DOI 10.70286/EOSS-16.02.2026.006.82-86

HIGH-PERFORMANCE METHODS AND CLOUD-BASED INFORMATION TECHNOLOGIES FOR THE ANALYSIS OF COGNITIVE SIGNALS OF NEURAL NODES

Bishchak Dmytro
PhD Student
Department of Software Engineering
Ternopil Ivan Puluj National Technical University, Ukraine

Abstract. This paper presents a high-performance methodological and technological framework for multimodal analysis of cognitive signals of neural nodes by integrating electroencephalographic (EEG) data with graphomotor trajectories obtained from spiral drawing tasks. A ΔR motor deviation metric is introduced to quantify tremor-induced radial deviations from an ideal Archimedean spiral.

The analytical pipeline includes frequency-domain characterization and EEG–motor synchronization assessment through cross-correlation analysis. To ensure scalability, reproducibility, and telemedicine readiness, a secure serverless cloud architecture is proposed using API-driven execution and stateless analytical services.

The proposed solution demonstrates how modern information technologies can transform multimodal neurodiagnostic research into scalable, secure, and high-performance computational systems suitable for clinical deployment.

Keywords: EEG, tremor, ΔR metric, multimodal analysis, serverless computing, telemedicine, scalable neurodiagnostics.

Introduction. Tremor-related neurological disorders, including Parkinson's disease and Essential Tremor, are characterized by oscillatory motor disturbances strongly associated with abnormal neural dynamics. Traditional clinical assessments rely heavily on visual scoring scales and isolated signal analysis, which limits diagnostic precision and reproducibility.

Multimodal approaches integrating electrophysiological and motor data significantly improve characterization of tremor patterns. Spiral drawing tasks, recorded using high-resolution graphics tablets, enable precise capture of motor trajectories. Simultaneously recorded EEG signals provide insight into cortical neural node activity involved in motor regulation.

However, most existing analytical systems suffer from:
- limited scalability;
- insufficient reproducibility;
- hardware-bound processing;
- lack of standardized computational pipelines.

This research proposes a unified analytical and technological framework combining:

- a ΔR-based motor deviation metric;
- EEG–motor synchronization analysis;
- a secure, high-performance cloud-based analytical architecture [1].

Objective of the Study. The objective of this study is to develop a high-performance analytical and technological framework for multimodal analysis of cognitive signals of neural nodes through the integration of electroencephalographic (EEG) activity and graphomotor trajectories obtained from spiral drawing tasks.

The study aims to:

- formalize ΔR as a motor deviation metric for tremor quantification;
- establish frequency-domain characterization of tremor dynamics;
- evaluate EEG–motor synchronization using correlation-based analysis [2];
- design a secure, scalable cloud-based analytical infrastructure suitable for clinical and telemedicine deployment.

The central hypothesis is that integrating ΔR-based motor analysis with synchronized EEG signals within a reproducible computational architecture enhances objectivity, scalability, and applicability of tremor diagnostics.

Materials and Methods.

1. Experimental Materials. The experimental setup includes:

- high-resolution graphics tablet for spiral trajectory recording;
- EEG acquisition system with synchronized timestamping;
- secure digital storage for multimodal datasets;
- serverless cloud execution environment for analytical processing.

Spiral trajectories are recorded at high sampling rates, allowing precise extraction of radial deviation metrics. EEG signals are recorded from cortical regions involved in motor control.

All data streams are synchronized via shared timestamps.

2. ΔR Motor Deviation Metric. Motor performance is quantified relative to an ideal Archimedean spiral.

The radial deviation metric is defined as:

$$\Delta R(t) = R_{observed}(t) - R_{ideal}(t) \tag{1}$$

where: $R_{observed}(t)$ is the instantaneous radial coordinate of the stylus, $R_{ideal}(t)$ is the expected radial coordinate of the reference spiral.

ΔR(t) isolates tremor-induced oscillatory components while reducing geometric distortions caused by trajectory curvature.

Segment-wise decomposition of ΔR allows local analysis of tremor amplitude and variability.

