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ISSUE №57

EUROPEAN OPEN SCIENCE SPACE

COLLECTION OF SCIENTIFIC PAPERS

5TH INTERNATIONAL SCIENTIFIC AND PRACTICAL CONFERENCE

MODERN PERSPECTIVES ON GLOBAL SCIENTIFIC SOLUTIONS

OCTOBER 13-15, 2025, BERGEN, NORWAY

UDC 01.1

Collection of Scientific Papers with the Proceedings of the 5th International Scientific and Practical Conference «Modern Perspectives on Global Scientific Solutions» (October 13-15, 2025, Bergen, Norway). European Open Science Space, 2025. 304 p.

ISBN 979-8-89704-959-2 (series)
DOI 10.70286/EOSS-13.10.2025

The conference is included in the Academic Research Index ResearchBib International catalog of scientific conferences.

The conference is registered in the database of scientific and technical events of UkrISTEI to be held on the territory of Ukraine (Certificate №556 dated 16.06.2025).

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AUTOMATED DETECTION OF PARKINSONIAN-TYPE TREMOR BASED ON EMG SIGNAL PROCESSING

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Parkinson's disease (PD) is one of the most common neurodegenerative disorders characterized by progressive degeneration of dopaminergic neurons in the substantia nigra of the brain. According to the World Health Organization (WHO), the number of patients with PD exceeds 10 million worldwide, and its prevalence among people over 60 years of age reaches 1–2% [1]. One of the most typical clinical manifestations of the disease is Parkinsonian tremor – rhythmic oscillations of the limbs with a frequency of 4–6 Hz, which occur at rest and significantly reduce the patient's quality of life.

The clinical assessment of tremor based on visual observation is subjective and depends on the physician's experience. Therefore, there is an increasing need for objective methods of tremor recording and quantitative analysis, which would ensure the reliability of diagnosis and allow for monitoring the effectiveness of treatment.

The most informative method for studying muscle activity is electromyography (EMG) [8] — a technique for recording bioelectrical potentials that reflects muscle motor activity in both the time and frequency domains. Analysis of EMG signals makes it possible to identify signs of pathological contractions, evaluate the spectral characteristics of tremor, its regularity, and phase relationships between muscle groups.

At the same time, traditional EMG analysis methods – spectral [1, 4, 5], statistical [1–3, 6], temporal [2, 3], and machine learning approaches [1, 7] – often fail to provide sufficient accuracy in detecting short or weakly expressed tremor episodes. This justifies the need to develop automated algorithms capable of localizing episodes of pathological tremor under conditions of noise and signal variability.

The aim of this work is to develop and implement a method for automated detection of Parkinsonian-type tremor based on the processing of electromyographic signals. The development of the method is based on the principles of designing information systems for the acquisition and processing of biosignals proposed in [9].

The EMG signal during tremor is represented as an additive sum of three components:

$$s(t) = n(t) + T(t) + m(t), \tag{1}$$

where $n(t)$ – background biological noise;

$h(t)$ – high-frequency muscle activity;

T(t) – low-frequency component corresponding to pathological tremor (4-6 Hz).

Episodic tremor is accounted for through an activity mask:

$$T(t) = A_T \sin(2\pi f_0 t) M(t), \tag{2}$$

where M(t)= 1 during tremor and 0 at rest.

The background noise is modeled as a Gaussian process $N(0, \sigma^2)$, and the high-frequency component describes spikes and motion artifacts in the range of 50-150 Hz.

This model adequately reproduces the real EMG signal, allowing you to test the effectiveness of the detection algorithm.

The basis of the tremor detection algorithm is cross-correlation analysis between the EMG signal and a reference sinusoidal signal with a frequency of 5 Hz.

A reference signal with a duration of 1 s is described by the expression:

$$r(t) = \sin(2\pi f_0 t). \tag{3}$$

For each signal segment, the normalized cross-correlation is calculated:

$$C(k) = \frac{\sum_{m=1}^{N} (s[m] - \bar{s})(r[m-k] - \bar{r})}{\sqrt{\sum_{m=0}^{N} (s[m] - \bar{s})^2} \sqrt{\sum_{m=0}^{N-1} (r[m] - \bar{r})^2}}, \tag{4}$$

The maximum C_{max} value for each segment is used as an indicator of the presence of tremor..

