The new method of online extra heart beats detection based on analytical spectra mutual correlation

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Abstract
The paper is devoted to research and development of a new, based on Multiscale Correlation Analysis method of PVC (premature ventricular complexes) extra beats and SPB (supraventricular premature beats) online detection. It is shown that for ECG, where a signal has a form of repeated pulses, the instruments previously developed by the authors and called the analytical spectra technique are highly effective. The results of the PVC/SPB detection for real ECG recordings from standard MIT-BIH and SADB databases are briefly summarized in the last section and characterized in some conclusions.

Keywords
Biomedical signal processing, ECG monitoring and analysis, Heart rate variability, Premature extra beats, Computer aided diagnosis, Multiscale correlation analysis, Analytical spectra

Imprint

Introduction
Advancements in semiconductor industry substantiate a dramatic growth of the rate of innovations in a wide range of human activities from computer technology and communications to home appliances and transport. This acceleration is due mainly to delivering smaller, cheaper, more reliable solutions able to integrate critical functions such as analog circuits, and embedded microprocessors in a single device. Medical technology is a broad field where these innovations play a crucial role in sustaining health. The development of medical devices and equipment has made significant contributions to improving the health of people all around the world from “small” innovations like healthcare gadgets that help a person to monitor and manage serious health conditions such as asthma, heart problems (Fig. 1), diabetes, etc. to larger, more complex technologies like MRI machines, artificial organs, and robotic prosthetic limbs that have undoubtedly made an incredible impact on medicine.

It should be noted that the development of low-cost, low power, multi-functional medical devices, that are small and can communicate in wireless manner over short distances, like ECG monitor shown in Fig. 1, is only the visible tip of the modern medical technology iceberg. Its main core is that medical devices are getting smarter. Embedded microprocessors, SOC (System On a Chip), SBC (Single Board Computers), integral PDAs (Personal digital assistants) and advanced sensor technology are all common elements of today’s medical devices. The computing power of microprocessors and high performance of peripherals give us unlimited possibilities in modern medical devices design and development.

In this report under discussion are our experience in the development of a modern high-tech medical device, namely, cardio monitor, in part similar to the Holter monitor, but detecting heart rate failures in real time is presented with some results obtained in its implementation, including the main result: the new method of online extra beats (PVC/SPB) detection.

Method
The detection of heart extra beats in our method is based on the heart rate estimation, its sharp changes allocation and subsequent analysis of these
changes. To estimate the rate the analytical spectra (ASP) technique [1] based on the multiscale correlation analysis (MCA) [2] was used (details of implementation can be also found in [3]).

Before detecting sharp changes in rate and their subsequent analysis, quantitative estimation of rate – the dynamics of the local period of heart contractions should be performed. The implementation of this procedure in the off-line form, for ECG curves which are already registered, was discussed in detail in our previous works [1-9]. Its basic idea is as follows. For each current time moment \( t \) under analysis two adjacent time intervals of ~ 1.5 sec from left (local past) and from right (local future) of \( t \) were taken for ASP [1] calculation (using FFT – standard fast Fourier transform (FFT)). After that, the product of analytical spectra was weighed with some frequency window and then the inverse Fourier transform (iFFT) of the result was calculated. The resulting quadratic ECG representation was used to find its side maximum, whose location estimates in some manner the value of corresponding current local period. Note that by using the fast FFT / iFFT procedures the algorithm for computing the dynamics of the local period is also fast.

Implementation of the method described above for the online ECG processing is not available because the current time \( t \) for it coincides with the real time and, therefore, having the past to \( t \), we physically have not the future to it. The solution to this problem was found in the fact that the unknown complete future of the current heartbeat is in the case of the normal heart rate dynamics reproduced with a good accuracy by the future of the previous heartbeat. So, algorithmically this procedure is implemented as follows: to form an analytical spectrum of the past the fragment of ~ 1.5 sec supplemented with 1.5 sec of zeros is taken (similar as in off-line case), and for forming analytical spectrum of the future a signal interval of 1.5 sec from time \( t – 3 \) sec to time \( t – 1.5 \) sec is taken (with supplementing it by 1.5 sec of zeros). Further steps of the local period estimation are performed just as in the off-line procedure, with the only difference being that this estimate is calculated as 3 sec – \( t_{sp} \), where \( t_{sp} \) is the position of the side peak of the resulting presentation.

