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Discrimination of different myocardial infarction stages using wide band electrocardiogram

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ABSTRACT

Most of usual electrocardiogram (ECG) signals normally keep the signal energy in the 0.05–100 Hz band, but higher frequencies containing valuable diagnostic information are also present in wide band (WB) ECG signals. Existing studies on computer-assisted myocardial infarction (MI) diagnosis are mostly based on the usual ECG signals, and the valuable diagnostic information has not been used sufficiently yet. Multivariable autoregressive coefficients were extracted from WB orthogonal ECG (OECG) signals for the classification purpose in this research. The data for the analysis were taken from Physikalisch Technische Bundesanstalt diagnostic ECG database including health control, MI in early stage and MI in acute stage. In order to further investigate the performance of WB ECG signals, standard ECG signals with a wide frequency band were utilized for the feature extraction and classification as the same way. The experimental results showed that the MI classification accuracy could be improved by introducing WB ECG signals and the features extracted from WB OECG signals with a frequency of 0–250 Hz would be the best efficient representation for discriminating different MI stages. The classifiable and efficient features can be extracted from WB OECG signals for the classification of MI stages with a high accuracy.

1. Introduction

From the view of pathology, the evolution processes of myocardial infarction (MI) can be orderly separated into the stages: From health control (HC) to MI in early stage (MIES, within several minutes or hours) to MI in acute stage (MIAS) ect. If patients can obtain the thrombolytic therapy during MIES, the heart tissue that is closer to death can be saved and continue to survive, otherwise the irreversible heart tissue damage will occur and even lead to inevitable sudden death in later stages. The various MI stages are directly related to the size of the damaged myocardium on which the outcome of early prognosis depends. Thus, it is essential and significant to identify different MI stages for patient's urgent treatment and management [1,2].

The electrocardiogram (ECG) signal analysis is an effective non-invasive clinical diagnostic method. According to the medical definition, the typical symptoms of MI in clinic can be described as: In early stage of MI, T wave and ST segment start to elevate, abnormal Q wave does not appear yet, while R wave is still preserved. In acute stage of MI, R wave disappears, abnormal Q wave is easy to be discerned, a flatted or negative T waves can be observed [3]. On the other hand, we should notice that these abnormal changes appeared in ECG are low-level signals during the evolution processes. Actually, less than half of patients with MIES have clear diagnostic changes of ECG on their first trace. Automatic detection and classification of the abnormalities in ECG will be of great help in medical examinations or monitoring of critical ill patients. In existing studies on abnormal changes of MI ECG, MIES and MIAS were grouped together, and rare attention has been paid to the detection of MIES [4,5,6,7,8]. Thus, the reliable computer assisted automatic MI recognition remains a study for a cardiovascular diagnostic system.

Most of usual ECG signals are derived from the frequencies limited to 0.05–100 Hz, but higher frequencies (HF) are also present in the ECG signals. Wide band (WB) ECG usually refers to the ECGs with an extended bandwidth of up to 1000 Hz. In current study, the ECG signals with a frequency bandwidth above 100 Hz are also called as WB ECG. It was reported that root mean square (RMS)

Abbreviations: ECG, Electrocardiogram; HC, Health control; HF, Higher frequency; HPF, High-pass filter; KLT, Karhunen–Loeve transform; LPF, Low-pass filter; MAR, Multivariable autoregressive; MI, Myocardial infarction; MIAS, Myocardial infarction in acute stage; MIES, Myocardial infarction in early stage; OECG, Orthogonal electrocardiogram; RAZ, Reduced amplitude zone; RMS, Root mean square; SECG, Standard electrocardiogram; SSE, Sum-squared error; SVM, Support vector machine; WB, Wide band.

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List of notations

100 Hz_OECG OECG signal with a bandwidth of 0–100 Hz
250 Hz_OECG OECG signal with a bandwidth of 0–250 Hz
500 Hz_OECG OECG signal with a bandwidth of 0–500 Hz
FMAR coefficient MAR model coefficients estimated from the OECG signal
SMAR coefficient MAR model coefficients estimated from the SECG signal
100 Hz_FMAR FMAR coefficients estimated from 100 Hz_OECG
250 Hz_FMAR FMAR coefficients estimated from 250 Hz_OECG
500 Hz_FMAR FMAR coefficients estimated from 500 Hz_OECG
100 Hz_SECG SECG signal with a bandwidth of 0–100 Hz
250 Hz_SECG SECG signal with a bandwidth of 0–250 Hz
500 Hz_SECG SECG signal with a bandwidth of 0–500 Hz
100 Hz_SMAR SMAR coefficients estimated from 100 Hz_SECG
250 Hz_SMAR SMAR coefficients estimated from 250 Hz_SECG
500 Hz_SMAR SMAR coefficients estimated from 500 Hz_SECG

computed from the HF components of the QRS complex is more sensitive in the detecting acute coronary artery occlusion than conventional ST elevation diagnostic criterial [9]. Another significant reported example for the use of HF ECG is the reduced amplitude zone (RAZ) defined by Abbound et al. [10], it reported that RAZ could be detected earlier than either QRS complex or ST interval significant changes. Lots of existing studies on MI detection and classification are based on the usual ECG signals [1,4,11]. More and more attentions have been paid to diagnose cardiac diseases including MI and late potentials of myocardial depolarization using HF ECGs nowadays [2,5,10,12].

