A ROBUST KNOWLEDGE-BASED TECHNIQUE FOR ISCHEMIA DETECTION IN NOISY ECGs

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A Robust Knowledge-Based Technique for Ischemia Detection in Noisy ECGs

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ABSTRACT

In cases where the signal-to-noise ratio (SNR) in ECGs is very poor the correct definition of characteristics as the isoelectric line and the J-point (beginning of the ST segment) is difficult. Inaccurate definition of those ECG characteristics can lead an automated ischemia detector to an incorrect diagnosis. We propose a method capable of extracting from noisy long duration ECG recordings those ECG characteristics that can be used for myocardial ischemia detection and analysis. We tested the performance of the method using noisy ECGs from the European Society of Cardiology ST-T database (ESC ST-T database). The results were more than satisfactory and the performance of our ischemia detector was improved in all cases. The proposed technique has low computational effort and can be executed in real time.

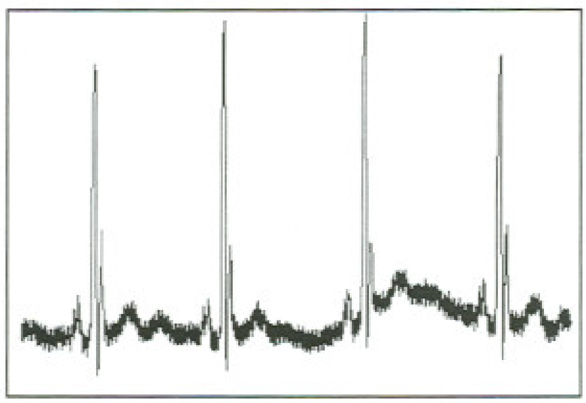
Introduction

Myocardial ischemia is the most common cardiac disease and is characterized by a high risk of sudden cardiac death [1]. Until now, ECG recordings that are used for the diagnosis of ischemic episodes are affected by noise, which deteriorates significantly the diagnostic accuracy [8]. Better handling of the noisy ECGs can improve the accuracy of the diagnostic methods and increase their applications in every day practice.

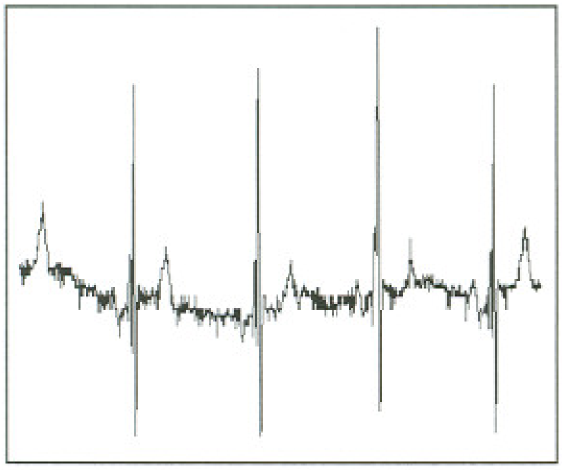
There are three types of noise in the ECG signal: (a) power line interference (A/C interference), (b) electromyographic contamination (EMG noise), and (c) baseline wandering (BW) [2]. In Fig. 1 it is shown how these three types of noise distort the ECG signal. A/C interference contaminates the ECG signal with main frequency interference, which sometimes is phase-shifted with respect to the main voltage (50 or 60 Hz) [3]. EMG noise is correlated with muscle contraction and overlaps with the frequency spectrum of the ECG signal [4]. It is obvious that the removal of the EMG noise alters also the original ECG signal. Finally, the baseline wandering is caused by respiration and motion artifacts and generally is a low frequency noise [5].

In order for the diagnosis of ischemia to be achieved we need to detect the existing ischemic episodes. Ischemic episodes are defined by continuous alterations in the ST segment or the T wave. To be more specific, if a cardiac beat appears to have an ST deviation ($\geq$ 1 mm) or a change in polarity in the T wave, then this beat is characterized as an ischemic beat. A series of ischemic beats, usually more than 30 seconds in duration (in accordance with the ESC recommendations) define an ischemic episode [8]. As a result even slight alterations in the original ECG signal due to noise corruption can lead to false decisions because either the isoelectric line or the J point are identified inaccurately.

