

Effect of averaging of high-resolution cardiac signals in medical diagnostics using Simson's method

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Abstract. Simson's method employed in cardiological diagnostics detects the presence or absence of late ventricular potentials to indicate cardiac pathologies. It has been a long time since the development of Simson's method, but it is still used in clinics and is often mentioned in studies related to high-resolution ECGs and averaging of ECG signals. An optimal algorithm of high-resolution ECG averaging was chosen and implemented in this study. Efficiency of Simson's method was assessed on the cardiac signal recorded using a modern hardware and software complex. The result of the study showed no relationship between late ventricular potentials and localized micropotentials on the ST interval in individual cardiac pulses.

1. Introduction

High quality of medical diagnostics is due to the development of technologies for monitoring the physiological state of a person. Data analysis methods are being developed and improved, and new medical hardware and software complexes are being created to increase the accuracy of examination of an object or process. Advanced hardware and software complexes increase the amount of data and expand knowledge about the object. To assess the data obtained, new techniques should be compared with known methods used in medicine [1].

A well-known Simson's method [2] employed in cardiological diagnostics aims to identify late ventricular potentials (LVPs) of the heart. LVPs are referred to low-amplitude (about 5–20 μV) high-frequency (over 20–50 Hz) ECG components that appear at the end of the QRS complex and at the beginning of the ST segment.

In this study, Simson's method was chosen because it employs different signal processing techniques: averaging, filtering and summation of three orthogonal leads. The method also describes in detail the algorithm for determining Simson's curve, which is used to set the patient's diagnosis. Particular attention is paid to averaging, which Simson used to reduce the noise component in the signal in order to analyze low-level potentials of the heart, which are invisible against the background of the signal noise.

2. Hardware and software complex

A nanosensor-based hardware and software complex with a sampling frequency of 32 kHz has been developed at National Research Tomsk Polytechnic University, Laboratory for Medical Engineering. The complex is capable of detecting 1 μV micropotentials [3]. Technical parameters are presented in Table 1.



Table 1. Technical parameters of the apparatus developed.

Parameter	Value
The current consumed by the HSC during ECG recording	no more than 300 mA
Input voltage range for ECG recording	from $\pm 0.3\mu\text{V}$ to $\pm 10\text{ mV}$
Frequency range	from 0 to 10000 Hz
Sampling frequency	32,000 Hz
Input impedance	no less than 10 M Ω
Frequency response unevenness in the range from 0 to 10,000 Hz	from $\pm 20\%$ to $\pm 10\%$
DC in the volunteer's circuit	no more than 0.1 μA
Range of the measured durations of micropotentials	from 0.3 ms to 100 ms

Signal averaging is a common approach to the study of a signal with intervals similar in shape. ECG is referred to this type of signal, which consists of sequentially recorded cardiac cycles of the patient. The cardiac cycle includes waves showing the dynamics in the state of the human heart. To perform correct averaging, it is necessary to establish the time synchronism of the segments with extremely precise coincidence of waveforms when superimposed. Otherwise, the effect of signal spreading will appear (decreased amplitude and increased segment duration). For example, averaging can be followed by the increased duration of waves in the cardiac cycle, which will affect the results of the study.

Simson's method employs averaging to reduce the noise level relative to the useful signal. Simson averaged about 400 cardiac cycles to obtain an acceptable value of this indicator for calculating the resulting curve in order to set a diagnosis. However, the number of cardiac pulses can be reduced using new approaches [4] or synthesis of averaging and filtering [5] to reduce noise.

An important step in averaging is the choice of reference points to sum up other samples in the cardiac cycles. In most cases, the QRS complex is used as it is easier to detect its location in the ECG. There are also studies [6] where other intervals in the cardiac cycles are used for these purposes. This depends on the task posed, and if you want to investigate a specific area, it is better to use reference points that are closer to this area to reduce the blurring effect.

In our study, the QRS complex was chosen as reference points for several reasons: it is simpler to detect compared to other waves, the area close to the QRS complex should be investigated, and the QRS center is used in Simson's method for filtering. As noted by the authors [7], detection of the QRS complex has been used for a long time in ECG diagnostics. Since we analyzed a high-resolution ECG signal, the trapezoidal method that employs rising and decreasing R-wave fronts was chosen for the study.

Unlike signals used in [8], we used signals that more accurately describe inclinations of the R wave due to technical characteristics of the apparatus. To sum up cardiac cycles, a single reference point is sufficient, for example, the R wave peak, but Figure 1 shows that the peak M is not fixed in time relative to the R wave fronts. This reference point can distort the results of averaging. To adjust the position of this point, a low-pass filter can be used, but this will affect the algorithm efficiency [8]. Since the sampling frequency of the analyzed signal is 32 kHz, the total number of signal samples processed during 30 seconds with 3 channels will be about 3 million points. Due to this, we chose an algorithm with a smaller number of calculations and a large number of signal samples.

