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Advances in ECG Signal Processing: Improved R-Peak Detection and Denoising Techniques for Accurate Cardiac Diagnosis

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The analysis of electrocardiograms (ECGs) is critical for diagnosing various cardiac diseases, which are the leading cause of mortality in developed countries. The significant points of the ECG, which consist of characteristic wave peaks and boundaries, contain essential information about intervals and amplitudes that are clinically relevant. It is, therefore, crucial to continuously test and improve the accuracy and robustness of techniques used for automatically delineating ECGs, particularly when analyzing extended recordings. To address this need for ongoing improvement, there are now open-source tools available, such as Neurokit [1]. These tools can help researchers and clinicians to evaluate and refine their techniques for automatically analyzing ECGs, which ultimately leads to more accurate diagnoses and better patient outcomes. Therefore, the development and utilization of such tools are crucial for advancing the field of ECG analysis and improving the diagnosis and treatment of cardiac diseases [2].

Most R-peak detectors currently available struggle with the non-stationary nature of both QRS morphology and noise. To address this challenge Rakshit et al. (2016), proposed an improved four-stage method for detecting R-peaks that uses the Shannon energy envelope [3]. In addition, during recording, the ECG signal can be distorted by various types of noise, which may result in an incorrect diagnosis. As a result, Samann et al. (2019) emphasize the importance of obtaining clear ECG signals to facilitate accurate cardiac disorder diagnosis. To this end, the researchers propose an efficient ECG denoising method that combines discrete wavelet with the Savitzky-Golay (S-G) filter [4]. It's important to note that none of them have been integrated into Neurokit,

The proposed improved algorithms are evaluated using various databases, namely the MIT-BIH Arrhythmia database, the Normal Sinus Rhythm database, the Glasgow University Database, and the Lobachevsky University Electrocardiography Database. The MIT-BIH Arrhythmia database includes 48 half-hour two-channel ECG recordings obtained from 47 subjects who were studied by the BIH Arrhythmia Laboratory between 1975 and 1979. The digitized ECG signal is sampled at a frequency of 360 samples per second per channel, with 11-bit resolution spanning a range of 10 mV.

Rakshit et al. (2016) four stages are: pre-processing, Shannon energy envelope extraction, peak estimation logic, and true R-peak detection. In the pre-processing stage, noise is suppressed and the QRS complex is enhanced by using a band-pass filter, first-order differentiation, and amplitude normalization. In the Shannon energy envelope extraction stage, a smooth Shannon energy envelope is produced by calculating the Shannon energy and using a moving average filter. In the peak estimation logic stage, pre-processing for R-peak detection is done using first-order differentiation, amplitude normalization, squaring, followed by a moving average filter for smoothing. In the true R-peak detection stage, the actual location of the R-peak is detected.

Samann et al. (2019) suggests applying three stages of filtering. The first stage involves eliminating the baseline wandering noise by fitting a low-order polynomial (with a polynomial

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order of 6, as it has been found to be more effective) to the signal and then subtracting the result from the original signal. The second stage involves using a Savitzky-Golay (S-G) filter, and the third stage uses a discrete wavelet transform (DWT) filter to reduce the effect of white Gaussian noise, which is commonly present in ECG signals due to transmission.

To assess the efficacy of the detection methods following [3], we utilized three parameters: true positive (TP), false negative (FN), and false positive (FP), all of which were obtained from the detected R-peaks. TP represents the number of accurately detected R-peaks, FN is the number of missed R-peaks, and FP is the number of noise spikes identified as R-peaks. Figure 1 also present another important evaluation metric, a preliminary benchmark of the computing time needed to apply the algorithms.

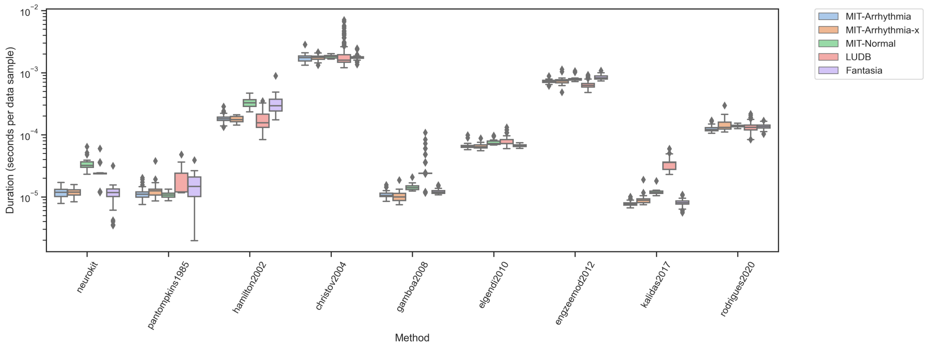

Figure 1: Benchmark of the implemented methods in Neurokit

The field of ECG signal processing is critical in improving the accuracy of cardiac disease diagnosis. To advance this field, it is crucial to benchmark new algorithms. Two valuable contributions to this field are the four-stage improved method proposed by Rakshit et. al. and Samann et al. for R-peak detection and the combined wavelet-Savitzky-Golay filter for ECG denoising. These algorithms can be easily accessible to researchers and practitioners by integrating them into open-source tools like Neurokit. Further improvements in ECG analysis and diagnosis can be facilitated by continuing to develop and test new algorithms and integrating them into existing tools for better healthcare outcomes.

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