3. Frequency-Domain Analysis and Sinusoidality Index. To characterize oscillatory structure, ΔR(t) is transformed into the frequency domain.

Dominant tremor frequency f_p is identified within clinically relevant bands.

The Sinusoidality Index (SI) is introduced to quantify the concentration of spectral energy around the dominant frequency [3].

Welch power spectral density estimation is applied to improve stability of spectral peak identification.

$$SI = \frac{\text{Energy around } f_p}{\text{Total tremor-band energy}} \quad (2)$$

High SI values indicate structured oscillatory tremor; lower values reflect irregular or broadband motor instability.

4. EEG–Motor Synchronization. To assess interaction between cortical activity and motor tremor, cross-correlation analysis is performed:

$$C_{xy}(\tau) = \sum x(t)\, y(t+\tau) \quad (3)$$

where: $x(t)$ represents EEG activity, $y(t)$ represents ΔR(t).

The maximum correlation coefficient and corresponding lag τindicate the strength and temporal relationship between neural oscillations and motor deviations.

5. High-Performance Computational Architecture. To ensure reproducibility and scalability, the analytical framework is implemented using a secure serverless architecture [4].

The system follows an API-driven execution model [5], where clinical applications interact exclusively through authenticated endpoints.

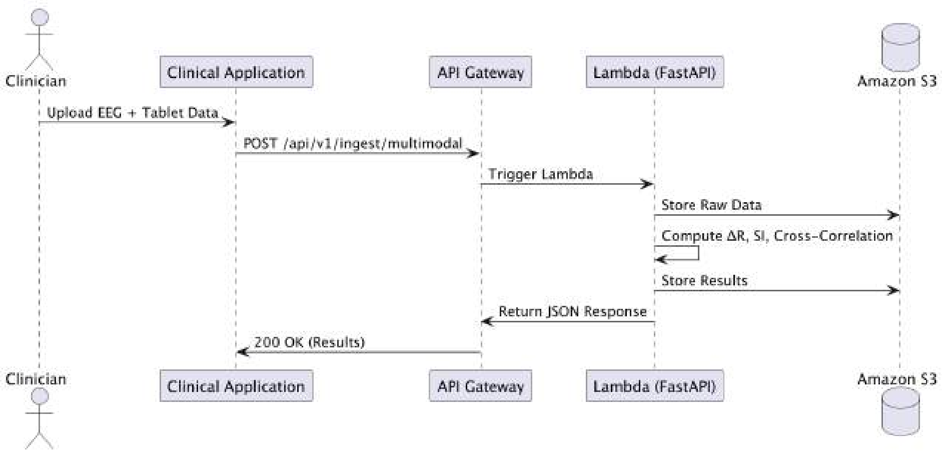

Figure 1. Architectural Overview. Multimodal EEG-ΔR Cloud Processing Pipeline

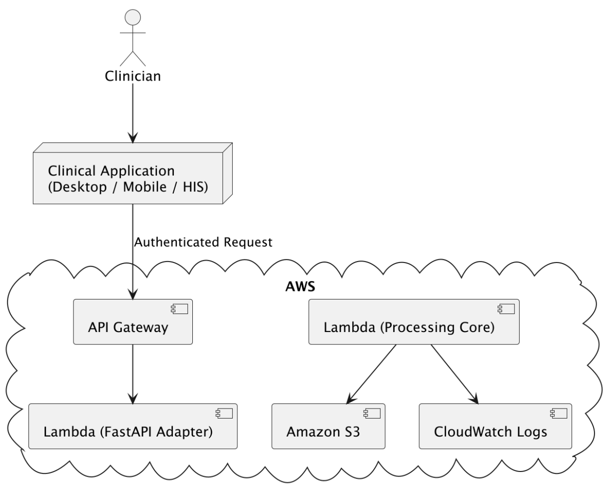

Figure 2. Architectural Overview. Secure Serverless Architecture for Multimodal Neuro-Motor Analysis

The analytical service operates in a stateless manner, allowing horizontal scaling and deterministic reproducibility.

