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Application of support vector machine for the detection of P- and T-waves in 12-lead electrocardiogram

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ABSTRACT

Electrocardiogram (ECG) is characterized by a recurrent wave sequence of P, QRS and T-wave associated with each beat. The performance of the computer-aided ECG analysis systems depends heavily upon the accurate and reliable detection of these component waves. This paper presents an efficient method for the detection of P- and T-waves in 12-lead ECG using support vector machine (SVM). Digital filtering techniques are used to remove power line interference and base line wander. SVM is used as a classifier for the detection of P- and T-waves. The algorithm is validated using original simultaneously recorded 12-lead ECG recordings from the standard CSE ECG database. Significant detection rate of 95.43% is achieved for P-wave detection and 96.89% for T-wave detection. The method successfully detects all kind of morphologies of P- and T-waves. The on-sets and off-sets of the detected P- and T-waves are found to be within the tolerance limits given in CSE library.

1. Introduction

The electrocardiogram (ECG) is a graphical representation of electrical activity of the heart. The ECG pattern consists of a recurrent wave sequence of P, QRS and T-wave associated with each beat. The automatic detection of ECG waves is important to cardiac disease diagnosis. In a clinical setting, such as intensive care units, it is essential for automated systems to accurately detect and classify ECG wave components. The correct performance of these systems depends on several important factors, including the quality of the ECG signal, the applied classification rule, the learning and testing dataset used.

Fig. 1 displays a typical ECG cycle. The first deflection, termed as P-wave is due to the depolarization of the atria. The large QRS-complex is due to the depolarization the ventricles. This is the complex with largest amplitude and is easy to detect. Numerous methods are reported in literature for the detection of QRS-complex [1–3]. The last deflection is T-wave. It corresponds to the ventricular repolarization of the heart. Reliable detection of P- and T-wave is more difficult than QRS-complex detection for several reasons including low amplitudes, low signal-to-noise ratio, amplitude and morphological variability. The P-wave may be even absent from some ECG recordings. Over the last few years, the P- and T-wave detection and delineation problem has been addressed using different approaches [4–14]. In most of these methods P- and T-waves are detected relative to the position of QRS-complex by applying appropriate threshold. The main problems of the thresholding techniques are their high noise sensitivity and their low efficiency when dealing with odd morphologies. This results in more false positive and false negative detections. Further, some of the algorithms detects only monophasic P- and T-waves and not suitable for biphasic P- and T-waves [13,14]. Therefore, more sophisticated techniques are needed to facilitate the development of new detection schemes with higher detection accuracy and suitable for all kind of morphologies of P- and T-waves.

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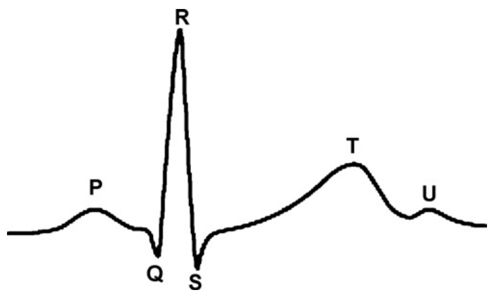

Fig. 1 – ECG signal.

SVMs are also applied for ECG signal analysis and arrhythmia classification [15–20], where in component wave detection is accomplished by using some other technique. SVM is successfully applied for the detection of QRS complexes in simultaneously recorded 12-lead ECG [2]. This paper presents a new method for the detection of P- and T-waves in the simultaneously recorded 12-lead ECG signal using SVM. The method is suitable for the detection of all morphologies of P- and T-waves.

2. Support vector machine

The technique of SVM, developed by Vapnik [21], is a powerful widely used technique for solving supervised classification problems due to its generalization ability. In essence, SVM classifiers maximize the margin between training data and the decision boundary (optimal separating hyperplane), which can be formulated as a quadratic optimization problem in a feature space. The subset of patterns those are closest to the decision boundary are called as support vectors.

