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Development of Novel Methods for Noise Cancellation in ECS

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Abstract

A review and analysis of methods in the field of noise cancellation in electrocardiosignals (ECS) for increasing diagnostic effectiveness of a human health state is conducted. New approaches to high-frequency (HF) and low-frequency (LF) noise analysis in the ECS are proposed and substantiated. An improved method for ECS processing using empirical mode decomposition and Hilbert-Huang transform is applied.

Keywords: Noise, electrocardiosignal, empirical mode decomposition, Hilbert-Huang transform.

INTRODUCTION

A large number of works are devoted to various changes in human electrocardiosignals (ECS) in conditions of free motor activity [1-7].

It is impossible to guarantee carrying out an optimal removal of various noise types without receiving measurement information on noise recorded in the ECS, or based only on the user's knowledge and experience. In ideal conditions, if there is no noise in the ECS, and if any filter is applied in the automation conditions, such a signal will be distorted. This also implies the need for the signal and recorded noise to be analyzed at the pre-processing stage (figure 1).

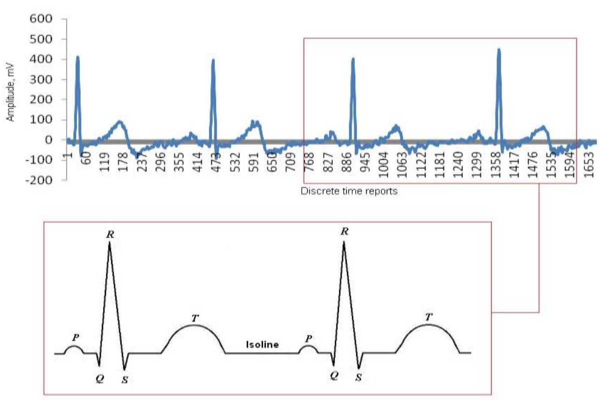

Figure 1: Electrocardiosignal

REVIEW AND DEVELOPMENT OF A NEW APPROACH TO NOISE ANALYSIS IN THE ECS

The most characteristic noise types in the ECS are isoline drift and movement artifact (low-frequency (LF) noise), network and muscle noise (high-frequency (HF) noise).

There is a well-known method for HF noise analysis in the ECS [8], based on the allocation and decomposition of the cardiac cycle (CC) into intrinsic mode functions (IMF), the addition of individual IMF, the Hilbert spectrum construction, and the transformation of the resulting image into a binary code followed by the calculation of its fractal dimension (FD).

The disadvantage of the known approach is the noise analysis of the only CC, which can affect the errors in the correct determination of various noise types with different intensity and duration (in conditions of free motor activity of the patient).

A modified method to overcome shortcomings of the known approach of the noise analysis in ECS is proposed (figure 2).

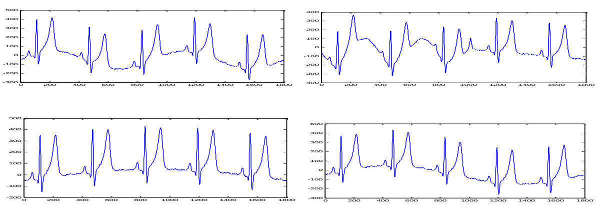

Figure 2: The types of LF noise in ECS

An operation of the proposed approach to the noise analysis in the ECS using empirical mode decomposition (EMD) begins with the ECS recording. Due to the registration of different ECS duration (under different conditions), it is proposed to normalize the recorded signal in time (1:30 seconds) when processing. This condition will allow limiting the probability of new IMF appearance in decomposition, since the peculiarity of the applied EMD method is its high sensitivity to the number of reports in the signal.

According to the review of literature sources [9-11], the authors have come to the conclusion that the movement noise and the bias of the electrodes are recorded on the last three IMF (when analyzing from one to five CC).

The main stage of the developed approach for the LF noise analysis in the ECS, as well as in the case of the known solutions, is the usage of EMD. It should be noted that the application of a classical EMD is characteristic for the LF noise analysis in the ECS, since other modifications of this method are characterized by the addition of a noise HF component that can introduce corresponding distortions into the processing results, and increase the number of IMF obtained as a decomposition result [12].

For the automation of the processing process and the speed increasing, the next stage of the developed approach to the noise analysis in the ECS is a complete removal of individual IMF formed as a result of decomposition, which value frequency exceeds the threshold value. The authors' preliminary studies of the IMF analysis of the ECS are given in [13, 14], which have shown that when the LF noise occurs in the ECS with the subsequent decomposition of the signal into IMF, new modes not characteristic for an ideal ECS are formed.

In the article a novel adaptive, automated and fast method for the LF noise analysis in the ECS is proposed, the research of which will be carried out in subsequent works.

REVIEW AND DEVELOPMENT OF A NEW APPROACH TO NOISE CANCELLATION IN THE ECS.

Various methods for noise cancellation in the ECS have been developed [9-11, 15-18].

There is a method for LF noise cancellation [10], carrying out the decomposition of the ECS into IMF, the complete removal of the IMF corresponding to the LF noise, and the reverse recovery of the ECS. The disadvantage of this approach is the possible removal of the useful component of the ECS with the complete removal of some IMF. Thus, the conducted studies of the author's dissertation [13] have shown that when removing the last three IMF, the cancellation of the LF noise components occurs, but the useful component of the signal is distorted at the same time.

