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DETECTION OF BIOMEDICAL SIGNALS DISRUPTION USING A SLIDING WINDOW

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Summary. *The article proposes the method of setting the time moments of biomedical signal disruption, in particular, the electroencephalographic (for establishing the time moments of the appearance of the processes of the speech process) and the electrical probe signals (for setting the time moments of the beginning and the end of the polymerization process) based on the application of the sliding window. The parameters of the window (its width and the value of the shift step) are substantiated. The results of elaboration of EEG signals within the sliding window are analyzed and it is established that the maximum accuracy of setting the time moments of the appearance of the disorder will be achieved in the case of the maximum overlapping of the previous and next windows, that is, with a minimum displacement value (in the case of discrete sequences, the minimum displacement value will be equal to the sampling period).*

Keywords: *biomedical signal, electric probe signal, rolling window, polymerization, electroencephalographic signal.*

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The statement of the problem. Detection of changes in the properties of biomedical signals, that according to the system-signal concept are the means for transferring of information about the relative parts or systems operation [1], is one of the common problems of biomedical information analysis and processing. A lot of applied data processing problems obtained by the biomedical information collection systems, such as the Golter's monitoring systems, electroencephalographic complexes, systems of polyanalysis, biometric systems, etc., are reduced to it. Making comparison with radio engineering, the abrupt changes in the properties of biomedical signals that occur at unknown moments of time, can be expressed by the term "disruption" [2, 3]. Data about the probability distributions of values of the analyzed process before and after possible disruption are input data for the solution of the problem. Herewith, classical methods for the disruption detection are based on the appliance of algorithms for calculation of cumulative sums [2,3] what allows to detect single disruption of a random process and to obtain the assessment of the maximum credibility of coordinates abruptness. However, it is necessary to identify the sequence of the analyzed function abruptness in most applied problems of biomedical data processing [3]. Hence, the problem of developing the method for determination of such sequences in the structure of biomedical signals is important.

The survey of available investigations. The processing of biosignals in medicine assumes the description of the biosignal on the base of certain mathematical model with following transformation of obtained representation into the required form. The final step in the processing is distinction and usage of informative content of the signal. There are two widespread approaches to mathematical modelling of biosignals, particularly deterministic and stochastic. According to [1,4] a biosignal cannot be treated as deterministic process because it does not contain any diagnostic information for such case. The stationary model is known for stochastic approach [1, 4]. The popularity of its application is explained by

availability of developed methods and procedures of correlation-spectral analysis, simulation and imitation. Such model describes only the spectral distribution of oscillations' power [1], but does not contain any means for the assessment of phase-time structure of the signal. For biosignals the changes of phase-time structure often reflect moments of occurrence of early changes in the performance of organs or systems, namely time moments of disruption appearance.

The analysis of biosignals of different types, namely that are described in [6 – 9], has shown that the adequate representation for diagnosis (state recognition) problem is their stochastic nonstationary process. It is found that disfunctions caused by pathology states lead to appearance of nonstationarity in biosignals with their preserving as piecewise or local stationary processes, or to the change of nonstationarity type. Therefore the representation of biosignals as stochastic nonstationary process is adequate to the problem of medical diagnostics. The mathematical apparatus of energy theory for stochastic signals was applied for modelling of some types of biosignals in [6 – 9], herewith biosignals were represented as periodically correlated random process.

The reasoning of the method for electrical cardio signal (ECS) processing in the problem of detection of the appearance of coronary heart disease (CHD), particularly the time moments of appearance of CHD, is done in [10]. The method of assessment of structure change of ECS as human organism respond on dosed physical loads is described in [11]. The method of voice signals processing for the problem of detection of voice apparatus organs diseases and the technic for determination of time moments of some diseases appearance are reasoned in the paper [12]. The way how to recover the communicative function of human language by means of time moments detection of speech process' features appearance in the structure of electrical-myograph and electrical encephalograph (EEG) signals is described in the article [13]. The technic of assessment of polymerization process for stomatological matter by means of receiving and processing of electrical probe signals and time moments detection of polymerization process termination are described in the paper [14]. All mentioned above methods contain the separate problem of time moments detection of biosignals structure changes – in other words the disruption appearance. The assessment of availability of abrupt changes in probability characteristics of these signals' samples on a given translated in time interval (sliding window) was carried out in that papers.

