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Original Research Article

Characterization of cardiac arrhythmias by variational mode decomposition technique

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ABSTRACT

Automatic detection of cardiac abnormalities in early stage is a popular area of research for decades. In this work a novel algorithm for detection of cardiac arrhythmia is proposed using variational mode decomposition (VMD). Arrhythmia is a crucial abnormality of heart in which the rhythmic disorder may lead to sudden cardiac arrest. Existing algorithms for arrhythmia detection are based on accuracy of detection of fiducial points, parameter selection and extraction, quality of classifier and other factors. Unlike other works, proposed method tries to characterize both atrial and ventricular arrhythmias simultaneously and independently from the segmented sections of the signal. VMD, being able to separate closely spaced frequencies, has a good potential to be useful to provide significant features in transformed domain. Unique feature combinations are also proposed to characterize different arrhythmic events.

1. Introduction

Irregular heartbeats (arrhythmia) due to irregular electrical activity in heart may lead to sudden cardiac arrest (SCA) [1]. It is necessary to monitor and treat the cardiac patients regularly. Automatic diagnosis of arrhythmia at its initial stage may increase the probability of survival from SCA incident. This motivates development of an automated system for analysis of cardiac activity and detection of arrhythmic events from ECG signal.

From the generation prospective of arrhythmia, it can be divided into two types – atrial and ventricular arrhythmia. In general arrhythmia is characterized by episodes (atrial fibrillation (AF), atrial flutter (AFL), bundle branch block, etc.) or by sudden occurrence of ectopic beats like premature ventricular contraction (PVC).

AF rhythm (Fig. 1e) is characterized by replacement of P-wave by fibrillatory wave in ratio of 2:1, 4:1 [2] in comparison to normal rhythm. It is also characterized by irregular R to R duration. AFL (Fig. 1f) is usually characterized with fast heart rate (250–400 beats per minute) and accompanied by a varying

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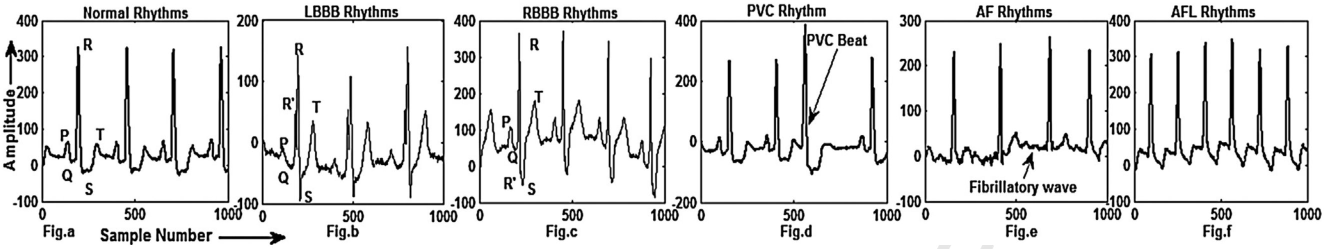

Fig. 1 – Different cardiac rhythms.

degree of AV (atrial ventricular) block [3]. Similar to AF ratio of fibrillatory waves over ventricular contractions may be of 1:1, 2:1 or 4:1 [4].

Disturbances in the conduction path of electrical pulse also generate irregular heart rate. For example, block in either bundle branch reduces the conduction through Bundle of His causing RBBB (Fig. 1c) in the right side of ventricle and LBBB arises due to similar problem in left side. This type of rhythms is characterized by wide QRS complex, additional R′ peak and deep S-wave in the ECG signal and inverted T wave [5]. PVC rhythm (Fig. 1d) generally arises when heartbeat is initiated by Purkinje fibres in the ventricles [6]. R to R interval for a PVC cycle and its earlier cardiac cycle is smaller than usual whereas it is large for the next cycle.

Diagnosis of cardiac abnormalities from ECG signal has been proposed by many researchers in recent past. Most of the works are taken consideration of either abnormalities in atrial zone or ventricular zone of ECG signal. For example detection of ventricular abnormalities like PVC, based on statistical approach, neural network or wavelet transform is proposed in [7–12]. Other ventricular abnormalities like LBBB and RBBB are analyzed from ECG signal independently by using time or frequency characteristics [13–20] of the rhythms. Composite study of both PVC and BBB rhythms is also proposed in [21]. Study of abnormal atrial episode like AF and AFL are proposed in different literature based on the time domain features like R to R interval or frequency domain analysis of fibrillatory wave [22–32]. Most of the study mainly characterizes the atrial fibrillation but composite analysis of both AF and AFL are also proposed in the literatures [33–35]. Hence proposed literatures are mainly base on to either ventricular or atrial activity. But this study focuses on the characterization of both activities of cardiac cycle by single processing of ECG signal.

A versatile and automated cardiac diagnostic tool should have a property to detect maximum number of abnormalities irrespective of the origin. Most of the previous works lead to a solution towards the detection problem of few ventricular or atrial abnormalities. In this work an effort has been made to address most of the cardiac arrhythmias resulting from both atrial and ventricular malfunctioning.

Further, a diagnostic tool should have the capacity of less classification hazard. Classification of any event depends on the quality of the derived features. Complicated classification techniques involve more computational complexity which results in delay in diagnosis.

Unlike other popular transformation techniques, variational mode decomposition (VMD) [36] is capable to separate any pair of harmonics irrespective of their amplitude and frequency. Hence this method is well suited for capturing arrhythmic condition for both atrial and ventricular regions. This work also focuses to characterize atrial and ventricular arrhythmia using a single transformation in unique characterization planes separately for both arrhythmias. Finally, multiclass characterization is made using multistage two class segmentation technique. This makes the zone-specific classification of beats with better visual impact. In general, biosignals are filtered [37] prior to feature extraction. Decomposition techniques are also used for signal enhancement [29]. This study also emphasis to skip the pre-processing of ECG signal like de-noising thereby leading to feature extraction directly after decomposition.

2. Method

This section illustrates the process of deriving unique modality from a raw ECG data to characterize the rhythms by spectral decomposition of the signal. The proposed method is pictorially represented in Fig. 2. The general description of VMD method is described below:

VMD method decomposes the input signal into desired number of mode N. These modes are compact around their centre frequency. The resulting constrain derivational problem of signal is the following:

$$\min_{v_N,\omega_N}\left\{\sum_N \left\|\partial_t\left[\left(\phi(t)+\frac{j}{\pi t}\right)*v_N\right]e^{-j\omega t}\right\|_2^2\right\} \qquad (1)$$

where $\sum_N v_N = x$; $v_N(N=1,2..K)$ denotes each decomposed mode and $\omega_N(N = 1, 2, \ldots K)$ is its centre frequency.

The reconstruction constraint can be addressed by making use of both a quadratic penalty term and Lagrangian multipliers, in order to render the problem unconstrained. The combination of the two terms helps in well convergence properties of the quadratic penalty at finite weight, and the strict enforcement of the constraint by the Lagrangian multiplier. Hence, augmented Lagrangian arguments Γ[38] can be introduced as follows:

$$\Gamma(v_N,\omega_N,\lambda)=\alpha\sum_N\left\|\partial_t\left[\left(\phi(t)+\frac{j}{\pi t}\right)*v_N\right]e^{-j\omega t}\right\|_2^2+\left\|x-\sum v_N\right\|_2^2 + \left\langle\lambda, x-\sum v_N\right\rangle \qquad (2)$$

where λ is Dual ascent, ϕ is Dirac distribution and α is Lagrange multiplier. The solution to the original minimization problem (1) can be found as the saddle point of the augmented

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