Another method of the LF noise cancellation in the ECS is the approach given in [15], according to which the ECS is decomposed into IMF, with complete removal of some IMF and processing of the other ones, with the subsequent restoration of the signal. Threshold processing in the known method [15] is carried out by soft tresholding. According to the information presented in the known method, IMF are subjected to removal, the sampling frequency of which does not exceed 2 Hz, and the threshold processing does not exceed 30 Hz. However, the author of the paper has proved [19] that from three to five IMF of the ECS fall into the threshold frequency range from 2 to 30 Hz, this leads to choice difficulties in the removal or threshold processing of individual IMF falling within the specified frequency range.

Another method for noise cancellation in the ECS is presented in [12]. However, the main disadvantage of this approach is the impossibility of simultaneous processing of the signal for solving the problems of noise-robust processing in the presence of HF and LF interference. Another drawback of the known approach is the limitations on the duration of the processed signal, from one to five CC, which is unacceptable for the long-term monitoring purpose of the health status and effective evaluation of a human mental health.

Thus, the disadvantages of the known methods are the absence of a reasonable choice of IMF subjected to processing, the presence of a high level of residual noise, as well as a high probability of distortion of the signal useful component.

In this article, an improved method for noise cancellation in the ECS is proposed. The essence of the proposed approach is the performing of the following steps (figure 3).

The operation of the proposed approach begins with the ECS input limited in duration (as in the case of the noise analysis method), and the confirming results of the noise presence in the investigated signal.

According to the proposed method, for the HF noise cancellation, the operation is reduced to performing the intermediate stage, i.e. an extraction of a TP segment.

The TP segment extraction in the ECS is carried out using a well-known approach presented in [20].

At the next stage of the proposed approach, the decomposition of the recorded ECS and a separate TP segment for the LF noise processing is performed, as well as the construction of energy density surfaces (EDS) for the HF noise processing.

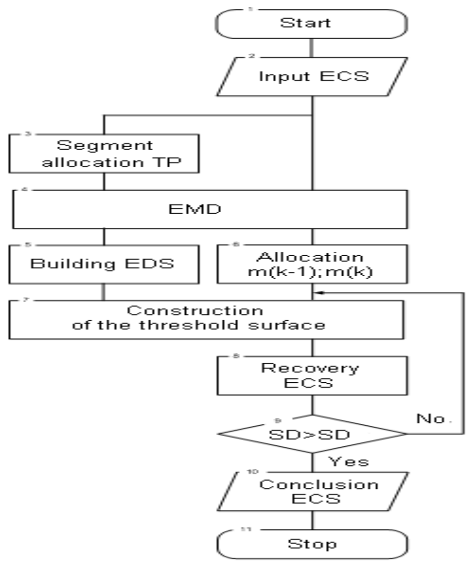

Figure 3: Method for noise cancellation in the ECS

When constructing signal EDS and TP, a threshold surface is formed. At this stage, the calculation of mean energy value $\overline{E}'_{f_j}(t_i)$ of the TP surface for each frequency value fj during a certain time interval [1, tk] is performed:

$$\overline{E}'_{f_j}(t) = \frac{1}{k}\sum_{i=1}^{k} E'_{f_j}(t_i) \quad (1)$$

where t is a discrete sampling of the ECS; j is a number of samples for each i-th IMF, j = 1 ... k; t1 is a sample taken for the middle of the TP segment; k is the total amount of the ECS samples.

The average values of $\overline{E}'_{f_j}(t_i)$ energy of the threshold surface of the TP segment, calculated from (1), make it possible to obtain $\overline{E}'(f_j)$ frequency distribution function of the mean energy value:

$$\overline{E}'(f_j) = \psi(\overline{E}'_{f_j}(t)) \quad (2)$$

where t = const.

The result of (2) is $\overline{E}'(f_j)$ distribution function describing the average TP segment surface slice.

After calculating the distribution function of the mean energy value in $\overline{E}'(f_j)$ frequency, the formation of the threshold surface as sums of the mean energy values occurs:

$$V_{f_j}(t_i) = \overline{E}'(f_j) \cdot \Delta t \quad (3)$$

where Δt is the duration of the registered ECS [t1, tk].

The result of (3) calculation is $V_{f_j}(t_i)$ threshold surface of the selected TP segment of the ECS in the energy-frequency-time coordinate system.

For cancellation of the LF noise in the ECS, the global trend (residual) s(j) is removed from the ECS, and the signal IMF is subjected to further processing, with frequencies lower than 30 Hz. There are two m(k-1), m(k) IMF of the ECS within this frequency range.

The isolated m(k-1), m(k) IMF are filtered using adaptive threshold processing presented in [13].

The calculation of the noise level and verification of its compliance with the acceptable level is carried out by calculating the statistical deviation criteria values. In case of unsatisfactory recovery, the cutoff frequency of the filter is carried out.

CONCLUSION

In the article, the methods for noise analyzing and the ECS processing in the conditions of a human free motor activity and the presence of various noise types are developed. The next stage of the authors' work will be the research of the developed algorithms and their introduction into clinical practice.

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