There are two typical ECG lead systems, namely, 12-standard lead system and 3-orthogonal Frank lead system, and the sampled ECG signals are called as orthogonal ECG (OECG) and standard ECG (SECG) respectively. From the view of electrophysiology, Frank OECG can better reflect the anatomic changes [3]. In addition, the number of leads for Frank lead system is less than for standard lead system. Lower dimensional feature vectors might be extracted easily from OECG compared to SECG. Both 12-lead SECG and 3-lead OECG are equally applicable for automated computer analysis and diagnosis [12]. A lot of quantitative OECG descriptors have been studied and provided different accuracy indices, but we should note that clear OECG criteria for assessment of myocardial condition have not been defined yet [2].

This is part of our previously related works that were aimed at building a high accurate classification system of different MI stages. The purpose of the work described in this paper is to investigate to what extent WB ECG signals would help in the classification of different MI stages and explore the practicality of using multivariable autoregressive (MAR) model to extract the classifiable features from WB OECG signals.

The remained of the paper is organized as follows: Section 2 describes the methods including ECG data processing, MAR modeling, feature extraction and classification. Section 3 presents the experimental results. Section 4 discusses the results and finally Section 5 concludes the study.

Table 1
Data collected from PTB diagnostic ECG database.

	Number of HC	Number of MIES	Number of MIAS
Total number	959	500	1100
Training data	300	200	400
Testing data	659	300	700

2. Methods

2.1. ECG data

In this investigation, the data from Physikalisch Technische Bundesanstalt diagnostic ECG database were used for the analysis. The database contains 549 records from 290 subjects. Each record includes 15 simultaneously measured signals including 12 standard ECG leads together with 3 orthogonal Frank leads. Each signal is digitized at 1000 samples per second with a 16-bit resolution over a range of 16.384 mV in the database. The WB ECG signal bandwidth is 0–500 Hz. The data were selected from the subjects under HC and the patients with ST-elevation who were confirmed to suffer from one of two abnormalities, namely, MIES and MIAS. Table 1 shows the data for the analysis, 300 out of 959 samples from HC, 200 out of 500 samples from MIES and 400 out of 1100 samples from MIAS were used for training, and the remaining 659 samples from HC, 300 samples from MIES and 700 samples from MIAS were used for testing. The training data were randomly selected from the three classes, and the rest were used as testing data.

The procedures of the preprocessing performed in this investigation are shown in Fig. 1. Generally, a bandwidth of 0.05–100 Hz is needed for clinical application purposes. In current study, a 0.04-Hz cut off frequency high-pass filter (HPF) was employed to suppress residual baseline drift and wandering, a 50-Hz notch filter was used to eliminate the power line interference. In order to explore to what extent WB-OECG signals would have effect on the detection of different MI stages, three types of different low-pass filters (LPF) were utilized to filter OECG signals to generate three different sets of OECG signals with different frequency ranges, the cutoff frequencies of which are 100 Hz, 250 Hz and 500 Hz respectively, and all the filters are based on a sampling rate of 1000 Hz in this study. In theory, the incoming signals must be digitized at least at twice the rate of the highest frequency of interest for signal retention. Thus, in order to reduce computation complexity as soon as possible for subsequent MAR modeling, the sampling rates of the OECG signals filtered by a 100-Hz cut off frequency LPF and a 250-Hz cut off frequency LPF were converted to 200 Hz and 500 Hz, respectively. The method described in Matlab decimate function was used to resample the signals. In the method, an eighth order low-pass Chebyshev Type I filter is used, and it filters the input sequence in both the forward and reverse directions to remove all phase distortion effectively. It resamples the filtered data by selecting every rth point ($r = 5$ for 200 Hz, $r = 2$ for 500 Hz). Thus, three sets of OECG signals were achieved, which the respective signal bandwidths are 0.05–100 Hz, 0.05–250 Hz and 0.05–500 Hz, hereafter called the signals as 100 Hz_OECG, 250 Hz_OECG and 500 Hz_OECG. The R peaks of OECGs were detected using Tompkin's algorithm [13]. The length of the segmented signals before and after the R peak in each beat is 0.3 s and 0.6 s, respectively, such that the window covers most of the characteristics of one ECG cycle[14].

2.2. MAR modeling and feature extraction

In MAR model, the current observation is represented as a weighted linear combination of past observations plus a random, uncorrelated input. In current study, the 3-lead OECG signals