, we simplified the procedures of identifying the important points and defined these points based only on heart rate and the R peak which is relatively unaffected by noise. Thirdly, an ST-deviations-based algorithm was used to identify both myocardial ischemic (MIs) and myocardial infarction (MIn) beats. Finally, a merging algorithm followed by correcting windowing was employed to re-evaluate the attribute of each beat for more accurately identify the beginning and end points of the episodes. The results show that, the proposed method raises the recognition rates from 87.53%, 85.12%, and 80.41%, in identifying MIs, MIn, and normal beats, respectively, to 94.63%, 91.56%, and 92.89%, respectively. The results demonstrate the efficiency and effectiveness of the proposed method in accurately identifying myocardial ischemic and infarction episodes.

CCS Concepts
• **Applied computing → Health informatics**

Keywords
Recognition system; ST-deviation; myocardial ischemic; myocardial infarction; re-attribution; beat type.

1. INTRODUCTION
Cardiovascular disease (CVD) has been a serious threat to people's health in recent years. According to the American Heart Association, cardiovascular disease is one of the leading causes of death in the United States, most of which are hypertension, coronary heart disease, and heart failure [1]. Similarly, in Taiwan, cardiovascular diseases are among the top three of the top ten causes of death in the calendar year [2]. Myocardial ischemia is the pathological state underlying ischemic heart disease. It can lead to myocardial infarction (commonly known as heart attack) which in its acute form can lead to the death of the affected person [3]. Coronary artery stenosis or obstruction can cause myocardial ischemia, and more seriously will cause myocardial infarction. Myocardial ischemia and myocardial infarction cause alterations in electrocardiographic (ECG) signal such as deviation in the ST segment [4]. When the ST segment is deviated for more than a certain level, the beat would be diagnosing as myocardial ischemia (ST depression) or myocardial infarction (ST elevation). Recently, several studies have been conducted to developing computer-aided diagnosis algorithms for the diagnosis of myocardial ischemia. Exarchos and coworkers [5] proposed to use rule-based mining technology to differentiate myocardial ischemic heartbeat from normal heartbeat. Khoshnoud and coworkers [6] used subband ECG signal decomposition with multi-level wavelet analysis and claimed that their method provided an easier way to locate the important points of the waveform for myocardial ischemia diagnosis with probabilistic neural networks (PNN).

However, conventional methods usually required to locate the fiducial points, e.g. T wave, *R* peak, *ISO* point, *J* point, as features for myocardial ischemic and infarction beat detection [7], but the fiducial points may become difficult to locate when the ECG signal is noisy or confronted with motion artifacts. To cope with this problem, our laboratory has proposed to use simple morphological features that are easy to detect and to be employed a correcting window to re-evaluate the results for more accurately identifying the myocardial beats and episodes [8]. The simplicity and effectiveness of our method demonstrated its potential to be implemented on portable devices and smart phones for the identification of myocardial ischemia and infarction.

Since serious myocardial ischemia usually lead to myocardial infarction, in this study, we designated to extend the system in [8] to identify not only myocardial ischemia, but also myocardial infarction. As in the previous study which only aimed to identify myocardial ischemia, simple look-up table approach was applied to detect the morphologically significant points in the ECG. The direct method followed to differentiate myocardial ischemic and infarction beats from the normal sinus rhythm based on the clinical symptoms of ST depression and ST elevation. A merging algorithm and a correcting window method proceeded to determine the attribute of the episodes to be either myocardial ischemic episode (MIs episode) or myocardial infarction episode (MIn episode). The advantages of the proposed method were demonstrated and the performance of the method was compare to other studies in the literature.

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2. METHOD

The block diagram of the proposed system is depicted in Figure 1. Each of the diagram blocks is described as follows.

