Steep slope method for real time QRS detection

Ivaylo I. Christov and Todor V. Stoyanov

A method for real time QRS detection by assessment of the signal steep slopes is proposed. It is based on comparison of the absolute value abs(D) of the differentiated electrocardiogram (ECG) to a varying threshold value. The method is independent of threshold and weighting constant. It is adaptive and self-synchronized to the steep slope of the QRS, regardless of the amplitude and the sampling frequency of the record. It is tested with the American Heart Association (AHA) and Massachusetts Institute of Technology Beth Israel Hospital (MIT-BIH) database. The test was performed and confirmed for more than 100 h of ECG recordings, equivalent to about 450000 heartbeats, at an assumed rate of 75 beats per minute. The method shows very satisfactory results, without the need of applying filtration of power-line interference and baseline wander. However, a fast moving average filtering is applied on the differentiated ECG for electromyogram for noise reduction.

Детекция на QRS комплекси в реално време с метод на стръмните наклони. *Предложен е метод основан на сравнение между абсолютната стойност abs(D) на диференцираната електрокардиограма (ECG) и праг с променливо ниво. Методът е адаптивен, независим от предварително фиксирани прагове и константи и се синхронизира самостоятелно към стръмността на QRS комплексите и честотата на дискретизация на ECG. Тестван е с базите записи на American Hearth Association (AHA) и Massachusetts Institute of Technology Beth Israel Hospital (MITBIH). Изследвани са повече от 100 часа ECG записи, което отговаря на около 450000 сърдечни удара при предполагаема честота от 75 удара за минута. Методът показа много добри резултати, без да има нужда от филтрация на мрежовите смущения и на дрейфа на нулевата линия. Все пак, бързо филтриране чрез пълзящо усредняване се прилага върху диференцираната ECG, за намаляване на шума от електромиографски сигнали.*

Introduction

The electrocardiogram (ECG) QRS-complex detection in real-time is widely used and implemented in all electrocardiographs and electrocardiogram monitors, where heart-rate measurement and bradycardia and tachycardia alarms are required. A real-time detection method should be simple to perform and yield a fast, practically sample-to-sample, decision result. Analysis per record epochs of several seconds could often be unacceptable.

The QRS identification should be successfully accomplished in the disturbance environment usually accompanying ECG signal acquisition – powerline interference, baseline wander, and electromyogram noise. Friesen et al. [1] compared the noise sensitivity of nine QRS detection algorithms, based on: i) amplitude and first derivative, ii) first derivative only, iii) first and second derivative and iv) digital filtering. Daskalov et al. [2] applied thesealgorithms to a database containing records with pronounced baseline drift. Unsatisfactory results were reported, probably due to the use of fixed detection thresholds, while adaptive ones could be more appropriate.

Automated ECG analysis requires wave amplitude and duration measurements. This process should begin with the identification of the QRS-complex, as the most expressed wave in the cardiac cycle. The method of Caceres [3] based on the differentiated ECG signal has been widely implemented. Daskalov and Christov [4] used the method for improvement of the resolution in measurement of electrocardiogram RR intervals by interpolation. They asserted that the measurement of RR intervals between points detected at the steepest slopes is of higher accuracy compared to points from any other part of the QRS complex. Although its good QRS detection performance, the method cannot be implemented in real time, due to the necessity of applying it on successive signal epochs.

Poli et al. [5] used generic algorithms for detection. The QRS-complex was enhanced and rectified by a polynomial filter and compared to an adaptive threshold. The method is inapplicable in real time.

The idea of adaptive threshold was also applied by Dotsinsky [6]. His algorithm is fast and simple and can be applied in real time. The complex was identified by its sharp peaks. Although the method is useful for the measurement of mean RR interval, its beat-by-beat performance is poor, due to the fact that it allows variation of the fiducial point. An example of the peak detection changes is shown in *Fig. 1*.

The diversity of algorithms for QRS detection and the continuous efforts for improvement shows that it is hardly probable to find one solution covering all possible types of waveforms [2].

Method

A steep slope method for real time QRS detection is developed. It is based on the comparison between the absolute value abs(D) of the differentiated ECG and a threshold value M (*Fig.* 2). A QRS is detected if abs(D) ≥ M. The method is independent of threshold and weighting constant. It is self-synchronized to the steep slope of the QRS regardless of the amplitude and the sampling frequency of the record.