The objective of the paper. Method of biosignal disruption determination, particularly: electroencephalographic (for the time moments detection of the detection of speech process' features) for the problem of recover the communicative function of the speech and electrical probe signals (for time moments detection of polymerization process termination) for the problems of assessment the state of the dental material, which are based on the sliding window application is, is substantiated in this paper.

The problem statement. As it mentioned above biosignals can be treated as piecewise stationary random process. The model of piecewise stationary random process is given in the paper [17]. If to expand this model on the class of biomedical signals with taking into account the problem of disruption detection, then the biosignal can be interpreted as random vector-process $\Xi_n(t) = (\xi_1(t), \xi_2(t), \dots, \xi_n(t))$ with stochastically independent stationary components. Let [17] such process is given on the interval $t \in [a, b]$ and let the sequence of sets $B_k, k = \overline{1, n}$ is the partitioning of the interval $[a, b]$ by points $t_1, t_2, \dots, t_k,$

and $I_{B_k}(t)$ is an indicator function of the set B_k , it is such that $I_{B_k}(t) = \begin{cases} 0, & t \notin B_k; \\ 1, & t \in B_k, \end{cases}$ then the following random process

$$\xi_{\Sigma}(t) = \sum_{k=1}^n \xi_k(t) I_{B_k}(t) \quad (1)$$

is the process of disruption, and the moments t_1, t_2, \dots, t_k are moments of disruption [17].

The problem of disruption detection is reduced to the determination of time moments of appearance of stationarity type change, and correspondently to the (1) with time moments t_1, t_2, \dots, t_n of disruption appearance in the structure of such signals.

It is offered the method for determining of time moments of disruption appearance that is based on the biosignals processing within the translated in time window (sliding window). It is necessary for this to estimate probability characteristics within the window in the rest time (without abruption) and when abruption is available. On the base of comparison of probability characteristics of signal samples for these two states it is necessary to substantiate the criterion for distinguishing of these two signals.

Let discuss two problems. The first one is the problem of disruption detection of EEG signal that indicates the start of speech process. And the second problem is disruption detection of electrical probe signal that characterizes the dynamics of polymerization process of dental matter.

The results of the investigation. *Detection of the EEG disruption.* It is necessary to determine the time moments of start and terminating of speech process on the base of results of EEG-signals processing according to the offered in [13] technique of recovering of human communicative function. The EEG-signal trace is used for the processing. This trace contains the signs of brain activity increasing after 12th second of recording (Fig. 1).

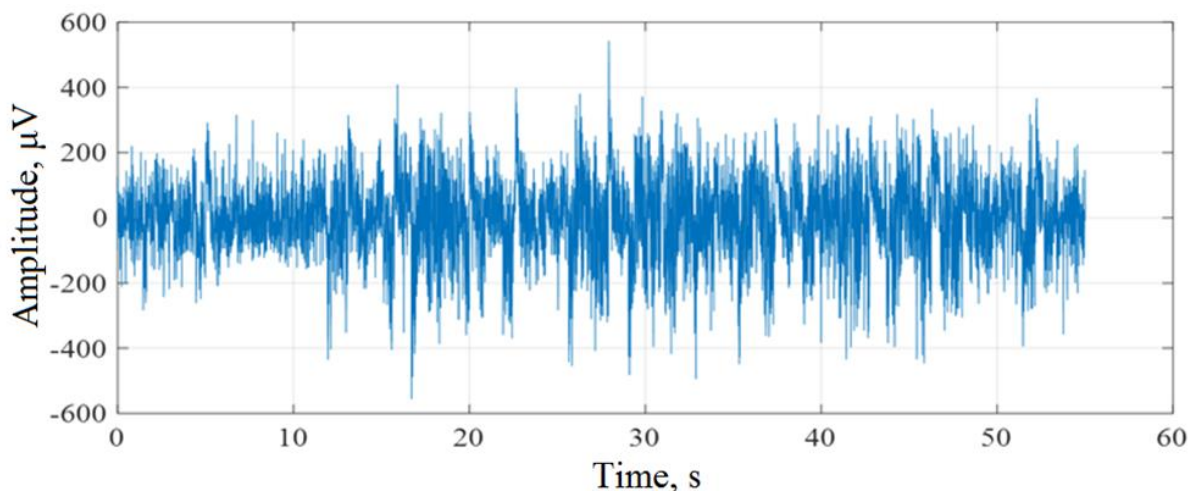


Figure 1. Registered EEG signal. Signs of brain activity increasing

The signal processing is gone within the window (shown as rectangular) that is moved in time according to the offered method of disruption detection (the occurrence of signs of brain activity increasing during the speech process) with application of sliding window (Fig. 2).