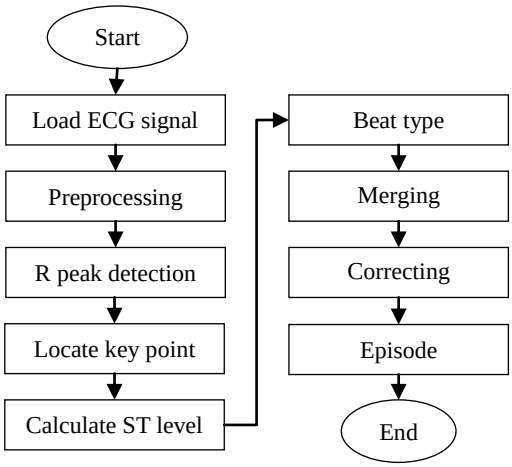

Figure 1. Experimental procedure

2.1 Database

The data used in the experiments were obtained from the European Society of Cardiology (ESC) ST-T database [9]. This database includes 79 data files recorded from patients suffered from myocardial ischemia and/or myocardial infarction. Each file contains two-lead, two-hours ECG signals sampled at 250 Hz. The start and end times of the segments with ST-level changes (myocardial ischemic episode and myocardial infarction episode) were clearly annotated in the files. Twelve records, that contain the same V4 lead ECG signals, were selected for the study.

2.2 Preprocessor

A preprocessor was employed to reduce baseline wander and high-frequency noise. The baseline wander was reduced by using a first-order high-pass filter with a cut-off frequency of 1 Hz. And the high-frequency noise was removed by using a first-order low-pass filter with a cut-off frequency of 20 Hz. The difference equations of the high-pass and low-pass filters are listed in equations (1) and (2), respectively.

$$y(n) = 0.9876\, x(n) - 0.9876\, x(n\text{-}1) + 0.9752\, y(n\text{-}1) \qquad (1)$$

$$y(n) = 0.2043\, x(n) + 0.2043\, x(n\text{-}1) + 0.5914\, y(n\text{-}1) \qquad (2)$$

2.3 *R* Peak Detection

In the analysis of ECG beats, the *R* peak is the most significant feature point of the ECG beat waveform. In this study, the Pan and Tompkins algorithm [10] was applied to locate the *R* peaks of the heartbeats. However, since the convolution operations sometimes causes minor shift of the waveform, the positions of the real *R* peaks were determined by searching the highest peaks in the vicinity (±3 samples) of the tentative *R* peaks in the preprocessed ECG signal. Once the *R* peak has been located, other points were needed to be determined.

2.4 Localization of Morphologically Significant Points

After the *R* peak has been located, the waveform with 35 samples before and 44 samples after the *R* peak was extracted as the representative waveform of a heartbeat (Figure 2). Then, the points of morphologically significance in characterizing myocardial beats were to be determined. Those points include the *J* and *Jx* points that define the start and end of the ST segment and the *ISO* point which is the comparison point for determine the ST segment deviation, as depicted in Figure 2.

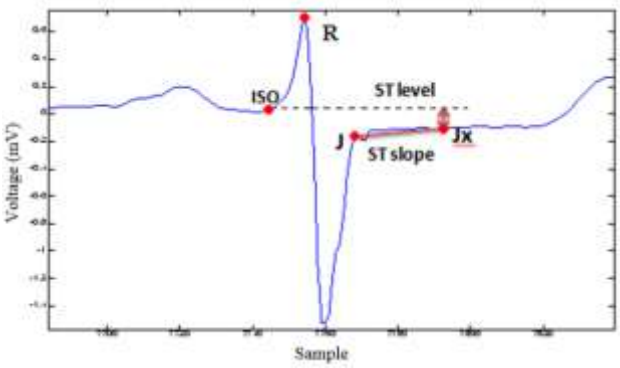

Figure 2. R peak and other morphologically key points

Table 1. Locations of the key points

Heart Rate (bpm)	*J*	*Jx*	*ISO*
HR<100	*R*+60ms	*R*+80ms	*R*-40ms
100≤HR≤120	*R*+40ms	*R*+80ms	*R*-40ms
HR > 120	*R*+40ms	*R*+60ms	*R*-40ms

Due to the fact that morphological features can be easily deteriorated by noises, a simple look-up table approach was applied to minimize the effect of noises and simplify the detecting procedure. By using a look-up table (Table 1), the three morphologically significant points *J*, *Jx*, and *ISO*, which are closely related to the *R* peak, can be easily located on the waveform according to the heart rate, as shown in Figure 2.

2.5 Direct Identification of MI Beat Types

The direct beat type identification method is to determine myocardial ischemic and myocardial infarction beats by direct comparison of the ST level of each heartbeat and that of a reference beat which is believed to be normal. The reference beat was determined in a record-based basis. The initial reference beat was obtained by averaging the ECG beats in the first 30 min of the record. However, when tracing the record from beginning, the reference beat was updated as a novel section of 30-second consecutive normal beats were detected.

