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Original article

K-means algorithm for the detection and delineation of QRS-complexes in Electrocardiogram

Algorithme K-means pour la détection et la délimitation des complexes QRS surl'électrocardiogramme

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Abstract

Electrocardiogram (ECG) is an important bioelectrical signal used to asses the cardiac state of a patient. It consists of a recurrent wave sequence of P-wave, QRS-complex and T-wave associated with each beat. The QRS-complex is the prominent feature of the ECG. This paper presents a simple method using K-means clustering algorithm for the detection of QRS-complexes in ECG signal. Digital filters are used to remove the power line interference and baseline wander present in the ECG signal. K-means algorithm is used to classify QRS and non-QRS-region in the ECG signal. The performance of the algorithm is validated using dataset-3 of the CSE multi-lead measurement library. Detection rate of 98.66% is obtained. The percentage of false positive and false negative is 1.14% and 1.34% respectively. The mean and standard deviation of the errors between automatic and manual annotations is calculated to validate the delineation performance of the algorithm. The onsets and offsets of the detected QRS-complexes are found well within the tolerance limits as specified by the CSE library.
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Keywords: ECG; QRS-complex; K-means Algorithm; ECG delineation

Résumé

L'électrocardiogramme (ECG) est un signal bioélectrique important utilisé pour évaluer l'état cardiaque du patient. Il consiste en une séquence d'ondes récurrente, l'onde P, le complexe QRS et l'onde T, associée à chaque battement. Le complexe QRS est l'onde dominante de l'ECG. Cet article présente une méthode simple utilisant l'algorithme des K-means pour la détection des complexes QRS dans le signal ECG. Des filtres numériques sont utilisés pour éliminer le bruit d'alimentation électrique et les fluctuations de ligne de base dans le signal ECG. L'algorithme K-means est utilisé pour différencier les régions QRS et non-QRS dans le signal ECG. Les performances de l'algorithme sont validées sur la base d'une librairie de données (CSE *multi-lead measurement library*). Le taux de détection est de 98,66 %. Les pourcentages de faux positifs et de faux négatifs sont respectivement de 1,14 % et 1,34 %. Les moyennes et écart-types des erreurs entre détections automatiques et manuelles sont calculés pour valider les limites de performances de l'algorithme. Les débuts et fin de détection des complexes QRS détectés sont dans les limites de tolérance spécifiées par la librairie CSE.
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Mots clés : ECG ; Complexe QRS ; Algorithme de K-means ; Tracé ECG

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1. Introduction

Electrocardiogram (ECG) is an essential tool for investigating cardiac abnormalities. As shown in Fig. 1, ECG is characterized by a recurrent wave sequence of P, QRS and T-wave associated with each beat. The QRS-complex is the most striking waveform within the ECG. Since it reflects the electrical activity within the heart during the ventricular contraction, the time of its occurrence and as well as its shape provides much information about the current state of heart. The ECG recordings may contain various challenging problems such as segment with high noise content, sudden change in QRS amplitude and morphology, or muscle and electrode artifact which are not often detected correctly. Hence reliable and correct detection of QRS complexes, under various backgrounds, is very important in any algorithm used for ECG analysis. The correct performance of these systems depends on several important factors such as quality of ECG signal, the applied detection rule, the learning and testing dataset used. Once the positions of the QRS-complexes are found, the locations of other components of ECG like P, T-waves and ST segment, etc. are found relative to the position of QRS, in order to analyze the complete cardiac period. In this sense, QRS-detection provides the fundamental for almost all automated ECG analysis algorithms.

The problem of QRS-detection is addressed by many researchers. The extensive review of the various approaches is given in [1–4]. Recently few other detectors based on Hybrid Complex Wavelet [5], transformative approach [6], PCA-ICA based algorithm [7], continuous wavelet transform [8], multiscale filtering based on mathematical morphology [9], Support Vector Machine [10–12], Adaptive quantized threshold [13] etc. have been proposed. Most of the QRS-detectors consist of two main stages: a preprocessing stage, including linear filtering followed by nonlinear transformation and the decision rule [2]. A simple clustering scheme using K-means algorithm is proposed in the present paper for the detection of QRS-complexes in single lead ECG signal.

