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Original Research Article

Automated diagnosis of atrial fibrillation ECG signals using entropy features extracted from flexible analytic wavelet transform

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ABSTRACT

Atrial fibrillation (AF) is the most common type of sustained arrhythmia. The electrocardiogram (ECG) signals are widely used to diagnose the AF. Automated diagnosis of AF can aid the clinicians to make a more accurate diagnosis. Hence, in this work, we have proposed a decision support system for AF using a novel nonlinear approach based on flexible analytic wavelet transform (FAWT). First, we have extracted 1000 ECG samples from the long duration ECG signals. Then, log energy entropy (LEE), and permutation entropy (PEn) are computed from the sub-band signals obtained using FAWT. The LEE and PEn features are extracted from different frequency bands of FAWT. We have found that LEE features showed better classification results as compared to PEn. The LEE features obtained maximum accuracy, sensitivity, and specificity of 96.84%, 95.8%, and 97.6% respectively with random forest (RF) classifier. Our system can be deployed in hospitals to assist cardiac physicians in their diagnosis.

1. Introduction

Q2 Atrial fibrillation (AF) is a type of cardiac arrhythmia which can be characterized by irregularity and rapidity of the cardiac contraction [5,35]. About 2.2 million people in the USA and 4.5 million people in European Union have this arrhythmia [18]. In the next 40 years, the number of people having AF is expected to double in north America [19]. AF may lead to stroke and congestive heart failure (CHF) [18]. The death rate for AF patients is double as compared to the normal subjects [18]. The risk of death may be reduced if timely treatment is available for

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the AF patients. Hence, an early stage diagnosis of AF can avoid unnecessary complications and save a life. The AF patients may show dyspnea and fatigue [5]. These signs may not be present in all the AF patients. Hence, there is a possibility that many AF patients may be left undetected. In order to diagnose the AF, the electrocardiogram (ECG) is widely used by the cardiologists. Manual detection of AF using ECG is tedious and time-consuming task [5]. The accuracy of the AF detection by many primary care physicians using ECG signals is not sufficiently high [34]. Hence, a computer-aided detection system for AF patients is required to help the doctors for accurate diagnosis.

Various approaches are suggested to diagnose the presence of AF. A method based on the absence of P-wave for AF detection over a short duration of ECG is proposed in [31]. An AF detection method based on time domain features is also presented in [16]. In [49], a computer-based AF detection algorithm is suggested. This algorithm is based on power spectral analysis of remainder ECG. Percent power of the remainder ECGs is observed to be significantly different for the rhythms of AF and control groups. A method based on sample entropy is presented in [32] can detect the AF using 12 ECG beats. The AF detection technique proposed in [53] computes symbolic sequence from the RR-interval sequence. Further, Shannon entropy is computed from the symbolic sequence to detect the presence of AF. In [25], the delta RR-interval distribution difference curve is used to detect the transition between the AF and normal rhythms. It is the reflection of the variability of RR-interval. In [33], root mean square of successive RR differences (RMSSD), Shannon and sample entropies are found to be useful in the assessment of AF. A four-step process is explored for the AF detection from RR-interval in [24]. These steps include the histogram, standard deviation analysis, numbering aberrant rhythm recognition, and Kolmogorov–Smirnov (KS) test.

Our objective is to propose a computer-based approach to diagnose the AF patients automatically. To achieve this objective, we have used entropy-based features in flexible analytic wavelet transform (FAWT) [9,52] domain to discriminate ECG segments of different classes. The ECG segments are decomposed into the sub-band signals using FAWT. We have computed log energy entropy (LEE) and permutation entropy (PEn) from these sub-band signals. Then, the features are fed to the random forest (RF) [13] and J48 decision tree [42,43] classifiers to classify the ECG segments of different classes. The block diagram of the proposed system is shown in Fig. 1.

2. Methodology

2.1. Dataset used

In this work, we have used MIT-BIH AF database (MIT-BIH AFDB) which is publicly available at physionet [39,20]. The dataset has ECG signals of 23 AF patients. The ECG signals present in the dataset are sampled at a rate of 250 samples per second. The duration of the recording is 10 h. The dataset contains four types of rhythm AFIB (atrial fibrillation), AFL (atrial flutter), Jr (AV junctional rhythm), and N (all other rhythms). In this work, we have studied AF and N rhythms. We have excluded the two patients (04936 and 05091) which are wrongly annotated [53] in this study. There are 243 N, 247 AF, 12 Jr, and 13 AFL rhythms of ECG signals corresponding to 21 patients in the dataset. In the dataset, two ECG signals are corresponding to each patient. We have used first ECG signal corresponding to each patient in this work.

2.2. Noise removal and ECG signals segmentation

The Daubechies 6 (db6) wavelet basis function for eliminating baseline wander and noise from the ECG signals is utilized [36,37]. After pre-processing, we have extracted 1000 samples segments from the N, AF, Jr, and AFL rhythms from 21 patients' ECG signals. We have obtained 77267 AF, 114214 N, 76 Jr, and 615 AFL ECG segments of length 1000 samples. In this work, we have formed two types of classification problems. First one is AF and N rhythms classes. The second one is classification of all the four groups. The number of ECG segments of Jr group are fewer than rest of other groups. Hence, in the second classification problem, we have examined 76 ECG segments from each group. In the present work, we did not eliminate the ectopic beats from the rhythms.

2.3. Signal decomposition using FAWT

FAWT has following properties [9,52]:

1. It is a rational-dilation wavelet transform.
2. It can be implemented by the iterative filter bank.
3. It has one low pass and two high pass channels at each level in its iterative filter bank.
4. The two high pass channels separate the negative and positive frequencies and provide analytic bases.

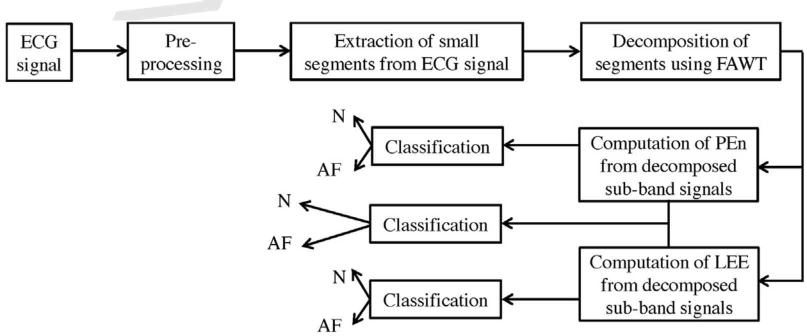

Fig. 1 – The proposed algorithm for the diagnosis of AF.

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