6. API-Based Analytical Execution. All analytical operations are encapsulated within controlled API contracts. Example endpoint:

POST /api/v1/analysis

Response includes: ΔR metrics, Sinusoidality Index, Dominant frequency, EEG–motor correlation metrics.

Infrastructure logic is separated from analytical core modules, ensuring modularity and maintainability.

Implementation fragment of the stateless analytical endpoint with FastAPI [6]:

```
from fastapi import FastAPI
from mangum import Mangum
from tremor_analysis.core import TremorAnalyzer

app = FastAPI()

@app.post("/api/v1/analysis")
def analyze(payload: dict):
analyzer = TremorAnalyzer()
return analyzer.process_multimodal(payload)

handler = Mangum(app)
```

This design decouples analytical mathematics from deployment logic.

Experimental Results and Discussion.

The framework was validated using synchronized multimodal recordings.

Comparative analysis between medicated and unmedicated states demonstrated:

- reduced ΔR amplitude after medication;
- decreased spectral concentration of tremor peaks;
- modified EEG–motor correlation patterns.

The ΔR metric allowed objective quantification of tremor variability, while SI provided structured oscillation characterization.

Cross-correlation analysis revealed measurable temporal coupling between cortical oscillations and motor tremor manifestation.

From a computational perspective, the serverless architecture enabled:

- deterministic analytical execution,
- scalability under concurrent processing,
- centralized multimodal data integration,
- suitability for remote telemedicine scenarios.

The stateless analytical design ensures reproducibility across sessions and deployment environments.

Conclusions. The study presents a unified framework integrating:

- ΔR as a motor deviation metric;
- frequency-domain tremor characterization;
- EEG–motor synchronization analysis;
- secure, scalable serverless analytical architecture.

The proposed approach demonstrates how multimodal neurodiagnostic analysis can be transformed into a high-performance, reproducible, and telemedicine-compatible computational system.

By combining mathematical signal formalization with cloud-native execution principles, the framework enables scalable and clinically applicable tremor assessment.

References

1. Amazon Web Services. (n.d.). Building serverless multi-tier architectures with Amazon API Gateway and AWS Lambda. https://docs.aws.amazon.com/whitepapers/latest/serverless-multi-tier-architectures-api-gateway-lambda/
2. Біщак Д.С., & Петрик М.Р. (2025). Кореляція між графомоторною активністю та ЕЕГ у пацієнтів із тремором при хворобі Паркінсона. Вчені Записки Таврійського Національного Університету Імені В.І.Вернадського, Серія «Технічні Науки», 2(4), 25–30. https://doi.org/10.32782/2663-5941/2025.4.2/04
3. Bishchak, D., & Petryk, M. (2025). Algorithmic approach to tremor classification based on EEG and graphomotor signals. Scientific Journal of the Ternopil National Technical University, 119(3), 35–44. https://doi.org/10.33108/visnyk_tntu2025.03.035
4. Amazon Web Services. (n.d.). AWS Lambda. https://aws.amazon.com/lambda/
5. Amazon Web Services. (n.d.). Amazon API Gateway. https://aws.amazon.com/api-gateway/
6. Ramírez, S. (n.d.). FastAPI: Modern, fast (high-performance) web framework for building APIs with Python. FastAPI. https://fastapi.tiangolo.com/

DOI 10.70286/EOSS-16.02.2026.007.86-88

CONTROLLED BENCHMARKS FOR STREAMING DECISION SUPPORT IN MULTIMODAL TIME SERIES

Uzun Illia
Postgraduate student
Institute of Artificial Intelligence and Robotics
National University «Odessa Polytechnic», Ukraine

Abstract. Validating streaming decision support systems under non-stationary conditions requires distinguishing between genuine concept drift (change in data distribution) and modality degradation (sensor faults, noise, missingness). This work presents a methodology for constructing controlled streaming benchmarks with deterministic injections of drift, degradation, and anomalies. We define a generative protocol where concept drift is modeled as a switch in modality relevance, while