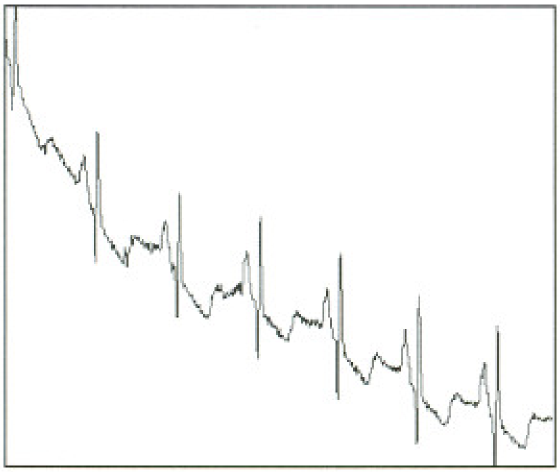
Fig. 1: The three types of noisy ECGs.



a) A/C interference



b) EMG noise



c) BW

Several techniques have been proposed for the removal of the three types of noise [3]-[7]. All these techniques are based on signal filtering to produce a "clean" ECG. Signal filtering results in many cases in alterations of the original waveform and as a consequence in an inaccurate identification of the ECG characteristics. The two techniques proposed in our work were developed to improve the performance of our knowledge-based ischemia detector [8], which uses the following rules for the identification of ischemic beats:

A beat is ischemic if:

(a) the ST segment is depressed $\leq$ 0.08 mm and has a slope $\geq 65°$, or
(b) the ST segment is elevated $\geq$ 0.08 mm, or
(c) the T wave is inverted.

It is obvious that the performance of the detector heavily depends on the correct definition of the isoelectric line and the J point identification.

Materials and Methods

The proposed technique requires first the accurate identification of the QRS complex. This is achieved using the algorithm described in Ref. [9] with some modifications that make the QRS detection procedure 30% faster.

The noise removal proceeds as follows: First the baseline wandering problem is treated. If we consider a small time interval in the ECG signal (e.g. one cardiac cycle) the baseline shift can be approximated by a first order polynomial (straight line). Then the subtraction of the polynomial from the recorded signal will reproduce the original ECG.

For each cardiac cycle we consider a time interval which starts 60 msec before the P wave and ends 60 msec after the T wave. Let $x(t)$, $t = 1,2,...,N$ be the recorded ECG signal. Using a least square procedure we can estimate the polynomial $p(t)$ that best fits $x(t)$:

$$p(t) = a_1 t + a_0 , \quad \text{for } t = 1,2,...,N \qquad (1)$$

where a_1 and a_0 are the polynomial coefficients.

The corrected ECG signal (without the baseline drift) is given by:

$$x'(t) = x(t) - p(t) , \quad \text{for } t = 1,2,...,N \qquad (2)$$

It must be noted that in cases where no baseline wandering exists the above procedure does not affect the original signal.

The above is the general procedure for the baseline wandering correction. However, in practice two modifications have been incorporated. First, the procedure is not directly applied to the signal $x(t)$ but to the signal $y(t) = x(t) - \bar{x}$, where $\bar{x}$ is the mean value of $x(t)$. This translates the recorded signal around the zero voltage level. Second, the estimation of the polynomial coefficients is realized in two sub-stages. In the first sub-stage we estimate the coefficients corresponding to $y(t)$. Then we subtract the estimated polynomial from this signal. In the second sub-stage the final polynomial is estimated for a signal obtained by replacing the QRS complex with the corresponding values of the polynomial estimated in the first sub-stage. The two sub-stages are necessary because the existence of the QRS complex slightly shifts the polynomial towards its main QRS polarity: if the QRS has a large R wave then the polynomial shifts upwards and the opposite happens when Q or S wave are large.