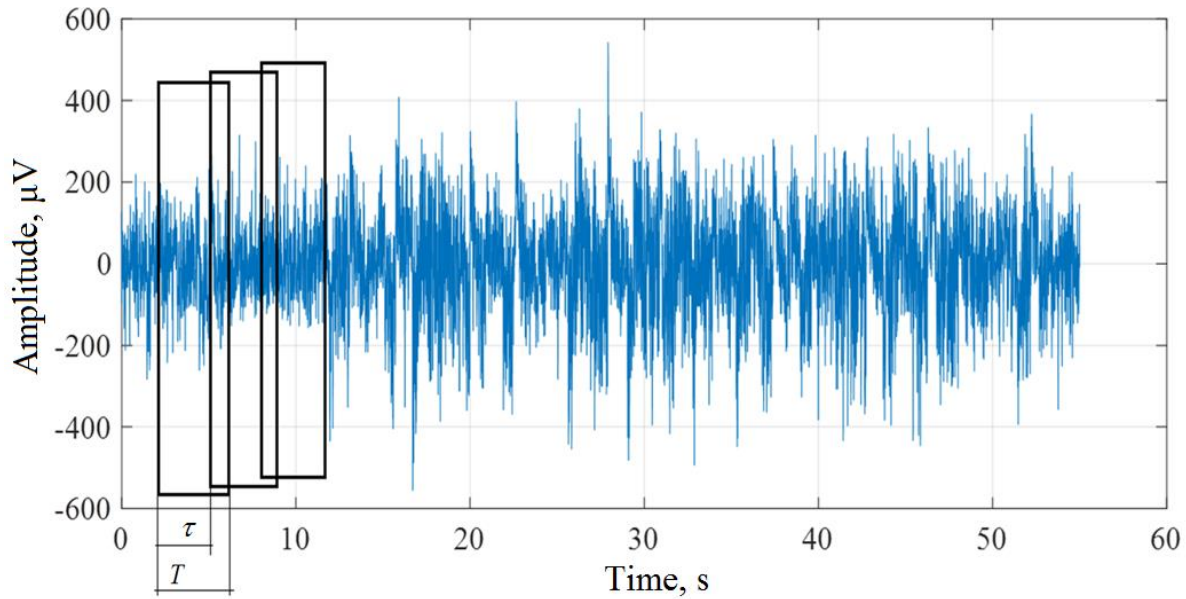


Figure 2. Motion of the sliding window along the EEG signal trace

Herewith the set of window parameters is important because their values influence on the accuracy of time moments determination of start and stop of speech process. It is enough to process the EEG signal within the window with width equal to 50 periods of main tone for determining of start and stop of this process according to the fact of existing of vocal cords oscillations before and after speech process (about 50 oscillation) [18]. The following expression is used for calculation of the window width:

$$T_{\text{window}} = \frac{N}{f}$$

where T_{window} is a width of a window; $f_{\text{basis of the tone}}$ is the frequency of main tone; N is a coefficient with value reasoned by the results of investigations in the paper [16] (N is equal about 50). For $f_{\text{basis of the tone}} = 189 \text{ Hz}$ $T_{\text{window}} = 0,26 \text{ s}$.

The calculation of estimations of spectral power density distribution with their following averaging was carried out within the sliding window for the detecting of the fact of disruption availability in the structure of the EEG signal on the given time interval (that is determined by the width and ordinal number of sliding window). The values of such averaged estimates were put one-by-one in time according to the ordinal number of a sliding window. The Fig. 3 represents the trace of EEG with signs of increased brain activity after 12th second (the availability of disruption) and the graph of change of averaged estimations assessments for spectral power density distribution calculated within each sliding window that are put sequentially in time. Graphs show that offered averaged assessments are sensitive to appearance of brain activity changes in the structure of EEG signals (their disruption).

The accuracy of disruption detection will increase if the previous and next window will overlap on some certain value τ . The form of the change in the averaged assessed values of the spectral power density in case when the previous and next the windows do not overlap ($\tau = T_{\text{window}}$), and in case when the windows are half-overlapped ($\tau = 0,5T_{\text{window}}$) is shown in the Fig. 4.