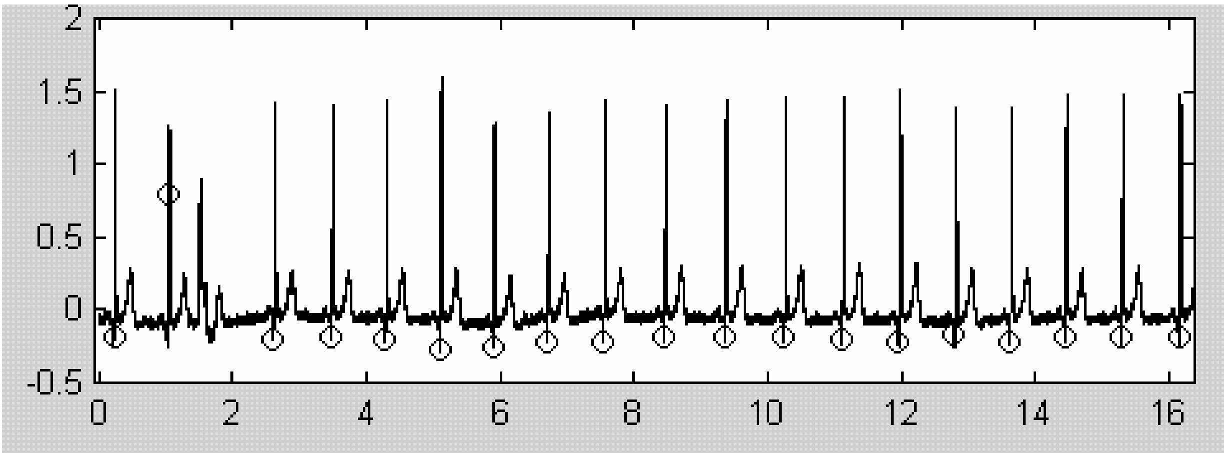

Fig. 1. Peak detection with the method of Dotsinsky [6]. Variation in the fiducial point is observed.
All QRS complexes are detected at the S peak, except the second one, detected at the R peak

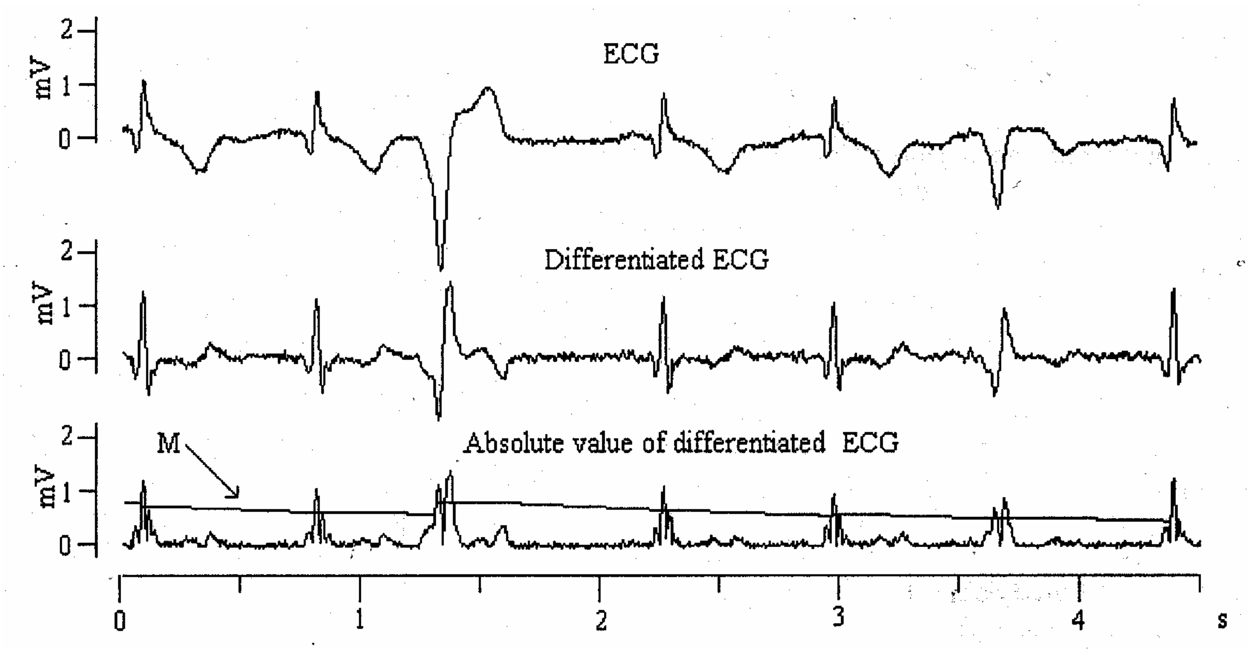

Fig. 2. ECG (first trace), differentiated ECG (second trace) and the absolute value of the differentiated ECG (third trace) compared to a varying threshold M

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If the sampling rate of the ECG signal is an integer multiple to the powerline frequency and the differentiation is performed on samples having equal interference phases, i.e. equal noise amplitudes, the differentiated ECG becomes interference-free, thus avoiding the need for pre-filtering.