This paper is structured as follows. A brief theory of the K-means algorithm is described in section 2. Description of the dataset 3 of the CSE multi-lead measurement library is provided in section 3. An algorithm for the detection of the QRS-complexes is explained in section 4. The detection and delineation results of the proposed algorithm are reported in section 5 with the aid of computer simulations and Bland-Altman analysis.

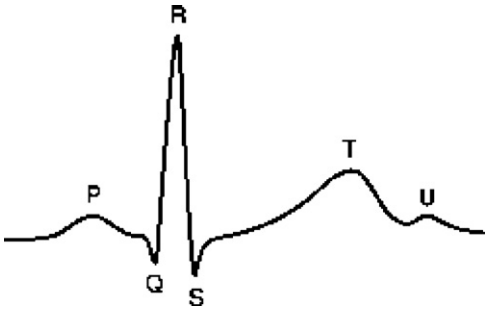

Fig. 1. Typical ECG Signal.

2. K-means algorithm

This section describes an outline of K-means algorithm used for the generation of feature signal [14]. When a number of samples are given and it is required to group them into K number of clusters, K-means algorithm can be used. It is based on the minimization of performance index, which is defined as the sum of squared distances from all points in a cluster domain to the cluster center. The various procedural steps of the K-means algorithm are as follows.

Step 1: choose initially K cluster centers $Z_1(1)$, $Z_2(1)\ldots Z_k(1)$. These are arbitrary and are usually selected as the first K samples of the given samples set X and $Z_{l+1}(1) \neq Z_l(1)$, for $l = 1, 2,\ldots, K-1$.

Step 2: at the k^{th} iterative step, distribute the samples X among the K cluster domain, using the following relation.

$$X \in S_j(k) \qquad \text{if } \left\|X - Z_j(k)\right\| < \|X - Z_i(k)\| \tag{1}$$

For all $i = 1, 2,\ldots, K$, $i \neq j$, where $S_j(k)$ denotes the set of samples whose cluster center is $Z_j(k)$.

Step 3: from the results of step 2, compute the new cluster centers $Z_j(k+1), j = 1, 2,\ldots, K$, such that the sum of the squared distances from all the points in $S_j(k)$ to the new cluster center is minimized. In other words, the new center $Z_j(k+1)$ is computed so that the performance index,

$$J_j = \sum_{X \in S_j(k)} \left\|X - Z_j(k+1)\right\|^2,$$

$$j = 1,\ 2,\ \ldots,\ K \text{ is minimized.} \tag{2}$$

The $Z_j(k+1)$, which minimizes this performance index is simply the sample mean of $S_j(k)$. Therefore, the new cluster center is given by,

$$Z_j(k+1) = \frac{1}{N_j} \sum_{X \in S_j(k)} X,\ j = 1,\ 2,\ \ldots,\ K \tag{3}$$

where, N_j is the number of samples in $S_j(k)$. The name "K-means" is obviously derived from the manner in which cluster are sequentially updated.

Step 4: if $Z_j(k+1) = Z_j(k)$ for $j = 1, 2,\ldots, K$, the algorithm has converged and the procedure is terminated.

The behavior of K-means algorithm is influenced by the number of cluster centers specified, the choice of initial cluster, the order in which the sample are taken and the geometrical properties of data.

3. CSE ECG Database

The validation of the proposed algorithm for QRS-complex detection and delineation is done using 1500 original ECG records of dataset-3 of CSE multi-lead measurement library [15]. This library has been developed to standardize and evaluate the performance of computer measurement programs. It consists of 125 original 12-leads simultaneously recorded ECGs i.e. 1500 single lead ECGs covering a wide variety of cardiac abnormal-

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