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ADAPTIVE DETECTION OF EPILEPTIC ACTIVITY IN EEG SIGNALS BASED ON MORPHOLOGICAL ANALYSIS AND THE NEYMAN-PEARSON CRITERION

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Epilepsy is one of the most common chronic neurological disorders, characterized by recurrent seizures caused by excessive synchronization of electrical activity in the brain's neurons. The primary diagnostic method is electroencephalography (EEG), which allows for the registration of bioelectrical activity in the cerebral cortex with high temporal resolution [8-10].

Traditional methods of EEG signal analysis have several limitations: spectral methods (Cerf R., Liang S., Tsipouras M.) [1, 2] do not localize events in time, correlation methods (Benbadis S., Zhang F.) [3, 4] do not consider the frequency structure, time-frequency methods (Tzallas A., Fotiadis D., Sucholeiki R., Ocak H.) [5-7] are dependent on a fixed window, and visual analysis is subjective. These limitations underscore the relevance of developing an automated morphological approach capable of detecting pathological patterns in real time.

The aim of the study is to develop a method and software for adaptive detection of epileptic activity based on EEG signal data.

The EEG signal $x(t)$ is represented as the sum of normal activity, pathological components, and noise:

$$x(t) = s_n(t) + s_p(t) + \eta(t), \quad (1)$$

where $s_n(t)$ – background brain rhythms, $s_p(t)$ – epileptic activity, $\eta(t)$ – artifacts (pulse, movements, network noise).

An example of a real signal with an epileptic episode is shown in Fig. 1.

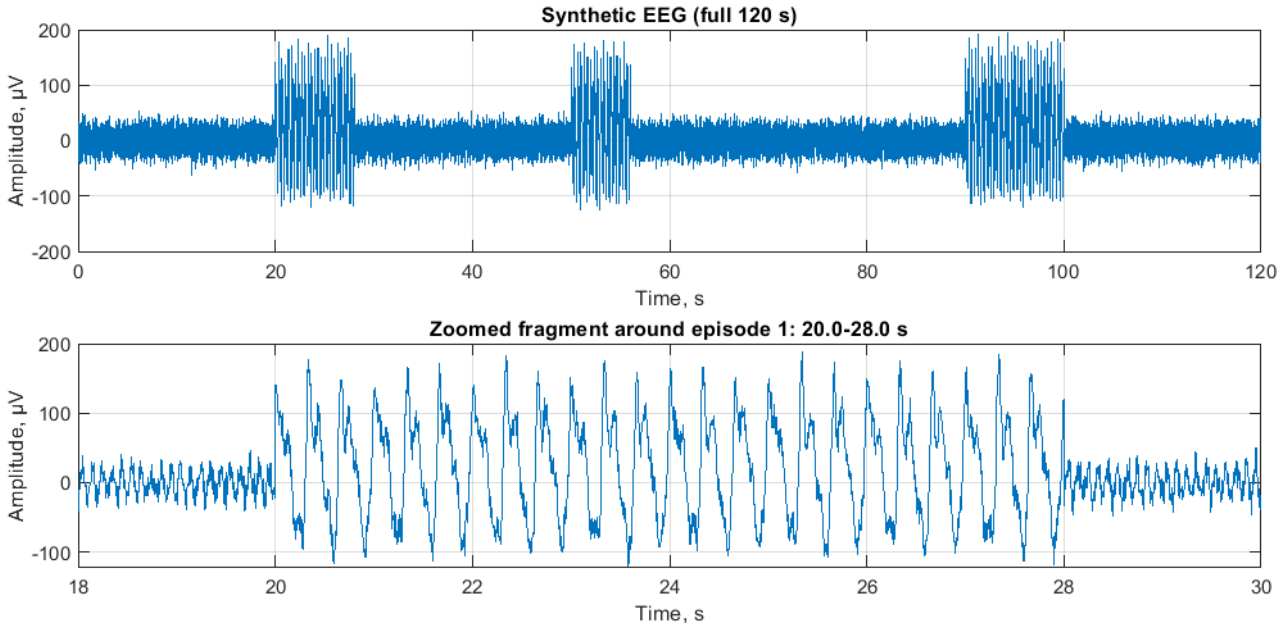

Fig. 1. Fragment of EEG signal with an epileptic episode

The proposed method is based on the evaluation of a morphological index, which describes local changes in the shape of the signal:

$$M_i = \omega_1 P_i + \omega_2 Z_i + \omega_3 C_i, \quad (1)$$

where ω_1, ω_2, ω_3 – weighting coefficients that normalize the contribution of each parameter to the overall assessment.

