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DETECTION OF P AND T WAVES POSITIONS IN ECG SIGNALS

Summary: Atrial and ventricular heart activity analysis requires accurate and precise detection of the positions of P wave, QRS complex and T wave. This includes positions of the start and end of each of the waves, and well as the detection of the peaks. QRS complex detection have been studied over decades and there are many developed methods, which show high detection accuracy. On the other hand, there are more problems with P and T waves detection. The article is devoted to the review of the existing methods for the detection of P and T waves positions. The authors analyze the methods especially taking into account their usage in the low computation battery-powered devices, which can be applied for a continuous heart examination. The methods are considered in terms of the robustness and handling of the noisy data.

Keywords: ECG signal, ECG normalization, segmentation, QRS complex detection, P wave detection, T wave detection

DETEKCJA POŁOŻENIA FAL TYPU P ORAZ T W SYGNAŁACH EKG

Streszczenie: Analiza aktywności serca przedsionkowej oraz komorowej wymaga odpowiedniej oraz precyzyjnej detekcji fal typu P, typu T oraz zespołu QRS. W ramach tejże analizy wyznacza się położenia początkowe oraz końcowe każdej z fal, a także wykrywa się ich piki. W pracy rozważa się także wykrywanie zespołu QRS. Ta charakterystyka była studiowana już od wielu dekad, zatem znanych jest wiele zaawansowanych metod, które cechują się wysoką dokładnością (precyzją) wyznaczania zespołu QRS. Natomiast, nadal jest więcej problemów z detekcją fal typu P oraz T. W niniejszym artykule dokonano przeglądu istniejących metod wyznaczania położeń fal typu P oraz T. Autorzy analizują poszczególne metody biorąc pod uwagę (w szczególności) ich użyteczność w przypadku użytkowania urządzeń zasilanych bateriami/akumulatorami oraz o ograniczonych możliwościach obliczeniowych. Tego typu urządzenia mogą być używane do ciągłego monitoring/badania pracy serca w każdych warunkach. Zestawione metody porównywano pod względem ich pewności oraz radzenia sobie z zaszumionymi danymi.

Słowa kluczowe: sygnał EKG (elektrokardiogram), normalizacja oraz segmentacja EKG, kompleksowa detekcja QRS, detekcja fal typu P, detekcja fal typu T

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1. Introduction

Heart diseases have long been the leading cause of death around the globe. The situation has started changing with the advances in technology and medicine. This year it was first reported that at least in higher-income countries the situation becomes better [1]. The researchers say that efforts to prevent and treat heart diseases in more prosperous countries help decrease the fatal rate. Although this progress, there is still much work to be done. A lot of heart diseases can be controlled when diagnosed on early stages. Taking into account high prices of health care and the limited medical assistance in some countries, it's important to develop diagnostics equipment one can use without going to a hospital.

One of the non-invasive diagnostics tools is electrocardiogram (ECG). During ECG procedure the changes in the electrical activation of heart are captures from different angles (leads) in time. In normal situation it should produce a recurring wave sequence of P, QRS and T waves (Fig. 1).

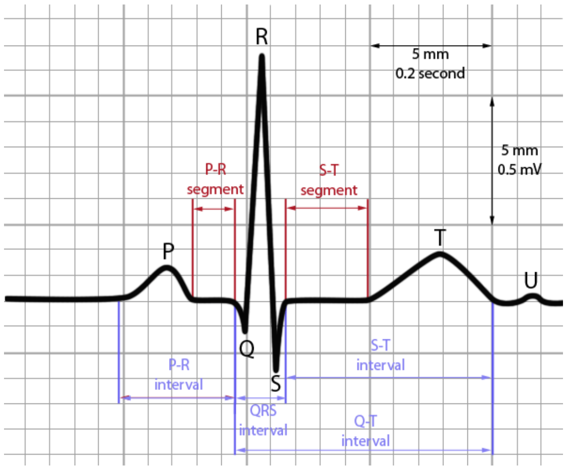

Figure 1. ECG of one cardiac cycle of normal heart with marked parameters

P-wave represents the time needed for the electrical impulse to travel through the atria from the sinus node to the ventricles. The normal PR interval is 120 to 200 ms. The Q-wave is the downward deflection and the first element of QRS complex. The normal individual will have a small Q wave in many beats, but not all. The normal duration of the QRS complex is between 80 and 100 ms. T-wave occurs after QRS complex and is asymmetric, with the second portion having a steeper decline compared to the first incline part [2].

During the ECG analysis, atrial and ventricular activities of the heart are considered. The QRS complex and the T wave represent the ventricular activity of the heart, and P wave represents the atrial activity.

A lot of heart diseases can be diagnosed by analyzing ECG including different types of arrhythmias, damages to heart muscles and problems with the blood flows, enlarged heart and more. But the analysis is very complicated and sophisticated because even professional cardiologists can make mistakes during the interpretation of the signals.

There are hand-held ECG recording devices developed, that can produce single-lead ECG recording and can be used outside the hospital. Such devices should be embedded with the accurate automatic ECG analysis algorithms, which helps in the early diagnostics of heart diseases, especially those with an episodic manner.

2. Denoising of ECG signals

The main challenge of the automatic ECG analysis is the presence of noise on the recorded ECGs. There are many sources of noise, some of the most common are:

- electrode contact noise caused by improper contact between the body and electrodes, with a frequency of about 1Hz;
- motion artifacts produced by patient's movements which affect electrode-skin impedance, resulting in, usually short-term, distortions;
- muscle contractions - noise with 10% of regular peak-to-peak ECG amplitude and frequency up to 10kHz;
- baseline wander caused by a respiratory activity and having 0-0.5Hz frequency [3].