After the baseline correction we proceed with the isoelectric line and J point identification. We combine the slope criterion ($C_s \leq 5$ μV/msec) reported in Ref. [10] with an averaging window technique. To make the slope criterion stricter we used a smaller threshold value ($C_s \leq 2.5$ μV/msec). The isoelectric line is defined by the mean value of a 20 msec interval located 60 msec before the R (or the S) wave. For the J point we use a moving averaging window of 20 msec. This window starts sliding point-by-point 20 msec after the R (or the S) wave and stops when it reaches 120 msec after this wave. During this sliding procedure we determine the J point as the first point that fulfils the slope criterion. We subtract –3 from the identified point due to the fact that the application of the sliding averaging window introduces a time shift. In the case of sampling frequency 250 Hz (as is the case in the ESC ST-T database) the averaging window uses 5 segments, which corresponds to a time shift of 3 segments.

Results

We tested the performance of the baseline correction procedure and the averaging window technique using data from the ESC ST-T database. We studied how well the isoelectric line and the J point are identified using the proposed approach. We performed some experiments using more than one cardiac cycles and higher order polynomials for the baseline correction. What we described above in the materials and methods section shows the best performance.

Table 1 displays results of the overall ischemia detector concerning the sensitivity (Se) and the positive predictive accuracy (PPA). It also provides comparative performance results when the proposed method is not used. Five ECGs were considered. ECGs e0124 and e0136 are contaminated with EMG and BW noise, e0147 with A/C interference and e0207 and e0404 with BW noise.

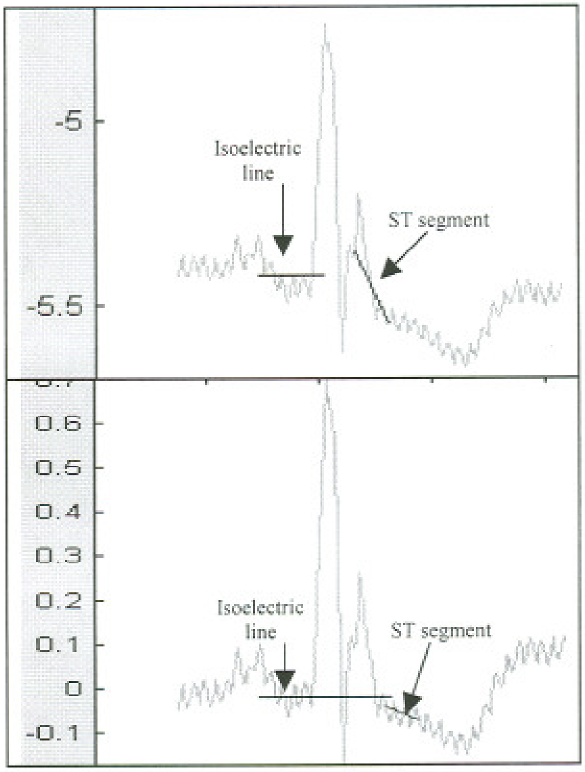
The proposed method shows excellent diagnostic behavior, due to the accurate identification of both the isoelectric line and the J point.

Fig. 2 shows how the isoelectric line and the ST segment were defined with and without the application of the proposed method for the three types of noise.

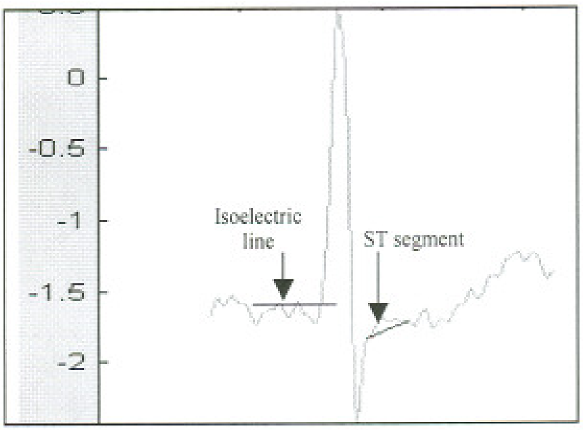
Table 1: Ischemia detector's performance with and without use of the proposed method.

