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Automatic ECG arrhythmia classification using dual tree complex wavelet based features

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ABSTRACT

Early detection of cardiac diseases using computer aided diagnosis system reduces the high mortality rate among heart patients. The detection of cardiac arrhythmias is a challenging task since the small variations in electrocardiogram (ECG) signals cannot be distinguished precisely by human eye. In this paper, dual tree complex wavelet transform (DTCWT) based feature extraction technique for automatic classification of cardiac arrhythmias is proposed. The feature set comprises of complex wavelet coefficients extracted from the fourth and fifth scale DTCWT decomposition of a QRS complex signal in conjunction with four other features (AC power, kurtosis, skewness and timing information) extracted from the QRS complex signal. This feature set is classified using multi-layer back propagation neural network. The performance of the proposed feature set is compared with statistical features extracted from the sub-bands obtained after decomposition of the QRS complex signal using discrete wavelet transform (DWT) and with four other features (AC power, kurtosis, skewness and timing information) extracted from the QRS complex signal. The experimental results indicate that the DWT and DTCWT based feature extraction technique classifies ECG beats with an overall sensitivity of 91.23% and 94.64%, respectively when tested over five types of ECG beats of MIT-BIH Arrhythmia database.

1. Introduction

The electrocardiogram (ECG) is widely used as a tool by cardiologists for determining the abnormalities of the human heart. An expert medical practitioner may fail to diagnose the heart abnormalities due to the nonstationary nature of ECG signals resulting in life threatening situations. A doctor interprets an ECG signal based on its morphological shape and other parameters such as RR interval, PP interval, and QT interval. The task of determining fiducial points and computation of parameter is a tedious job for doctors. Hence, there is a need for computer aided diagnosis system which can achieve a higher recognition accuracy.

In the literature, numerous feature extraction techniques are applied to analyze and classify ECG beats [1,13]. In [1], premature ventricular contraction beats are classified from normal and other abnormal beats by using wavelet transform based and timing information based feature. In this technique, an overall accuracy of 95.16% was reported using artificial neural network (ANN) classifier. Six types of ECG beats that are normal (N), premature ventricular contraction (V), fusion of ventricular and normal beat (F), atrial premature beat (A), right bundle branch block (R) beat and fusion of paced and normal beat (f) are classified using particle swarm optimization (PSO) and radial basis functional neural network (RBFNN) in the literature [2]. In this technique, the experimental results are limited over a small data set of MIT-BIH database. ECG arrhythmia detection using wavelet transform and probabilistic neural network gives an accuracy of 99.65% as reported in the literature [3]. However, the experimental results are evaluated only on 23 ECG records of MIT-BIH database. In [4], the authors have used small MIT-BIH database for classification of ECG arrhythmias. In [5], higher order statistics (HOS) of sub-band components as feature and neural network based on back propagation algorithm as classifier are used. An accuracy of 96.34% is achieved using this technique. In [6], Kadambe et al. have concentrated on classifying three ECG waves – P, QRS and T, since the U wave almost does not appear in actual ECG data. In addition, they have also classified normal vs. abnormal ECG waves and achieved 96%, 90% and 93.3% overall classification accuracy of abnormal vs. normal P waves, QRS waves and T waves, respectively. In [7], principal component analysis (PCA) is used as a tool for classifying five types of ECG beats that are normal (N), left bundle branch block (L), right bundle branch block (R), atrial premature (A) and ventricular contraction (V). In [9], a combination of independent features and compressed ECG

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data is used as input to the multilayered perceptron network. An accuracy of 88.3% is reported over 10 files of MIT-BIH database. In [10], ECG morphology, heart beat intervals and RR intervals as feature and classifier model based on linear discriminants are used for classifying five types of ECG beats recommended by Association for the Advancement of Medical Instrumentation (AAMI) standard [11], i.e. N beat, ventricular ectopic beat (VEB), supraventricular ectopic beat (SVEB), fusion of normal and VEB, unknown beat and achieved an accuracy of 85.9%. In [12], statistical features are obtained from the selected Lyapunov exponents, wavelet coefficients and the power levels of power spectral density (PSD) values using eigenvector methods of the ECG signals for classification of four types of ECG beats (N beat, congestive heart failure beat, ventricular tachyarrhythmia beat and atrial fibrillation beat). In [13], an experimental study is performed to determine the effects of pulsed electromagnetic field (PEMF) at extremely low frequency (ELF) in response to photoplethysmographic (PPG), electrocardiographic (ECG), and electroencephalographic (EEG) activity using discrete wavelet transform. Many of the aforementioned techniques have shown significant performance only on small dataset of MIT-BIH database and hence these techniques may fail to classify ECG beats of large dataset. In addition, ECG signal classification techniques based on past approaches have not performed well due to their inconsistent performance when classifying a new patient's ECG waveform. This makes them unreliable to use clinically.