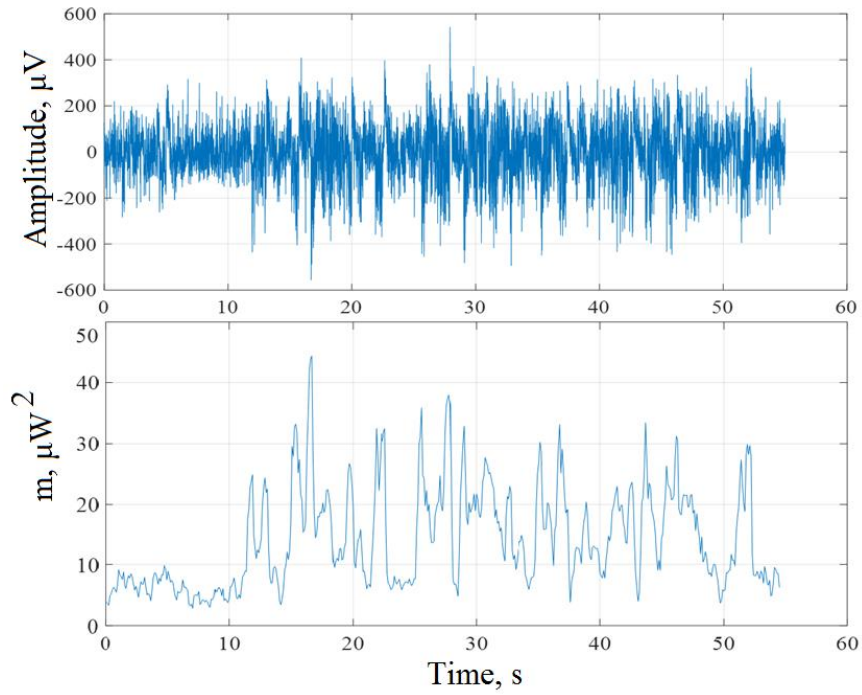
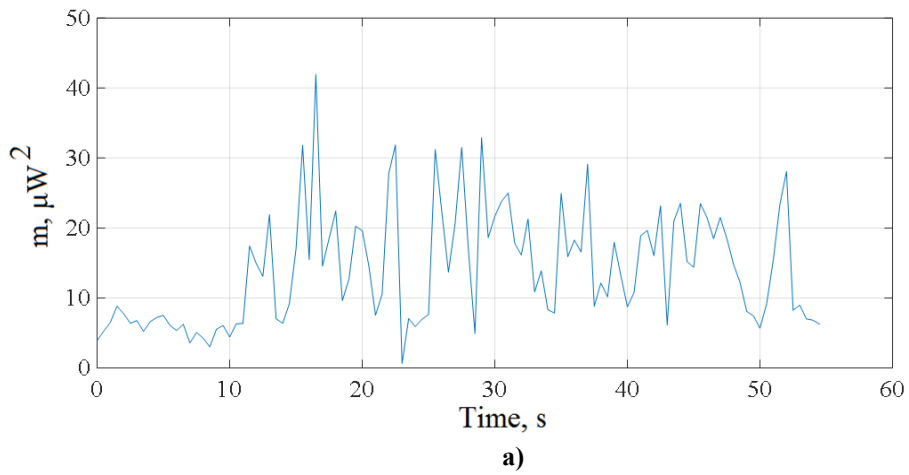
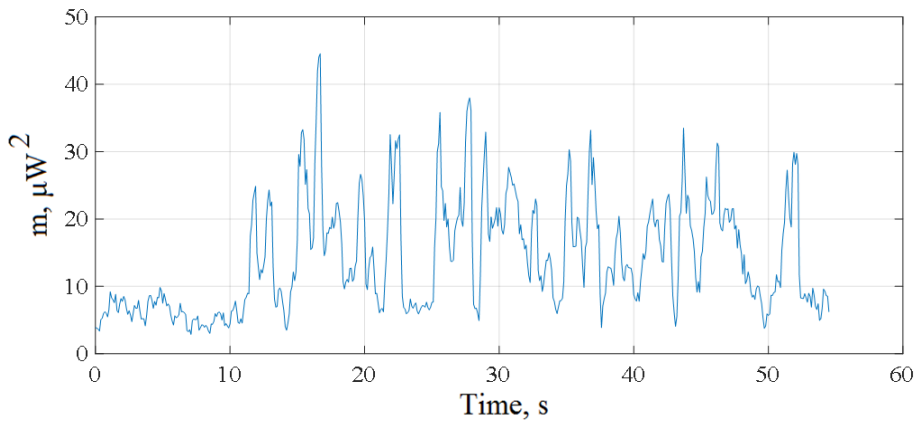


