QRS Detection Optimization in Stress Test Recordings Using Evolutionary Algorithms

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Abstract

QRS detection in exercise stress test recordings remains a challenging task because they are highly non-stationary and contaminated with noise. An algorithm to find the optimal set of parameters for QRS detection in these recordings is proposed. The performance improves up to 10.46 % in noisy recordings.

Introduction

Analysis and interpretation of heart rate variability (HRV) during exercise remains today as one of the main open problems in the field of treatment of cardiovascular signals. The difficulty is mainly due to the highly non-stationary nature of the signals acquired during exercise and the very high levels of noise in this context. Detecting each beat and delineating the waves for each detected beat therefore become very complex. The main objective of this project is the development of a robust algorithm for QRS detection in noisy and nonstationary electrocardiogram (ECG) recordings, applicable to stress testing. Laboratories from Zaragoza (BSICoS) and from Rennes (LTSI) worked for several years on methods to address this problem [1, 2]. This project represents the first approach to integrate these different methods to produce a joint robust method.

Materials and methods

Databases

A training database was created using the MIT-BIH Arrhythmia Database, which contains 48 half-hour-length ECG recordings with manually-annotated QRS complexes. Each ECG recording is artificially contaminated with 3 types of real noise recordings. These recordings of noise were made using physically active volunteers and standard ECG recorders, leads, and electrodes; the electrodes were placed on the limbs in positions in which the subjects' ECGs were not visible. The three noise records were assembled from the recordings by selecting intervals that contained predominantly baseline wander, muscle artifact, and electrode motion artifact. Electrode motion artifact is generally considered the most troublesome, since it can mimic the appearance of ectopic beats and cannot be removed easily by simple filters, as can noise of other types. The signal to noise ratio during the noisy segments of these records were as low as -6 dB.

A second stress test database is used for evaluation. This database includes 54 real ECG signals, which were continuously recorded throughout baseline, exercise (ergocycle) and recovery phases. Also, the QRS complexes are manually-annotated to use as a reference.

Parameter optimization

Parameter optimization was addressed by an evolutionary algorithm. These optimization algorithms are particularly adapted to problems involving cost functions that are not differentiable and presenting multiple local minima.

An initial population was created, consisting of 100 individuals. Each individual was represented as a different set of values for the parameters which are going to be optimized. A cost function combining the detection error probability, the mean detection jitter, and its standard deviation was defined, in order to obtain a quantitative performance evaluation of the detector using the training database.

In each iteration of the algorithm, the best individuals are selected using a function based on the normalized geometric distribution. Then, a number of crossovers and mutations happen: a new individual is created using information from two parents or only one parent, respectively.

The algorithm was stopped after 15 iterations, and the optimal set of parameters is established as the individual wich present the best performance.

Evaluation

The evaluation database is used to compare the detector performance using both the default and optimal parameter values.

Results and discussion

The QRS detector with its optimized parameters showed a global improvement of 3.5% compared to its performance with the default parameters. Furthermore, the use of optimized parameters led to at least the same performance than the initial parameters for all records, and the improvement was higher (up to 10.46 %) in noisy records.

One of the most important parameter was the refractive period (*refper*), which prevents a detection within that period. In exercise stress testing, the heart rate varies from slow rate (resting phase) to fast rate (exercise phase). If the refractive period is too long, some QRS complexes will be lost, especially in the exercise phase, whereas if it is too short, the T waves could be wrongly detected as QRS complexes. This problem is more evident in exercise recordings, since the T waves morphology are more similar to QRS complexes than during resting environments. Two other parameters are included as thresholds in the detection to minimize this problem (*thres1, thres2*), and together with the refractive period, were the more sensitive parameters used in this optimization.

The evolution of these parameters is shown in Table 1 (mean ± standard deviation). It shows the default and the optimized values in iterations 1,5,10 and 15. Besides *refper, thres1* and *thres2*, *nsamp* is also shown, which represents the number of samples which are analyzed. Since the ECG signals are too long, it is divided into segments for detection, and several thresholds related to the signal to noise ratio in that interval are determined. Therefore, the length of these intervals is also introduced as an input parameter. Parameters *nsamp* and *refper* are measured in seconds.

Table 1. Evolution of the most important parameters (mean ± standard deviation)

	refper	***thres1***	***thres2***	***nsamp***
Def.	0.27	3.4949	0.5	260
It. 1	0.2457 ±0.0089	3.4780 ±0.2012	0.1201 ±0.0066	330.2 ±134.6
It. 5	0.2579 ±0.0023	3.6568 ±0.1064	0.1189 ±0.0046	327.9 ±21.1
It. 10	0.2563 ±5.8e-4	3.4947 ±0.0542	0.1241 ±9.3e-4	323.1 ±5.9
It. 15	0.2589 ±3.0e-4	3.5154 ±0.0697	0.1227 ±7.7e-4	322.2 ±1.9

Conclusion

This study uses an evolutionary algorithm to optimize the input parameters for a QRS detector in exercise stress test recordings. Problems such as the ECG morphology and the high level of noise during these tests lead to wrong annotations, which prevent a good interpretation of future heart rate variavility analysis.

After the parameter optimization, the detector performance shows a global improvement in the performance, being higher in the noisier recordings, demonstrating the advantages of the optimized parameters in noisy environments.

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