The above argumentation was the basis for the proposed numerical algorithm for detecting extra beats. It consists of two main steps. In the first step, the events of a sharp change in the period (with a characteristic structure of √-like complex) were detected by some form of the median filter. In the second step, each of the detected event was analyzed in detail for compliance with extra beat (PVC or SPB). This analysis consists in comparing the ECG fragment containing an event, with the preceding fragment of a normal rhythm.

Results

Records from NSRDB and SADB MIT-BIH databases [10] were used for experimental testing of the method proposed. Extra heart beats detected by our method were compared to the annotations, which accompanied all records of these databases. It permitted to evaluate the efficiency of the method and the results obtained with a well-checked data. The total of 20 hours of ECG-records were processed during the experiment.

Based on the consideration of convenience, the algorithm was tested in MATLAB software system. Such implementation of the method allows assessing any of its characteristics like efficiency and noise immunity. However, because MATLAB works in an interpretation mode, operation speed performance demonstrated by such implementation was obviously far from the limits.

The testing showed that the algorithm quite reliably detects extra
beats. From the processed 40 ventricular and 39 supraventricular, 37 and 36 were detected accordingly. Note that episodes where extra beats are arranged one after another with an interval of 1-2 sec. occur quite often in the records of SADB database. Our algorithm cannot obviously distinguish them, because it is based on the analysis of a fragment durations ~ 3 sec; so some extra beats were ignored. Practically if several extra beats were allocated in the same fragment, all of them were considered as one beat. Unfortunately, such approach does not allow counting their exact number in the record. Table 1 briefly summarizes all the results obtained and compares them with annotated objective data.

Conclusions
The testing of actual ECG by the method proposed in the report showed that it is good at determining ventricular and supraventricular beats (36 of 40 of the former and 37 of 39 of the latter were found) and demonstrates a high precision of the cardiac rhythm estimation. As for the accuracy of our method, it is better than the classical threshold methods based on the detection of R-peaks. Moreover, the most important feature of the proposed method is its reasonable demand for computing resources. For example, our method implemented in the MATLAB environment on PC with a 3 GHz CPU processes an hour ECG record only in three minutes. This opens possibilities for using the developed method in mobile and personal medical devices intended for automatic online monitoring of heart rate or extra heart beats detection. In particular, such devices could considerably simplify the Holter monitoring of patients.

<table>
<thead>
<tr>
<th>NSRDB record N</th>
<th>Events annotated</th>
<th>Results obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>16265</td>
<td>PVC1 PVC2 PVC3 PVC4</td>
<td>detected detected detected detected</td>
</tr>
<tr>
<td>16272</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>16273</td>
<td>SPB1</td>
<td>detected</td>
</tr>
<tr>
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<td>PVC1 PVC2 SPB1</td>
<td>detected detected marked</td>
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<tr>
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<td>SPB1 SPB2</td>
<td>detected detected</td>
</tr>
<tr>
<td>16539</td>
<td>SPB1 SPB2</td>
<td>marked marked</td>
</tr>
<tr>
<td>16773</td>
<td>SPB1 SPB2 SPB3</td>
<td>detected detected detected detected</td>
</tr>
<tr>
<td>16786</td>
<td>PVC1</td>
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<td>16795</td>
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<td>–</td>
</tr>
<tr>
<td>17052</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Table 1. NSRDB records processed and results obtained

Note: “detected” means that the analysis of an event confirmed that it was an extra beat; “marked” means that the event was found but not identified as PVC/SPB beat.

References
4. Antsiperov VE, Mansurov GK. Arterial blood pressure monitoring by active sensors based on heart rate estimation and pulse wave pattern prediction. Pattern Recognition and Image Analysis. 1 July 2016;26(3):533-47.