The varying threshold principle is adopted from Dotsinsky [6], but the process of variation is quite different:

- initially M is equal to 0.6*abs(D) in a 3 s period (where at least 2 QRS complexes should be present);
- when abs(D)>M, a QRS is detected. The maximum of the absolute value is searched in an interval of 200 ms after the detected complex and M is updated with M=0.6*max(abs(D)). The M-value is limited not to exceed 1.5 times the value of the previous QRS (QRS_{prev}). In cases when M=0.6*max(abs(D))>1.5*QRS_{prev}, M is refreshed by M=1.5*QRS_{prev}. The reasons for this limitation are to avoid the effect of very steep slope extrasystoles or artifacts e. g. from electrode movement, which would otherwise saturate M, making the algorithm inefficient for few seconds;
- no comparison is performed 200 ms after a detected QRS;
- M is being decreased in an interval of 200 to 1200 ms following the last detection with a slow rate, reaching 0.7 of its refreshed value in 1200 ms;
- The decrease of M is stopped when it reaches 0.25 of its initial value;

Results

The QRS detection method was tested with the American Heart Association (AHA) database. We used the 30 min long, 2-channel AHA records, sampled at a rate of 250 Hz. For a power-line interference of 50 Hz, the differentiation was applied on samples 20 ms apart.

The Massachusetts Institute of Technology -Beth Israel Hospital (MIT-BIH) database (30 min, 2-channel, 360 Hz, 60 Hz power-line interference) was also used. The differentiation was applied on points of equal interference phase 16.666 ms apart

The tests were performed and confirmed for more then 100 h ECG recordings, equivalent to about 450000 heart-beats at a rate of 75 beats per minute.

The QRS detection, applied on an ECG signal with varying power-line interference amplitude is shown in *Fig. 3*.

Fig. 4 shows the detection performance on an ECG record with very strong baseline wander and electromyogram noise, the latter being most expressed between the 10^{th} and 14^{th} second.

As seen from the examples (*Fig. 3* and *Fig. 4*), the method shows very satisfactory results, without the need of applying power-line interference and baseline wander filtering.

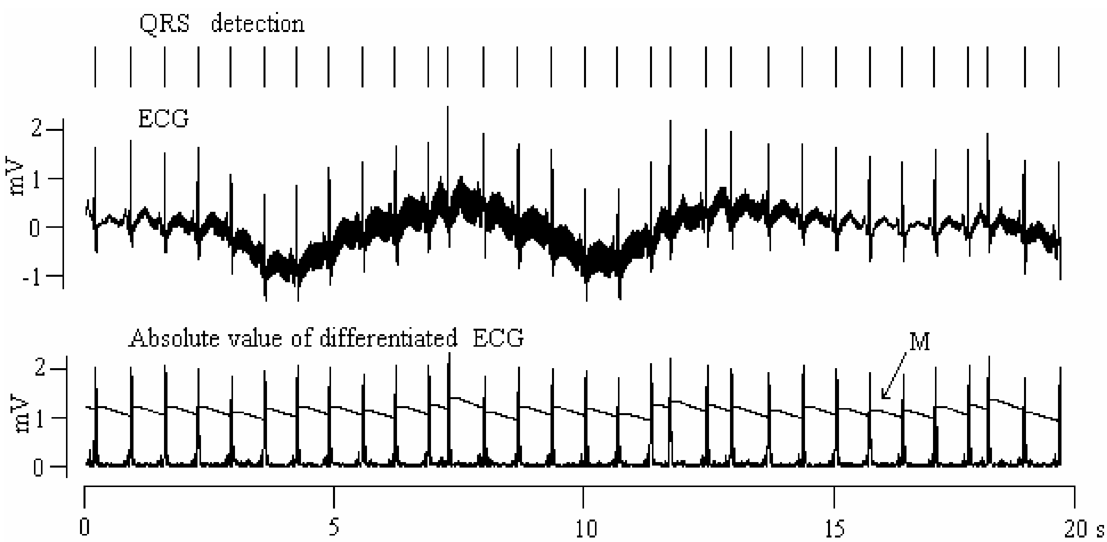

Fig. 3. QRS detection of ECG signal with varying amplitude of the power-line interference.