Next, moving average smoothing is performed to eliminate noise fluctuations and adaptive threshold detection based on the statistical characteristics of the correlation signal:

$$P = \mu_C + \alpha \sigma_C, \tag{5}$$

where P – threshold, μ_C and σ_C – average and standard deviation of correlation values, k – adaptation coefficient (0.8-1.2).

Tremor detection occurs according to the rule:

$$m_i = \begin{cases} 1, & C_i > P, \\ 0, & \textit{інакше}. \end{cases} \tag{6}$$

In the tremor detection algorithm, after the threshold decision, a binary mask m_i is formed, where:

$$m_i = \begin{cases} 1, & \textit{якщо тремор присутній}, \\ 0, & \textit{якщо тремору немає}. \end{cases} \tag{7}$$

To determine the beginning and end of tremor episodes, the mask difference between adjacent points is calculated.:

$$\Delta m_i = m_i - m_{i-1}, \quad \begin{cases} \Delta m_i = +1, & \text{початок епізоду,} \\ \Delta m_i = -1, & \text{кінець епізоду.} \end{cases} \quad (8)$$

Episode start: $\Delta m_i = +1$ - this corresponds to the transition 0→1, i.e. the segment where the tremor appeared. Episode end: $\Delta m_i = -1$ - this corresponds to the transition 1→0, i.e. the segment where the tremor ended

The constructed binary activity mask allows for precise determination of the temporal boundaries of tremor episodes.

Fig. 1 shows an algorithm for detecting Parkinsonian tremor..

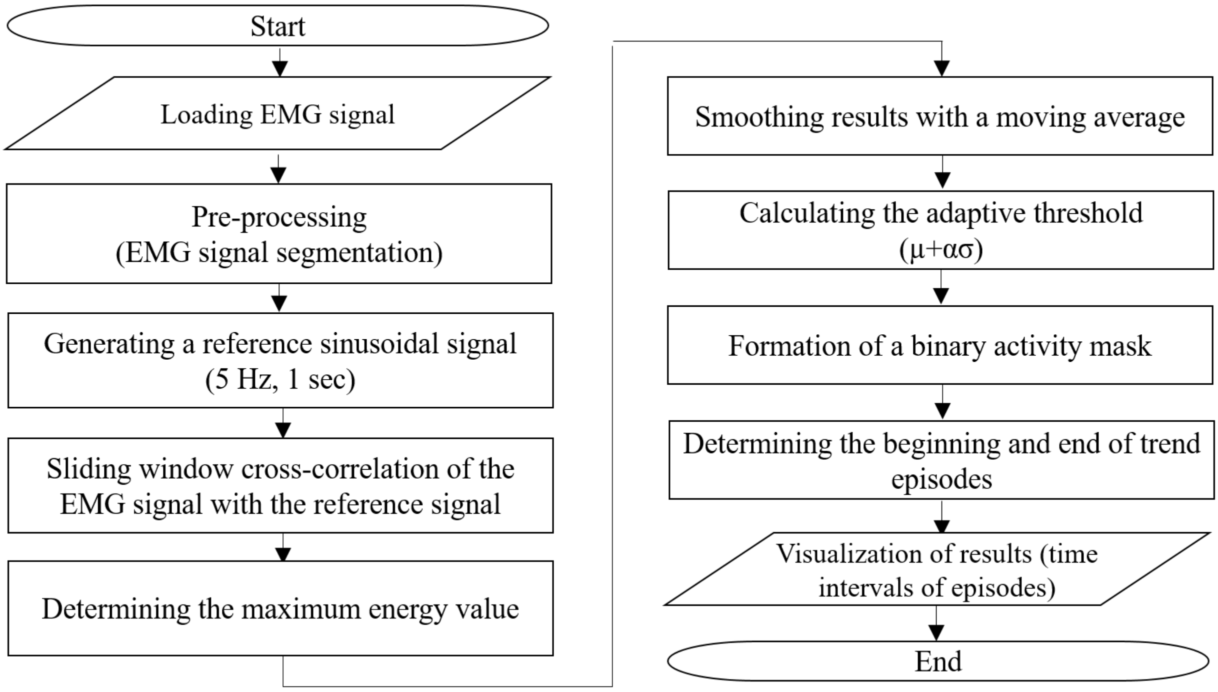

Figure 1. Tremor detection algorithm

The proposed algorithm is implemented programmatically in the Matlab environment. Figure 2 shows the results of detecting Parkinson's tremor episodes from EMG signals.