Clinically, if the deviation of the ST level in a test beat exceeds the value of the reference signal (e.g. depression > 0.1 mV and elevation > 0.2mV), the test beat is diagnosed as a myocardial ischemic (MIs) beat or a myocardial infarction (MIn) beat accordingly [4]

2.6 Re-attribute the Beat Type

The beat type determined by the direct identification method was based entirely on ST depression or elevation. However, in the European Society of Cardiology (ESC) ST-T database [9], the annotation file only marks the beginning and the end points of the ischemic or infarction episodes. In each episode, the majority, but not necessary all, of the beats show ST depression or ST elevation depending on the beat episode types. Yet some of the beats in these episodes may demonstrate normal ST level and distribute

sparsely among the ST-depressed and ST-elevated beats, especially at the beginning and the end of the episodes. This property of MI episodes usually causes problems when managing to accurately identify the beginning and end points of an episode.

To tackle this problem, we proposed to re-examine the occurrence rate of each beat type determined solely by their ST levels, such that the directly identified beats can be more faithfully re-attribute to the correct episode it belongs to. The approach of using a merging algorithm followed by a correcting window method was proposed for this purpose.

2.7 Merging Algorithm

The myocardial ischemic or infarction episodes usually begin with the occurrence of sparse ST-deviated beats, followed by intensive occurrence, and end with gradually reduced occurrence rate of the same beat types. The merging algorithm designated to merge the ECG segment with sparsely occurrence of ST-deviated beats right before and after the intensive occurrence segment into a more complete episode.

The first step of the merging algorithm was using a 30-beat window to detect ECG segments that contained 30 consecutive beats with the same type of ST-deviation. For each of the 30-beat segment, the 10 beats before and after the segment were checked. If the majority of the 10 beats belong to the same beat type as the associated segment, the entire 10 beats were re-attributed to be the same beat type as the segment. Otherwise the checked beats remained as their original attribute.

2.8 Correcting Window Method

The merging algorithm is a preliminary rectification method for the beginning and the end of MI episode. However, some of the beats inside an MI episode may still reveal normal ST level and distributed sparsely among the ST-depressed and ST-elevated beats. Therefore, we applied a correcting window method that employed two windows with window sizes of 10-beat and 20 beats to rectify the attribution of beat type. Firstly, a window of 10 beats was moved along the re-attributed result after the merging algorithm. If more than half of the 10 beats belonged to the same MI beat type, the entire 10 beats were re-attributed to be that beat type, otherwise remained as their originally determined attribute. The same process was conducted with the second window of 20 beats in size and the resulting attribute was determined for the segmentation of MIs and MIn episodes.

3. RESULTS AND DISCUSSIONS

Twelve records were selected from the European Society of Cardiology (ESC) ST-T database [9] for experiments. Each of the 12 records includes one V4 lead ECG signal which contains at least one myocardial ischemic (MIs) episode or myocardial infarction (MIn) episode. The start and end times of the MI episodes were annotated in the files. Table 2 summarizes the records used in the study, including the numbers of the MIs and MIn episodes, the number of beats in the two episodes and the number of normal beats in each of the records. Consequently, a totally of 15 V4 lead ECG records containing 15 MI episodes, including 3955 beats in the MIs episodes, 2364 beats in the MIn episodes, and 44891 beats in the normal segments, were recruited for the study.

By using the morphologically key points ISO, J, and *Jx*, and comparing the ST level in each beat to that of the reference normal beats, we can directly identify the MIs and MIn beats. Figure 3-(a) depicts the result when applying the direct identification method to record 124, in which the normal, MIs, and MIn beats are represented by 0, -1, and 1, respectively. It is evident that sparse MIs or MIn beats sometimes appear in the normal episodes and cause mistaken identification order to identify MIs and MIn that really are clinical significant. Through the proposed beat type re-attribution method, included a merging algorithm and a correcting window method, the episode duration can be more faithfully identified as Figure 3-(b). The performance of the direct beat type identification method and the proposed beat type re-attribution method are summarized in 0Also included for comparison is the performance of beat type re-attribution using only correcting window method.