P_i – amplitude characteristic (peak value), $P_i = \max(x_i) - \min(x_i)$ samples;

C_i – local curvature indicator of the signal $C_i = \sum_{k=2}^{N_\omega - 1} \left| x_i(k+1) - 2x_i(k) + x_i(k-1) \right|$;

Z_i – number of zero-crossings (characterizes frequency activity) $Z_i = \sum_{k=1}^{N_\omega - 1} \left\| \{ x_i(k) x_i(k+1) < 0 \} \right.$.

The Neyman-Pearson criterion is applied to make a decision regarding the presence of epileptic activity based on the data M_i, which allows minimizing the probability of Type I and Type II errors.

Two hypotheses are considered:

– H0: $x(t) = s_n(t) + \eta(t)$ (normal state);

– H1: $x(t) = s_n(t) + s_p(t) + \eta(t)$ (epileptic activity).

Likelihood ratio:

$$\Lambda(C_i) = \frac{p(x \mid H_1)}{p(x \mid H_0)}. \quad (2)$$

The decision is made according to the rule:

$$\Lambda(x) > \lambda_{кр} \Rightarrow H_1, \qquad \Lambda(x) \le \lambda_{кр} \Rightarrow H_0. \quad (3)$$

In practical implementation, the criterion is used in the form of an energy threshold for the morphological index:

$$M_i > \tau_{NP} \Rightarrow H_1, \qquad M_i \le \tau_{NP} \Rightarrow H_0, \quad (4)$$

where $\tau_{NP} = \mu_0 + \sigma_0 \Phi^{-1}(1-\alpha_{FA})$ - decision threshold based on the probability of error α_{FA}, $\mu_0 = \text{median}(M_i), \sigma_0 = 1.4826 \cdot \text{MAD}(M_i)$.

Fig. 2 shows the calculated time dependence of the morphological index M_i for each iii-th sliding window of the EEG signal, computed in Matlab.

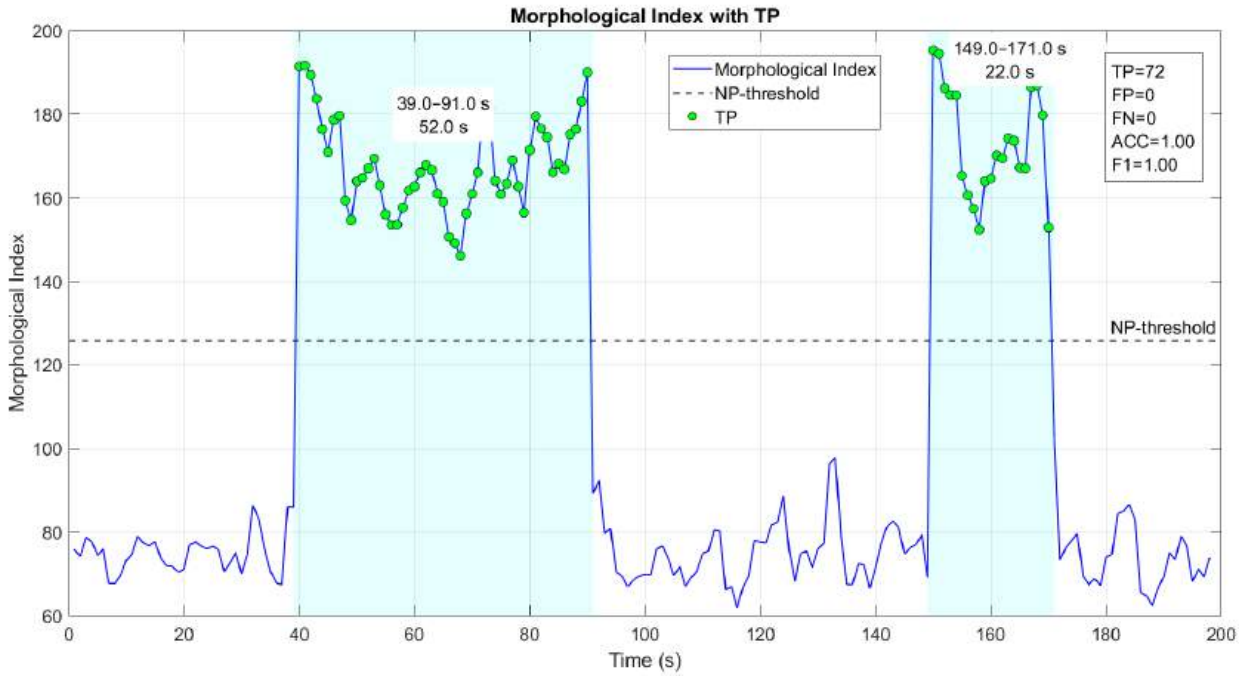

Fig. 2. Morphological index M_i and the threshold line defined by the Neyman-Pearson criterion

The solid curve represents the change in the value of the index M_i, while the dashed line indicates the NP-threshold calculated using the Neyman-Pearson criterion.