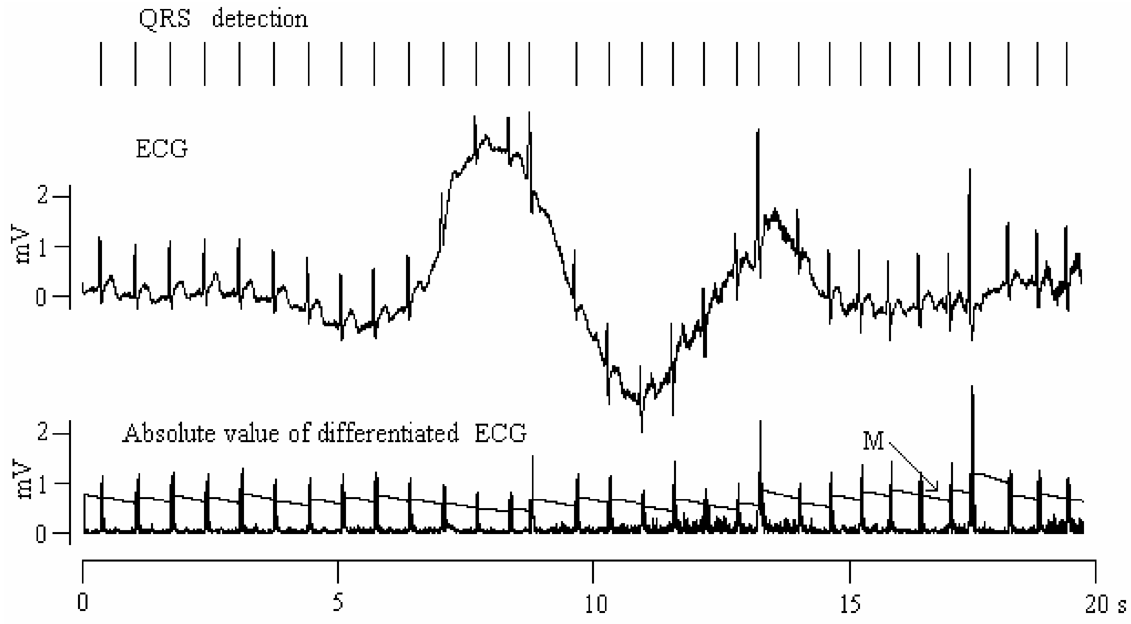

Fig. 4. QRS detection in a case of strong baseline wander

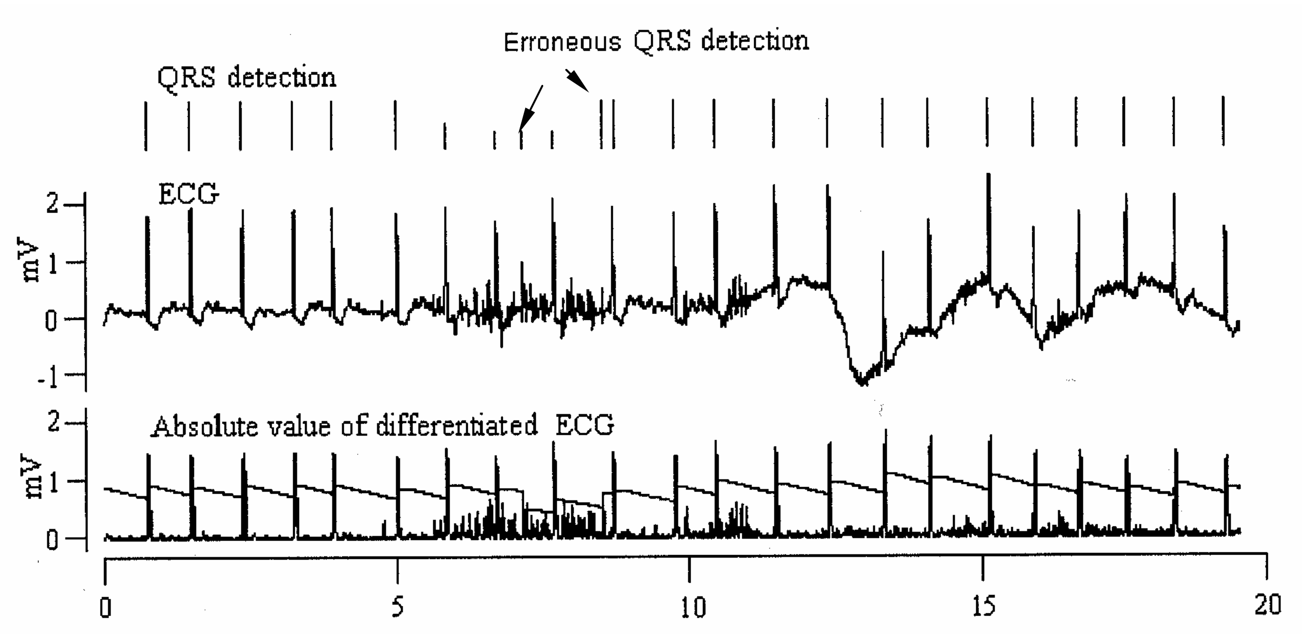

Fig. 5. QRS detection error caused by electromyogram noise.