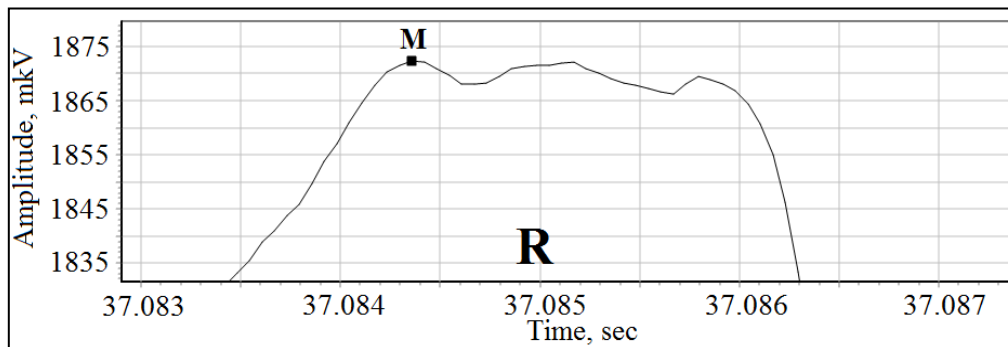


Figure 1. R wave peak detection.

The R wave peak and the iseline level were used to detect four points of the trapezoid ABCD (Figure 2). After calculating the R wave amplitude, the position of vertices of the trapezoid ABCD was detected according to the principle: let the distance from the iseline to the peak be H , then points A and D are at the level of $0.2 \times H$, and B and C are at the level of $0.8 \times H$. Knowing the time values of the points, we detect the O, the R wave center:

$$O = \frac{1}{2} * \left(\frac{(B+C)}{2} + \frac{A+D}{2} \right)$$

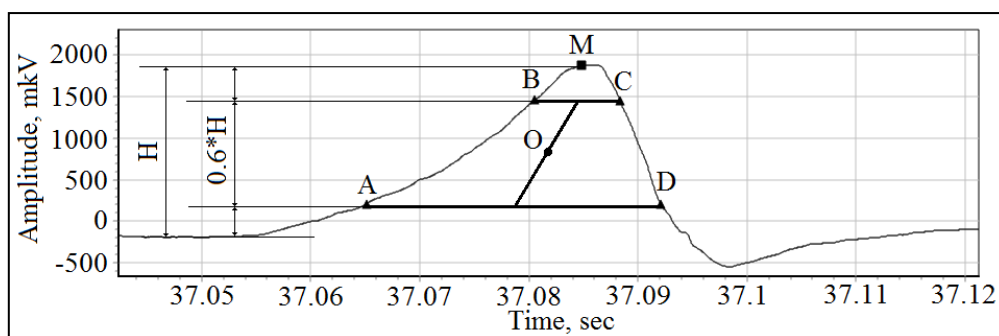


Figure 2. Detection of the R wave center using trapezoidal method

3. Results of the preliminary studies

The apparatus described allowed us to study the correlation dependence of micropotentials on individual cardiac cycles and micropotentials described in Simson's method. In the study of high-resolution cardiac signals, 37 cardiac cycles were averaged (Figure 3, line 2).

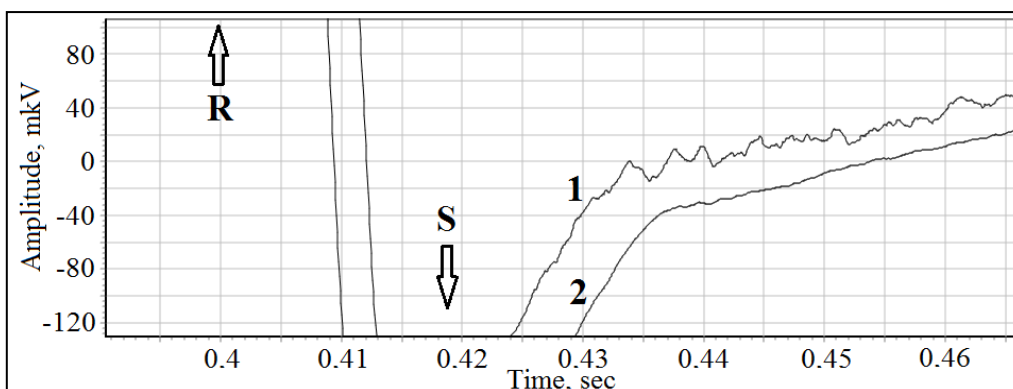


Figure 3. Individual (1) and averaged (2) ECG signal.

Figure 3 shows that after the signal averaging, micropotentials at the beginning of the ST segment almost disappear. Therefore, when analyzing the resulting curve, Simson's method is used to investigate fluctuations unrelated to micropotentials localized on the individual cardiac cycle 1. The Figure illustrates a significant decrease in the amplitude of micropotentials when averaging 37 cardiac cycles given that the correlation coefficient of these cardiac cycles is not less than 0.95. When averaging 400 cardiac cycles used in Simson's method, the amplitudes of micropotentials will be even smaller. Thus, LVPs recorded using Simson's method are not correlated to real micropotentials recorded using high-resolution HSC.

4. Conclusion

Simson's method is based on statistical data that show the relationship between LVPs and cardiac pathology. Therefore, a more thorough analysis of this method should be performed without averaging to identify causal relationship between the ECG signal analyzed and cardiac pathologies in order to improve the accuracy and reliability of diagnosis based on the study of real-time micropotentials.

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