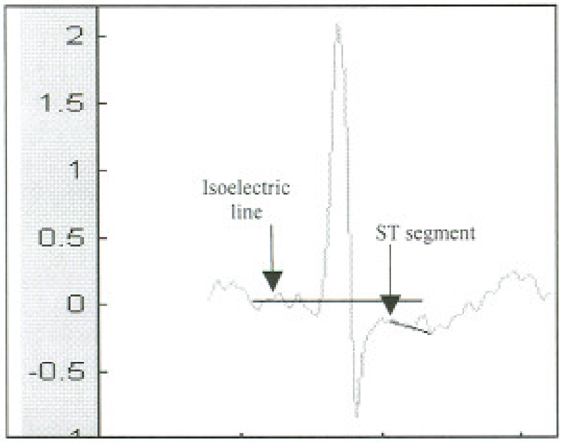
	With		Without	
File	**Se**	**PPA**	**Se**	**PPA**
e0124	85.71%	87.50%	14.29%	20.00%
e0136	83.33	71.43	50.00%	37.5%
e0147	100%	75%	100%	26.67%
e0207	80%	100%	60%	40%
e0404	100%	100%	100%	16.67%

Fig. 2: Identification of the isoelectric line and the ST segment in the three cases of contaminated ECG. In each case the top (bottom) figure corresponds to the identification without (with) the use of the proposed method.

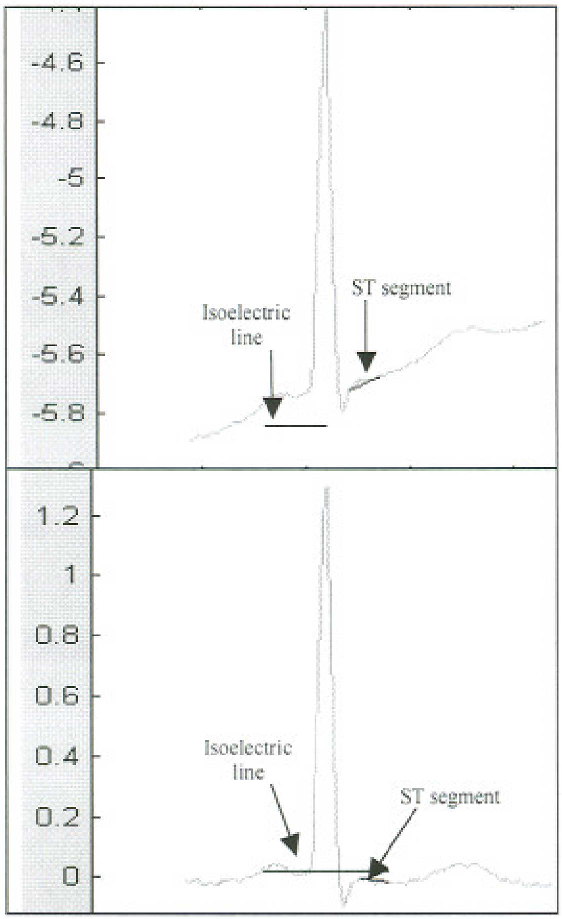


a) A/C interference (file: e0147, time: 30:42.12)





b) EMG noise (file: e0124, time: 15:54.96)



c) BW (file: e0404, time: 1:48:17.68)

Conclusions

We presented a technique for detecting the isoelectric line and the J point in cases where the ECG signal is contaminated with A/C interference, EMG noise and BW. This method can be incorporated in a real time knowledge-based diagnostic system and improve its performance even in cases with low SNR ECGs. We should mention that in highly corrupted by noise ECGs, the results were ambiguous, but in such cases even a medical expert cannot extract a safe diagnosis.

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