Consider a set of training examples $(\mathbf{x}_1, y_1), \ldots, (\mathbf{x}_1, y_1)$ where input $\mathbf{x}_i \in R^N$ and class labels $y_i \in \{-1, +1\}$. Decision function of the form $\mathrm{sgn}((\mathbf{w}, \mathbf{x}) + b)$ is considered, where $(\mathbf{w}, \mathbf{x})$ represents the inner product of $\mathbf{w}$ and $\mathbf{x}$, $\mathbf{w}$ is weight vector and b is bias. It is necessary to find a decision function $f_{w,b}$ with the properties

$$y_i((w \cdot \mathbf{x}_i) + b) \geq 1, \quad i = 1, \ldots, l. \tag{1}$$

In many practical situations, a separating hyperplane does not exist. To allow for possibilities of violating (1), slack variables, ξ_i are introduced like

$$\xi_i \geq 0, \quad i = 1, \ldots, l \tag{2}$$

to get

$$y_i((w \cdot \mathbf{x}_i) + b) \geq 1 - \xi_i, \quad i = 1, \ldots, l. \tag{3}$$

The support vector approach for minimizing the generalization error consists of the following:

$$\text{Minimize}: \Phi(w, \xi) = (w \cdot w) + C\sum_{i=1}^{l} \xi_i \tag{4}$$

subject to constraints (2) and (3).

The C is a user defined constant. It is called regularizing parameter and determines the balance between the maximization of the margin and minimization of the classification error.

The above minimization problem can be posed as a constrained quadratic programming (QP) problem. The solution gives rise to a decision function of the form:

$$f(\mathbf{x}) = \mathrm{sgn}\left[\sum_{i=1}^{l} y_i \alpha_i (\mathbf{x} \cdot \mathbf{x}_i) + b\right] \tag{5}$$

where α_i are Lagrange multipliers. Only a small fraction of the α_i coefficients are nonzero. The corresponding pairs of $\mathbf{x}_i$ entries are known as support vectors and they fully define the decision function.

By replacing the inner product $(\mathbf{x} \cdot \mathbf{x}_i)$ with kernel function $K(\mathbf{x}, \mathbf{x}_i)$; the input data are mapped to a higher dimensional space [22]. It is then in this higher dimensional space that a separating hyperplane is constructed to maximize the margin.

3. ECG signal preprocessing

A raw ECG signal of a patient is acquired. As shown in Fig. 2(a), a raw ECG signal is often contaminated by disturbances such as power line interference and baseline wander. The finite impulse response (FIR) notch filter proposed by Van Alste and Schilder [23] is used to remove baseline wander. The adaptive filter to remove base line wander is a special case of notch filter, with notch at zero frequency (or dc). This filter has a “zero” at dc and consequently creates a notch with a bandwidth of $(\mu/\pi)f_s$, where f_s is the sampling frequency of the signal and μ is the convergence parameter. Frequencies in the range 0–0.5 Hz are removed to reduce the base line drift. The filter proposed by Furno and Tompkins [24] is used to remove 50 Hz power line interference. Fig. 2(b) displays the filtered ECG signal after removal of power line interference and base line wander.

SVM-based method proposed in Ref. [2] is used for the detection of QRS-complexes. Fig. 2(c) shows the locations of the QRS-complexes detected by this method. These QRS-complexes are removed from the ECG signal by replacing them by the base line. The baseline replacing the QRS-complexes has the uniform level of the onset of the detected QRS-complex. The ECG signal without QRS-complexes is displayed in Fig. 2(d). The slope at every sampling instant is calculated to enhance the signal in the region of T-waves. The slope is used as an important discriminating feature because slope of the ECG signal is much more in the T-wave region as compared to region other than T-waves as displayed in Fig. 2(e). These slope values are then normalized. This way a set of 12 normalized slope curves is obtained, one for each lead.

4. P- and T-wave detection algorithm

This section describes the algorithm developed for the detection of P- and T-waves in simultaneously recorded 12-lead ECG signal.