A lot of methods for ECG signal denoising are based on digital filters [4], adaptive filters [5], wavelet transform [6], empirical mode decomposition [7], neural networks [8]. Haritha et al [9] published a survey, which covers a lot of ECG noise removal techniques.

3. QRS detection

Automatic ECG analysis usually starts with the detection of the QRS complex. Due to its high amplitude, it is the most resistant to noise. The accuracies of modern QRS complex detection algorithms are already quite high, showing over 99% sensitivity on MIT-BIH [10] arrhythmia database.

One of the most commonly used algorithms for QRS detection was proposed by Pan et al [11], and is based on the quadratic energy of the signal. Other approaches include analysis of the peaks, using Shannon energy envelope [12], wavelet transform [13] and the usage of adaptive threshold [14]. Xiang et al [15] proposed the two-level 1D convolutional neural network for QRS complex detection.

A wide review of the approaches to the QRS complex detection is given by Kohler et al [[16].

With the detected positions of R peaks, it is possible to compute the heart rate. Changes in heart rate can be used to diagnose some of the heart diseases like slow and fast rate (bradycardia and tachycardia), missing beats, ectopic beats etc. In particular, heart rate variability (HRV) [17] method is commonly used to assess the state of the cardiovascular system. It is a combination of time-domain methods, which analyze the changes in the beat-to-beat interval timing, and frequency-domain methods, which compute power spectral density over a number of frequency intervals.

4. Detection of P and T waves

Further analysis of the ventricular activity uses T wave detection. While the pick of the T wave is informative for the evaluation of the heart health, accurate identification of the start and end of the wave is more widely used. One of the approaches is the beat-to-beat analysis of the QT-interval (Fig. 1) between the onset of the Q-wave and the end of T-wave. Prolonged length of the QT-interval was reported as a predictor of sudden death in patients with myocardial infarction. High variability of the QT-interval can be used to detect ischemia [18].

The problem of T wave position estimation is more challenging than QRS detection due to lower amplitudes, variability of the amplitude and morphology and possible overlapping of the P and T waves which can be caused by changes in the heart rate, presence of the heart diseases, noise and interferences.

One of the classic and widely adopted methods for the end of T wave estimation is based on a threshold on the first derivative [19]. T-wave end is defined as a point where the derivative crosses a certain threshold, proportional to the maximum absolute value of the derivative. The benefit of this method is that it is rate-independent and works well even during a high heart rate. However, the selection of the threshold is problematic, because it has to be adapted to the level of noise.

Boix et al [20] proposed a method of measuring T-wave alternants as the difference between amplitudes of the augmented T-waves and the normal ones by applying the wavelet transform to electrocardiographic synthetic signals.

Shang et al [21] published a method for T wave detection based on sliding window area with adaptive parameters, which can be used on devices with limited computational power.

The performance of the T-wave detection models on noisy ECG recordings was the topic of [18]. The authors proposed the T-wave location detection algorithm based on the computation of Trapezium's area.

P-wave is the wave with the lowest amplitude (U-wave practically always ignored from the analysis), but it is critical for the analysis of the atrial activity of the heart and diagnostics of supraventricular tachycardia, atrial fibrillation as well as confirmation of ventricular arrhythmias.

Detection of the P waves is difficult particularly because:

- they have a low signal-to-noise ratio (SNR);
- their waveform shows high inter-patient variability;
- they have no exclusive time and frequency characteristics;
- they might be invisible on the ECG signal.

The absence of P wave may signify sinoatrial block. And the presence of two or more smaller waves suggests problems with the atrial electrical pathways, which is a sign of atrial flutter.

P wave detection methods can be grouped into:

- the methods, which search locally in the area outside QT-interval (or in the area before QRS complex)
- ventricular and atrial source separation methods, which use QRS-T cancellation (usually by subtracting QRS-T template, adopted to the heart rate of the signal)

A significant number of papers suggest P wave detection based on wavelet transform [22][23]. It provides information about the mathematical morphology of the wave, but as the amplitude of the wave is small, the accuracy of such models is usually low.

Rekik et al [24] combined the wavelet transform with the entropic criterion (EC) to improve the accuracy of the model. The method uses Pan-Tompkins algorithm [11] for QRS detection and the custom logic for the best P-wave analysis window position and width selection.

Chatterjee et al [25] proposed a robust method for real time P and T wave detection using field programmable gate array (FPGA) based system. The algorithm is based on slope detection of T and P wave in the TP interval, which is estimated on consecutive R peak detection.

Percentile based and graphical based automatic P and T wave detection methods were proposed in [26]. The first method uses percentile as an adaptive threshold to define the locations of the waves. And the second one uses “feature wave-bank” to train a graphical probabilistic Hidden Conditional Random Field (HCRF) model.

5. Conclusions

In this paper, the review of methods for automatic P and T waves positions detection was done. Many T-wave position detection algorithms are used for ventricular activity analysis. These methods show good performance even in environments with limited computational resources. However, the detection of T-wave in the signals with noise is still problematic.

The problem of developing a reliable and powerful method for automatic detection of P-wave is still far from being solved. The performance of the currently available methods is significantly worse to the methods of T-wave analysis, especially those which can run under low computational constraints. Therefore, further research remains a topic of interest.

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