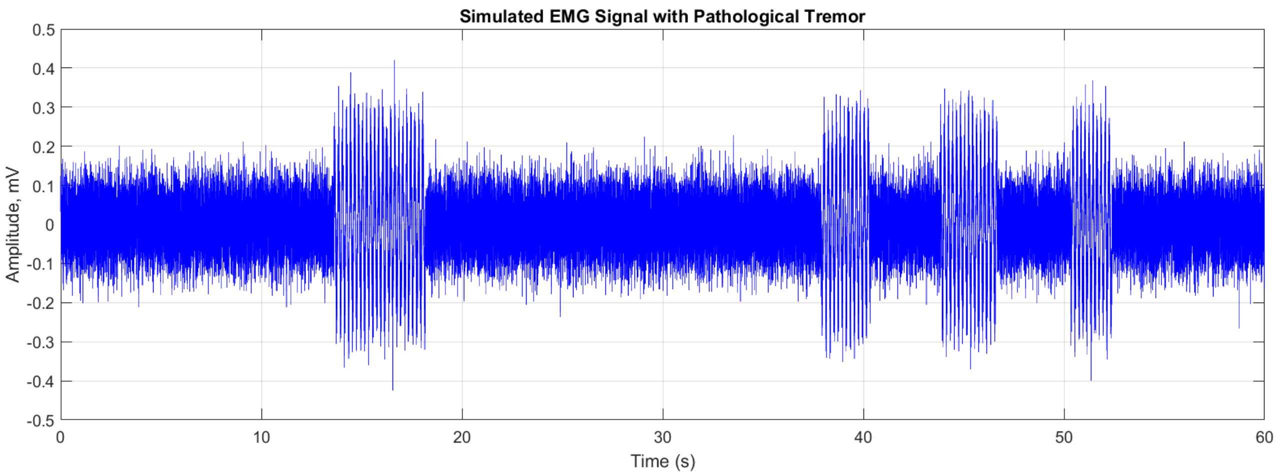

Figure 2. EMG signal with tremor episodes

Fig. 3 shows the result of calculating the maximum correlation with the reference signal (5 Hz) with a decision threshold imposed on it.