Figure 3. EEG registered signal (upper figure) and averaged spectral power density estimates (bottom figure) calculated within a sliding window



a)



b)

Figure 4. Averaged spectral power density estimates in the case when the previous and next window do not overlap (a) and in the case when the windows overlap on half (b)

It is determined as the result of the investigations that it is possible to increase the accuracy for detection of time moments of disruption appearance (start and stop of speech process) when the value of overlapping of next and previous windows decrease. The maximum accuracy will be ensured when window's shift on one tick of discreet sequence of EEG signal values. I.e. for the case of sampling frequency 500 Hz the value of shift is 2 ms.

The variation of averaged values of spectral power density $VAR(\hat{M}_P)$ is used as a criterion for time moments determination of disruption appearance (start and stop of the speech process).

It is found that the values of variation increase on more than one order when signs of increased brain activity are available.

$$VAR(\hat{M}_P)_{rest} = (2,9522 \pm 10\%)_{MKB^2}; \quad VAR(\hat{M}_P)_{disruption} = (83,3164 \pm 10\%)_{MKB^2}$$

Correspondently appliance of sliding window for detection of EEG signal disruption during speech process is effective, and offered criterion is sensitive and may be used for time moments determining of start and stop of speech process.

Disruption detection of probe electrical signal. Method of indirect evaluation of the dental material polymerization process by means of receiving and processing of electrical probe signals is described in the paper [14, 15, 16]. According to the signal recording method [15, 16], the electrical probe signal is the result of reflection of the series of ultraviolet flashes from the dental material and their transformation into the impulse alternating of electric voltage by means of the photoelectric transformer. These impulses are represented on the common time axis as the periodic extension (Fig. 5), what makes it possible to see the dependence of the change in the time of signal reflection the from flash to flash and to estimate the dynamics of polymerization process (by estimating the parameters change in time for such impulses).

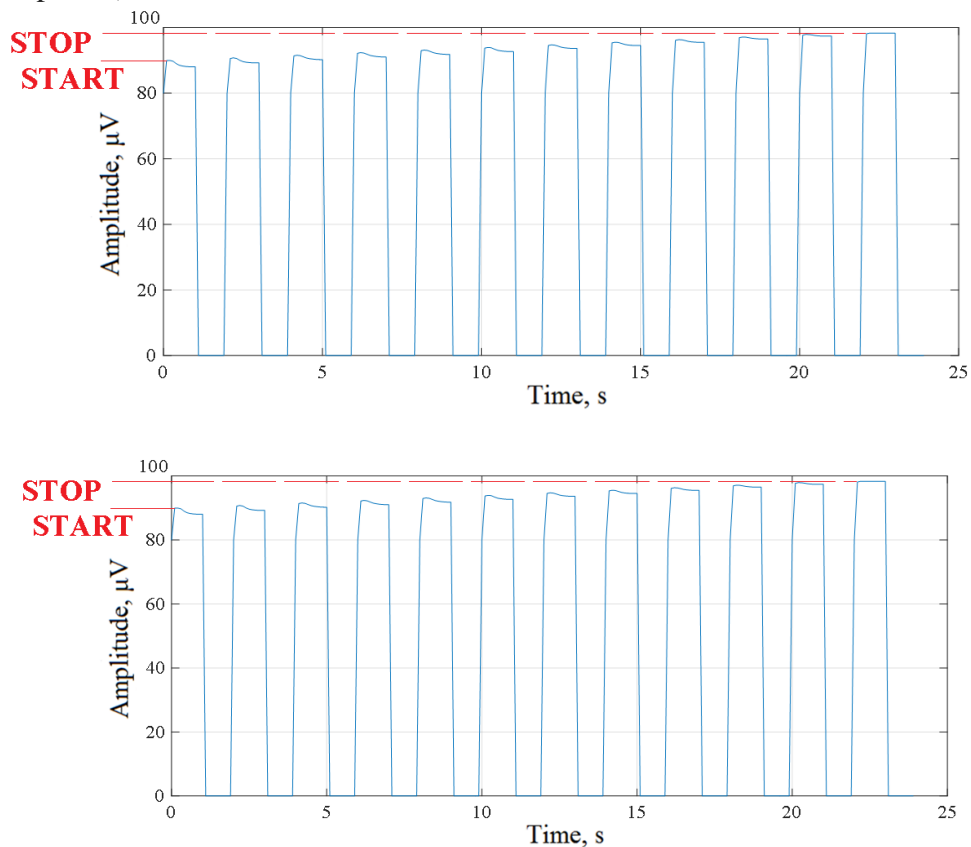


Figure 5. Representation of impulses of an electric probe signal on common time axis as its periodic extension

