

CHARACTERIZING THE ICTAL TRANSITION: A MULTI-MODAL FRAMEWORK FOR SEIZURE ONSET ZONE LOCALIZATION USING SIGNAL DYNAMICS AND EXPLAINABLE AI

Lekshmi M S¹, Malaika Jayachandran², Jibina Joby³, Celine Sony¹, Reginold John⁴, Joseph Mathew¹

¹Department of Applied Electronics and Instrumentation, Rajagiri School of Engineering & Technology, Kochi, India

²Department of Computer Science and Business Systems, Rajagiri School of Engineering & Technology, Kochi, India

³Department of Computer Science and Engineering, Rajagiri School of Engineering & Technology, Kochi, India

⁴Department of Business Administration, Rajagiri College of Social Science, Kochi, India

Corresponding Author: Joseph Mathew

Address: Rajagiri School of Engineering & Technology, Rajagiri Valley, Kakkanad, India.

Tel: +91 9496574790

Email: josephc@rajagiritech.edu.in

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ABSTRACT

Surgical intervention is essential for a patient with drug-resistant epilepsy. A favorable surgical outcome requires accurate localization of the seizure onset zone (SOZ). Current clinical practices primarily rely on visual analysis of intracranial electroencephalograms (iEEGs), which is a subjective and tiring process. This study introduces a computational framework for identifying and localizing SOZ. The Hospital of the University of Pennsylvania (HUP) dataset, which includes data from 20 patients, is used to validate this framework. Three quantitative biomarkers, specifically amplitude dynamics, epileptogenicity index (EI), and nonlinear signal complexity, were considered to understand the different aspects of the ictal state. To diminish inter-patient variability, features were standardized on a subject-specific basis. A gradient-boosted decision tree model was developed employing a Leave-One-Subject-Out (LOSO) cross-validation technique to guarantee subject-independent generalizability. Youden's J statistic was used to adjust the decision criterion to balance sensitivity and specificity. In addition, the SHAP (SHapley Additive exPlanations) method is used to provide a clear physiological interpretation of the subjects. The proposed framework achieved an average F1 score of 0.916 in the LOSO setting. The trade-off between sensitivity (0.91) and specificity (0.93) is balanced. This study demonstrates that incorporating nonlinear complexity metrics with interpretable machine learning substantially improves automated identification of the epileptogenic zone.

Keywords: iEEG, Epilepsy, SHAP, localization, SOZ. Explainable AI

INTRODUCTION

Epilepsy exists as a persistent neurological condition that impacts more than 50 million people across the globe. In contrast, 30% of epilepsy patients develop drug-resistant epilepsy (DRE) after receiving standard anti-seizure medication evaluations [1]. Surgical treatment provides a hopeful treatment approach for patients who have drug-resistant focal epilepsy because it enables doctors to remove the seizure-causing area, which results in total seizure elimination [2]. The success of epilepsy surgery requires doctors to precisely identify the seizure onset zone (SOZ) because this brain area triggers seizures and spreads them first [3]

The current medical approach relies on human visual assessment of iEEG data to locate the SOZ, as this method produces subjective results that take a long time to complete and yield different results when different experts analyze the data [1]. Automated detection algorithms have solved these problems, but these systems remain unready for clinical use because they do not work for all subjects and cannot provide explanations for their predictions [4]. The difference between algorithmic precision and