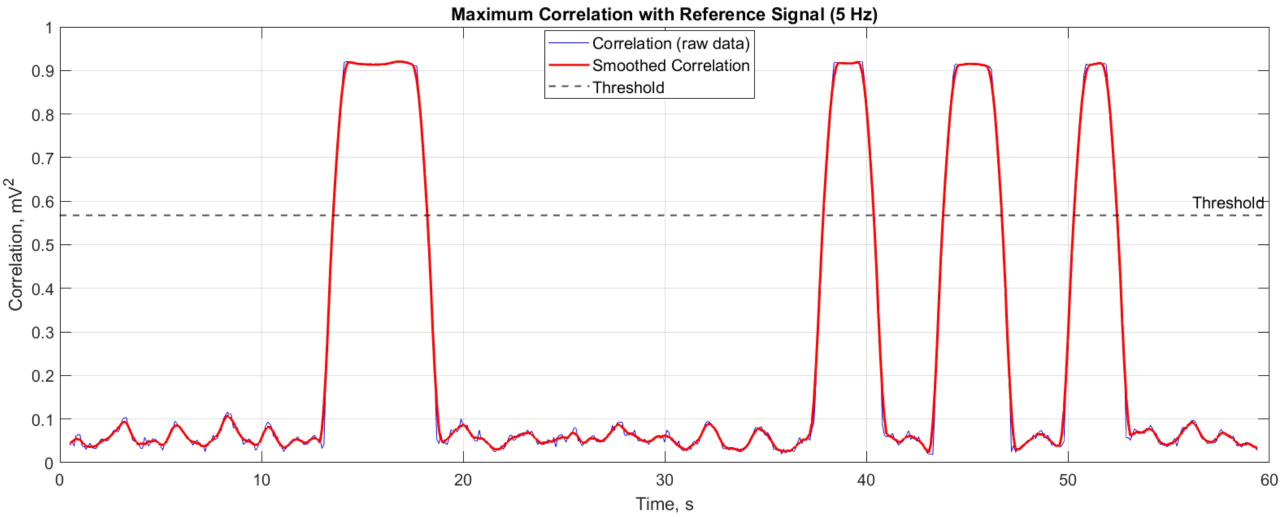

Figure 3. Maximum correlation with reference signal (5 Hz)

In areas without tremor, the correlation values are close to zero, while during periods of tremor they increase sharply, approaching 0.9-1.0 mV^2. Correlation values that exceed the threshold level are stated as manifestations of tremor.

Fig. 4 shows the detected tremor episodes.

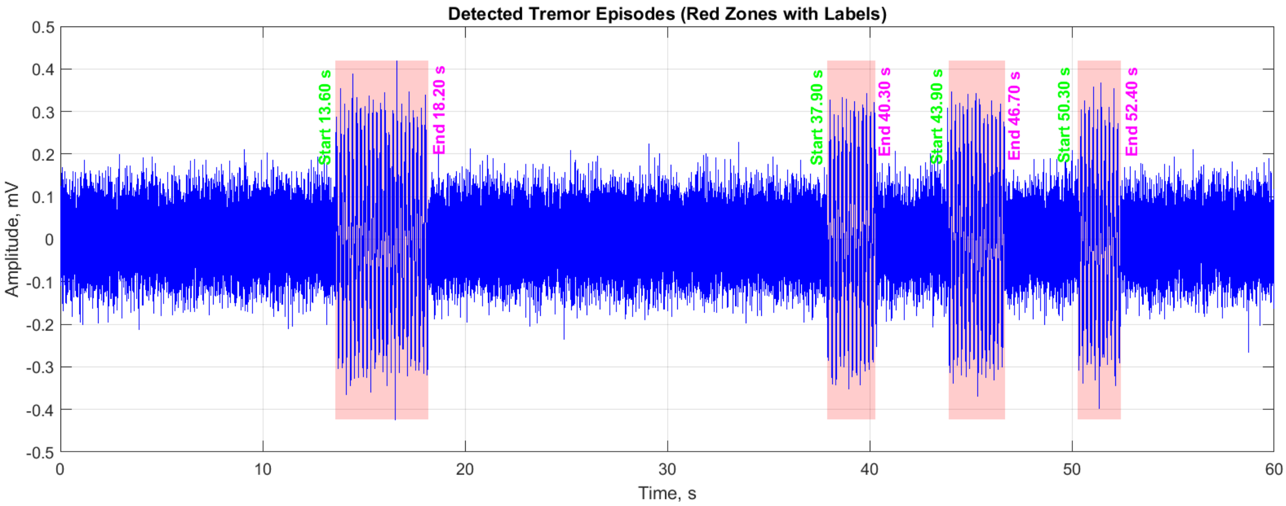

Figure 4. Detected tremor episodes (red areas with captions)

The graph shows the original EMG signal with superimposed translucent areas (patch areas) corresponding to the time intervals of the detected tremor.

Thus, the software, implemented in Matlab, recorded 4 tremor episodes with a total duration of about 11.9 seconds. This is approximately 19.83% of the time from the 60-second recording.

Thus, the work developed a comprehensive approach to automated detection of Parkinsonian-type tremor based on EMG signal processing.

A mathematical signal model, a cross-correlation detection method, an adaptive threshold analysis algorithm, and software implementation are proposed.

The experiments confirmed the effectiveness of the method in detecting tremor even in noisy conditions, which makes it promising for use in clinical practice.

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