Discussion

The absolute value of the signal derivative allows the detector fiducial point to occur at the first QRS steep slope following the isoelectric line. This fixed-point detection, irrespective of the complex polarity, facilitates further ECG morphological analyses.

The differentiation of an ECG signal typically enhances noise, but the algorithm performance is not affected.

An electromyogram noise of high amplitude may cause erroneous beat detection (*Fig. 5*). Running average filtering, often referred to as 'comb filtering', could be used on the differentiated signal. Applying it in 20 ms intervals, it is fast and readily applicable in real time.

Better results in electromyogram noise suppression can be obtained using the low-pass least squares approximation filter [7] on the differentiated signal. We recommend this filter for off-line application of the algorithm. For comparison, we present an example of QRS detection of the same noisy signal of *Fig. 5*, performed after applying the averaging filter, as shown in *Fig. 6*.

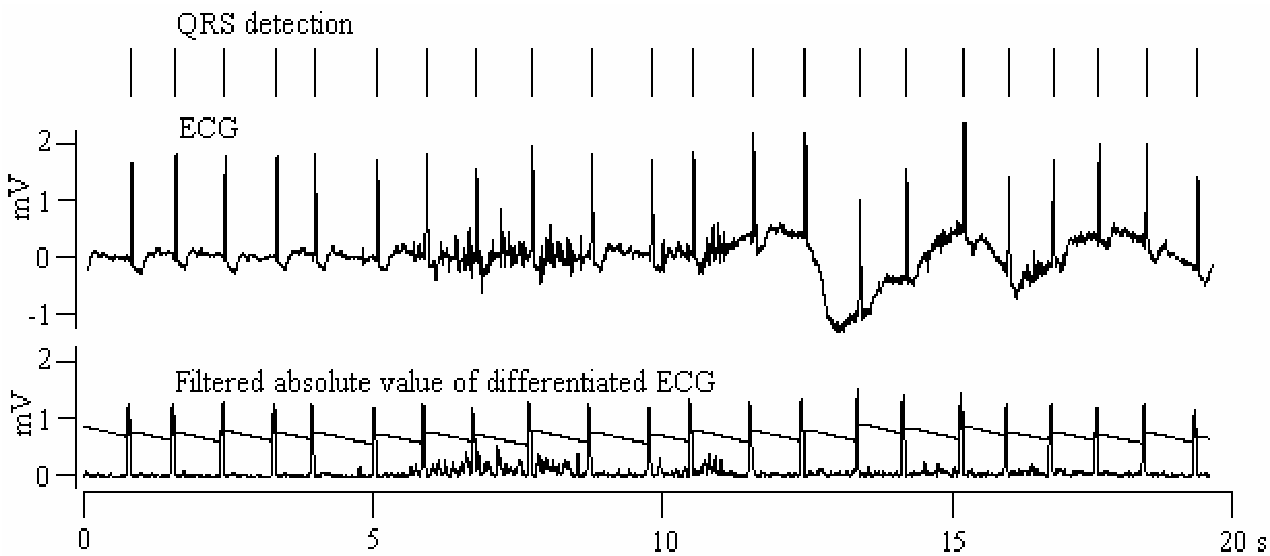

Fig. 6. QRS detection of the signal of Figure 5, after averaging filtering of the differentiated ECG.

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Assoc. Prof., Ph.D. Ivaylo I. Christov *is a present head of the Biosignal Analysis Department at the Centre of Biomedical Engineering of the Bulgarian Academy of Sciences. He graduated from the Technical University of Sofia, Faculty of Electronic Engineering, Division of Medical and Nuclear Engineering, with an MS degree in 1979. His present fields of interest include microcomputer ECG, EEG and EGG instrumentation, biosignal analysis and simulation, portable recorders, etc.*
e-mail: ivohr@bgcict.acad.bg

Res. Eng. Todor V. Stoyanov *graduated from the Technical University of Sofia, Faculty of Electronic Engineering, Division of Electronic Medical Equipment, with an MS degree in 1999. The same year he joints the Biosignal Analysis Department at the Centre of Biomedical Engineering of the Bulgarian Academy of Sciences. He is presently working on PC aided electrocardiographs.*
e-mail: dontodor@abv.bg