The highlighted areas indicate the time intervals where the index exceeds the threshold value, which is interpreted as epileptic activity. Green markers show true positive detections (TP), i.e., moments when the algorithm correctly classified the signal segments as pathological.

For the given signal fragment, the following results were obtained:

- TP = 72 — number of correctly detected segments;
- FP = 0 — no false detections were recorded;
- FN = 0 — no episodes were missed;
- ACC = 1.00, F1 = 1.00, this indicates 100% detection accuracy.

Two activity zones are observed in the intervals 39.0-91.0 s and 149.0-171.0 s, which fully coincide with the actual time stamps of seizures in the EEG signal recording.

Thus, Fig. 2 demonstrates the effectiveness of using the morphological index in combination with the Neyman-Pearson criterion for accurate automated detection of epileptic episodes without false detections.

As shown in Fig. 3, the application of this criterion allowed for effective highlighting of pathological regions in the EEG signal.

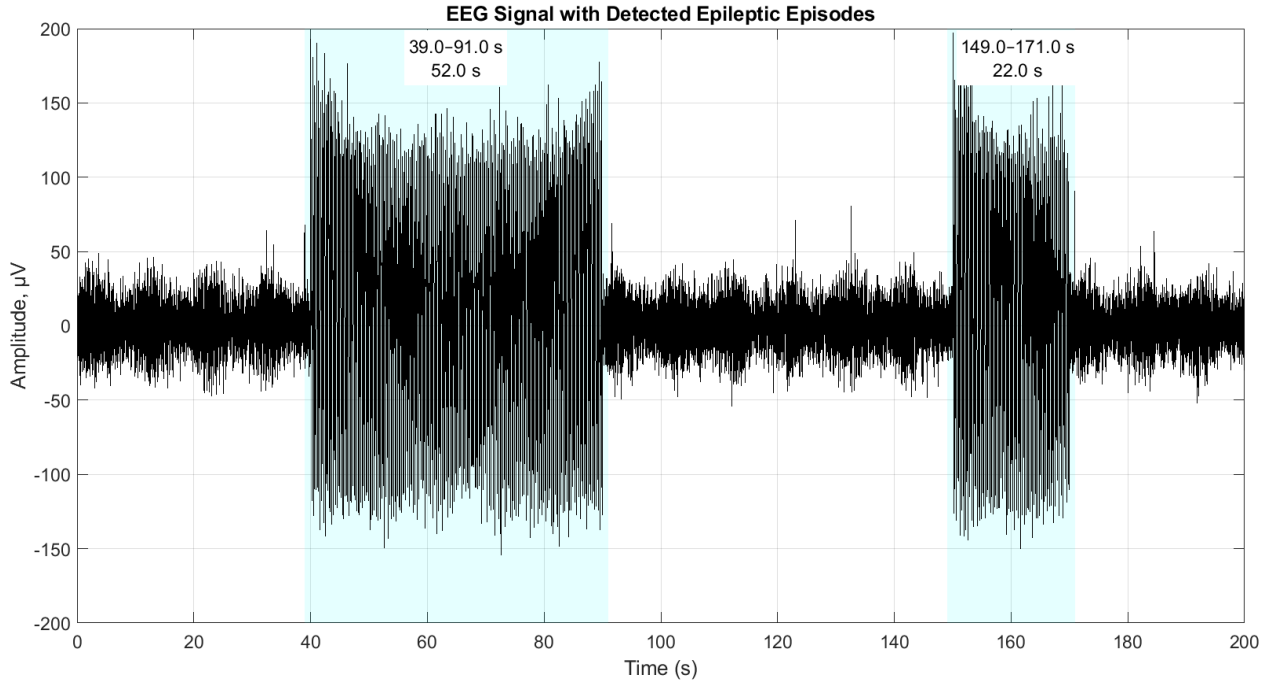

Fig. 3. Result of automatic detection of episodes (red areas – pathological activity)

Rectangular areas highlight the intervals 39.0-91.0 s and 149.0-171.0 s, which correspond to the detected epileptic episodes. In these regions, a sharp increase in amplitude and signal oscillation density is observed, indicating the presence of paroxysmal activity.

The morphological analysis method correctly identified both episodes without false detections, confirming its high accuracy (ACC=1.00) and full correspondence with the clinical seizure time stamps.

The developed method, combining the morphological index and the Neyman-Pearson criterion, has proven its high effectiveness and reliability in the automated and adaptive detection of epileptic seizures in EEG. The proposed index M_i successfully integrates key changes in the EEG signal's shape (amplitude, frequency, curvature), and the adaptive NP threshold makes the method robust to individual differences in the patients' background activity. The created software can serve as an effective tool for accelerating EEG signal analysis in clinical practice and scientific research.

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