The most important step in pattern classification problems is the feature extraction technique since a good classifier may fail to classify the beats, if the extracted features are not proper [13]. Feature extraction technique is a problem dependent task which varies for each application. It is the technique of extracting significant information from a signal thereby representing the signal in lower dimension. The feature extraction technique overcomes the problem of computational complexity and over fitting of the trained data. The LPC and MFCC based feature extraction techniques are widely used in speech signal processing. In [16], the reported work is integrated simultaneous masking, forward masking and temporal integration effect on MFCC feature extraction algorithm. This technique sharpens the power spectrum of the signal in time domain and frequency domain resulting in a better speech recognition algorithm. The DWT based feature extraction techniques provide better energy compaction property when compared to the LPC and MFCC based feature extraction technique [14]. Hence DWT features provide better recognition performance when compared to the LPC and MFCC based features. In [15], the combination of DWT and LPC technique is used for speech recognition. These features performed better than LPC and MFCC based features but their performance is not consistent and is poor in noisy environment. Noise robust feature extraction technique for speech recognition is proposed in [14], where the features obtained from the combination of DWT and LPC technique are subjected to cepstrum mean normalization technique. The wavelet transform so far, has remained popular in extracting feature vectors from ECG signal because of its ability to characterize time–frequency information which is important in this context. Due to its time–frequency localization properties, the wavelet transform is an efficient tool for analyzing nonstationary ECG signals. In wavelet, good time resolution and poor frequency resolution are found at high frequencies and good frequency resolution and poor time resolution are obtained at low frequencies. The wavelet transform can be used to decompose an ECG signal according to scale, thus allowing separation of the relevant ECG waveform morphology descriptors from the noise, interference, baseline drift, and amplitude variation of the original signal.

Though the conventional DWT technique is an efficient tool for analyzing nonstationary signals, it suffers from different problems such as oscillation, shift variance and aliasing. DWT lacks shift invariant property i.e. the energy of the wavelet coefficient varies significantly as the input signal is shifted. The ECG beats of the same patient may be of the same type, however one may be a slightly shifted version of the other. In such cases DTCWT classifies ECG beats efficiently than DWT technique. Another difficulty of wavelet analysis is its non-adaptive nature. Once the basic wavelet is selected, one need to use it to analyze all the ECG data. In this paper, a novel technique is proposed for classifying ECG beats using DTCWT technique. The approximate shift invariance property of this transform makes this technique useful in pattern recognition and signal analysis application [8]. The DTCWT features and four features extracted from the QRS complex of each cardiac cycle are used as the total feature set. In addition to the approximate shift invariance property, the DTCWT provides perfect reconstruction using short linear phase filters, limited redundancy which is independent of the number of scales (2^m for m-dimensional signal) and efficient computation (twice as simple DWT) [17]. The neural network based on back propagation training algorithm classifies ECG beats to appropriate classes. A comparative study is performed on features extracted using DTCWT and DWT technique. The experimental results indicate that DTCWT based features perform better than the DWT features for the 48 files of MIT-BIH database.

The rest of the paper is organized as follows: Section 2 presents the ECG database used in the experiment. The proposed technique is described in Section 3. Experimental results and discussions are presented in Section 4. The conclusion of this paper is reported in Section 5.

2. ECG data

MIT-BIH ECG Arrhythmia database is used to evaluate the performance of the proposed technique. The database contains normal beat and common type of life threatening arrhythmias. The database was created in 1980 as a reference standard for arrhythmia detectors. The database comprises of 48 recordings, each containing 30 min of ECG segment selected from 24 h recordings of 48 different patients. The first 23 recordings correspond to the routine clinical recordings while the remaining recordings contain the complex ventricular, junctional, and supraventricular arrhythmias [18]. These records were sampled at 360 Hz and band pass filtered at 0.1–100 Hz [18]. In this paper, normal (N), paced (P), right bundle branch block (R), left bundle branch block (L) and premature contraction (V) beats are used for performance evaluation of the proposed method to classify cardiac arrhythmias.

3. Proposed framework

The proposed technique consists of three main stages: (i) preprocessing, (ii) feature extraction and (iii) classification. Block diagram of the proposed technique is shown in Fig. 1. The preprocessing stage consists of amplitude normalization and filtering of ECG signals. The ECG signals are normalized to a mean of zero and standard deviation of unity, thereby reducing the amplitude variance from file to file. The embedded noises in ECG signals are removed using a band pass filter with a cutoff frequency of 4–22 Hz. The pre-processed ECG signal is used in next stage for extracting significant features. The R peaks of ECG signals are located using the annotated file of MIT-BIH database. The features extracted using DTCWT technique is applied as input to an ANN classifier which maps the feature vectors to the respective class labels.

3.1. Feature extraction

This paper proposes the feature extraction technique based on a DTCWT technique which consists of complex wavelet coefficients