It is important here to provide the possibility of the time moments detection for the termination of polymerization process. The sliding window is offered to apply to solve this problem, within of which the processing by means of the described in papers [14, 15] method is carried out. It is assumed that the width of the window should be divisible to the period of such signals, and the value of shift should be divisible to the duration of one period of electric probe signal.

Conclusion. The actuality of the problem of the time moments detection of disrupt changes occurrence in biomedical signals for medicine is shown in the paper and such changes are defined as "disruption" particularly for time moments determining of signs of speech appearance in the structure of EEG signals and for assessment of dental process dynamics in the structure of electrical probe signals. The method of the time moments determination for the disruption occurrence of such biomedical signals based on their mathematical model in the form of the piecewise stationary random process using spectral-correlation analysis methods is offered.

It is established that for processing of biomedical signals of other types, especially electrocardiographic signals for the problem of identifying the coronary heart disease symptoms and estimation of adaptive processes in human organism during physical activity, the appliance of the sliding window method shows positive results.

The processing of EEG signals for the problem of determination of the time moments of the speech process signs using the methods of spectral-correlation analysis and the method of the sliding window is carried out. Herewith the sliding window parameters (its width and the value of the step of shift) are substantiated. It is determined that the informative features of the speech process are the averaged assessed values of the spectral density of the EEG signal power calculated within the sliding window. The results of EEG signals processing within the sliding window are analyzed and it is established that the maximum accuracy of determination the time moments of the disruption occurrence (characterizing the speech process symptoms) is achieved in the case of the maximum previous and next window overlapping, that is, at minimum shift value (in case of discrete sequences the minimum shift value equals to the sampling period).

The application of the described above method for electrical probe signals processing makes it possible to estimate of the state dynamics of a dental process and evaluate the time moments of the termination of the dental material polymerization process.

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ВИЯВЛЕННЯ РОЗЛАДКИ БІОМЕДИЧНИХ СИГНАЛІВ ІЗ ВИКОРИСТАННЯМ КОВЗНОГО ВІКНА

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Резюме. В статті обґрунтовано актуальність задачі виявлення часових моментів появи розладки в структурі біомедичних сигналів, що характеризуватиме зміни у функціонуванні відповідних органів та систем. Для цієї задачі обґрунтовано математичну модель біомедичних сигналів у вигляді кусково стаціонарного випадкового процесу. Запропоновано спосіб встановлення часових моментів появи розладки біомедичних сигналів, зокрема електроенцефалографічного (для встановлення часових моментів появи ознак процесу мовлення) та електричних зонд-сигналів (для встановлення часових моментів закінчення процесу полімеризації), що ґрунтується на застосуванні методів спектрально-кореляційного аналізу із використанням методу ковзного вікна. Обґрунтовано параметри вікна (його ширина та величина кроку зсуву). В межах ковзного вікна проведено опрацювання ЕЕГ сигналів та встановлено, що інформативними ознаками процесу мовлення будуть усереднені оцінки середньої густини потужності. Також виявлено, що максимальна точність встановлення часових моментів появи розладки в структурі ЕЕГ сигналів, що характеризують процес мовлення, буде досягнута у випадку максимального перекриття попереднього та наступного вікна, тобто при мінімальній величині зсуву вікна (у випадку дискретних послідовностей мінімальна величина зсуву буде рівною періоду дискретизації ЕЕГ сигналу). Показано переваги, що їх дає застосування запропонованого методу до опрацювання електричних зонд-сигналів для задачі оцінювання стану стоматологічного процесу, зокрема оцінювання динаміки та встановлення часових моментів закінчення процесу полімеризації стоматологічного матеріалу.

Ключові слова: біомедичний сигнал, електричний зонд-сигнал, ковзне вікно, полімеризація, електроенцефалографічний сигнал.

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