Table 2. Records used in the study

Record	MIs episodes	MIn episodes	Normal beats	Beats in MIs episodes	Beats in MIn episodes
e0103		4	3470		631
e0113		2	4531		172
e0118		3	3329		725
e0124	3		4383	845	
e0125	1		4896	68	
e0136	1	4	3636	36	208
e0147	3		2953	642	
e0148	4		2908	666	
e0159	1		3861	1132	
e0161		1	3804		594
e0163	1		3971	48	
e0166	1	1	3149	518	34
Total	15	15	44891	3955	2364

Table 3. Performance comparison of different beat type attribution methods

Method	The average accuracy of records (%)			
	Normal Beats	MIs Beats	MIn beats	Total
Direct method	80.41	87.53	85.12	84.66
Correcting window only	91.31	91.76	90.03	90.77
Merging + Correcting window	92.89	94.63	91.56	93.29

The direct method, although seem naïve and straightforward, achieved fairly well recognition rates of 87.53%, 85.12%, and 80.41%, in identifying MIs, MIn, and normal beats, respectively. Employing the proposed beat type re-attribution method boost the performance and elevated the recognition rates to 94.63%, 91.56%, and 92.89%, in recognizing MIs, MIn, and normal beat, respectively. Comparatively, using only correcting windows to re-attribute beat type also improve the recognition rates, but to a minor extent.

The performance of the proposed method was compared to that of three representative methods published in the literature [5, 6, 8], although the databases were not exactly the same. The comparative results were summarized in Table 4. It is impressive that the proposed method, although simple and straight forward,

achieved superior recognition rates when compared to other methods. More importantly, the proposed improved method is capable of differentiating both myocardial ischemic and myocardial infarction beats from normal sinus beats, yet the other method can only recognize myocardial ischemic beats from normal beats.

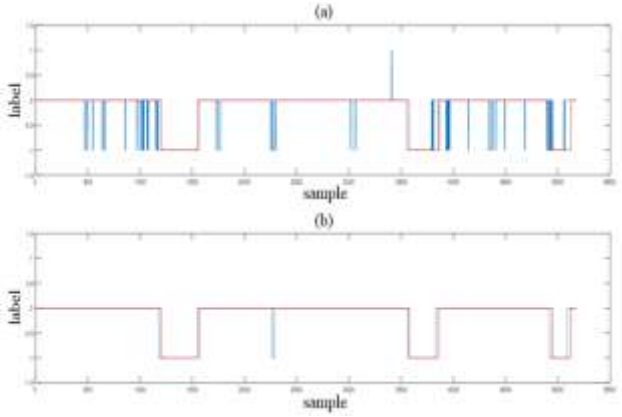

Figure 3. The correct beat types of record 124 comparing with (a) the direct identification of MI Beat Types and (b) both merging algorithm and correcting window method. (The red is the correct beat types and the blue is the experimental result.)

Table 4. Performance comparison of the proposed method with other studies

Method	Rule-based [5]	PNN classifier [6]	Yu and Tsai's method [8]	Proposed
Normal Beats Accuracy (%)	93	89.19	90.52	92.89
MIs Beats Accuracy (%)	87	96.67	95.16	94.63
MIn beats Accuracy (%)				91.56
Total Accuracy (%)	90	90.75	91.80	93.29

We further applied the proposed method to identify MIs and MIn episodes in the database. The performances are evaluated by the ratio of the true positive (TP) of the detected episodes over the true number of episode (N), the false positive (FP), and the coverage rate, i.e. the overlap of the detected and the annotated MI episodes. It is impressive to notice that all the 15 MIs episodes and 15 MIn episodes in the 12 records were faithfully detected with an average coverage rate of 97.06%. Moreover, the false positive (FP) numbers were minor; six FPs in 30 test records results in only a small FP rate of 0.2/record. Even in the records that show FPs, the coverage rates of the detected MI episodes exceeded 93.1%.

4. CONCLUSION

In this study, we extended the effective myocardial ischemia identification system proposed by Yu and Tsai [8] to be able to identify both myocardial ischemia (MIs) and myocardial infarction (MIn). The novel system includes an effective beat type identification method based on ST level followed by a beat type re-attribution method. Both of the two processes (merging and correction windows) of the re-attribution method were demonstrated to raise the recognition rates of the MIs/MIn identification system. Both processes contribute to the elevation of the beat type recognition rates and episode coverage rate, and the reduction of false positive rate. When compared to other representative studies, the proposed method outperforms them with superior recognition rates to differentiate more beat types. The results demonstrate the efficiency and effectiveness of the proposed method in accurately identifying myocardial ischemic and myocardial infarction episodes.

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