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A Systematic Review of Machine Learning-Based Methods for Detecting Epileptic Episodes in Advance

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Abstract
Epilepsy is a chronic neurological disorder which is characterized by recurring seizures and affects around 50 million people globally, making it problematic to the healthcare systems and diminishing patients' quality of life. Traditional seizure detection methods, primarily based on electroencephalogram (EEG) analysis and clinical observation, are constrained by their limited accuracy and real-time monitoring capabilities. Nevertheless, there has been the availability of the machine learning (ML) which opened new doors for early detection and prediction epileptic events. There are ML algorithms such as support vector machines (SVMs), neural networks, deep learning models which comprises of the convolutional neural networks (CNNs) and recurrent neural networks (RNNs) that have demonstrated significant potential in identifying precursor patterns and biomarkers from EEG data. The early detection of epileptic events is crucial for the well-being of people with epilepsy because it enables timely interventions that would ease the management of this condition. Machine learning (ML) is a recent tool used to predict epileptic seizure by analyzing large datasets with intricate algorithms in order to detect particular patterns indicative of forthcoming activities. Based on the secondary data this systematic review explores prominent research contributions in various machine learning-based approaches for the early detection of epileptic events, highlighting the methodologies, data types, performance metrics, and key findings from recent studies. By synthesizing and discreetly analysing the current state of research, this review aims to delve deeply into the most effective strategies and identify areas for future investigation.
Keywords: Epilepsy, machine learning, early detection, seizure prediction, systematic review.

1.1 Objectives:

- To explore how early detection of epileptic events using ML can be used determining timely interventions and personalized treatment strategies.
- To analyse the limitations and challenges of current seizure detection techniques based on electroencephalogram (EEG) analysis and clinical observation.

1.2 Introduction

Epilepsy is an insidious disease caused by seizures t hat affects millions of people worldwide, causing s erious medical problems and shortening patients' li ves by a good margin. Seizures occur suddenly with out any control over the burst of electricity in the b rain and often cause many symptoms, including co nvulsions, loss of consciousness, and confusion.

The unpredictable nature of seizures presents a formidable obstacle for patients and caregivers, necessitating the development of reliable methods for early detection and intervention. Epilepsy is a psychiatric disease caused by an unpredictable phenomenon that affects approximately 50 million people worldwide (World Health Organization, 2023). Not being able to have a seizure positively affects the lives of people with epilepsy, so early diagnosis and timely intervention are important. Traditional methods for seizure prediction, such as electroencephalogram (EEG) analysis, have been limited in accuracy and reliability. However, the advent of machine learning (ML) has opened new avenues for enhancing the precision and timeliness of epileptic event detection.

Traditionally, the diagnosis and management of epilepsy have relied on clinical observation, patient history, and diagnostic tests such as electroencephalography (EEG) and magnetic resonance imaging (MRI). While these tools provide valuable insights into the underlying neurological abnormalities associated with epilepsy, they have limitations in terms of sensitivity, specificity, and real-time monitoring capabilities. Moreover, the sheer volume and complexity of EEG data make manual interpretation and analysis a daunting task for healthcare practitioners.

In recent years, the emergence of machine learning (ML) has revolutionized epilepsy research, providing new ways for early detection and prediction of epilepsy cases. Machine learning algorithms leverage advances in computing power and data analysis to perform quantitative analysis of EEG data to identify structural changes and biomarkers that signify a seizure. By learning from labelled examples of EEG signals recorded during both seizure and non-seizure states, ML models can extract discriminative features and build predictive models capable of forecasting seizure onset with high accuracy.

The integration of ML techniques with EEG-based seizure detection holds immense promise for improving clinical outcomes and patient care in epilepsy management. Early detection of epileptic events enables timely interventions, such as medication adjustments, lifestyle modifications, or electrical stimulation therapies, aimed at preventing or mitigating the impact of seizures. Moreover, ML-based approaches have the potential to personalize treatment strategies by tailoring interventions to individual patient profiles and seizure patterns.

Despite the remarkable progress made in ML-based seizure detection research, several challenges and opportunities remain on the horizon. The heterogeneity of epilepsy phenotypes, variability in seizure onset patterns, and the need for real-time, interpretable predictive models pose significant hurdles for translation into clinical practice. Furthermore, issues related to data standardization, model generalization across patient populations, and regulatory approval processes necessitate collaborative efforts from multidisciplinary teams comprising clinicians, data scientists, and regulatory authorities.

Machine learning algorithms, with their ability to process large datasets and uncover hidden patterns, offer promising solutions for predicting seizures before they occur. These approaches utilize various types of data, including EEG signals, imaging data, and patient records, to train models that can predict seizures with high accuracy. This systematic review aims to provide an overview of machine learning-based approaches for early detection of epilepsy cases and discuss their advantages, limitations, and potential for medical use.

In this systematic review, we aim to general framework of machine learning-based methods for early detection of epilepsy cases. Through a synthesis of recent literature, we will explore the methodologies, data types, performance metrics, and clinical implications of ML models in seizure prediction.

By critically evaluating the strengths, limitations, and future directions of ML-based seizure detection research, we seek to contribute to the ongoing discourse on optimizing epilepsy management strategies and improving the improved quality of life for the people who have been suffering with such debilitating condition.

1.3 Literature Review

Saminu, Sani & et al (2021) [2] in their research on which was based on the Detection and of Epileptic Seizure Techniques with the help of EEG Signal, has focused on exploring various techniques to improve accuracy and efficiency. The research highlights the use of conventional and deep learning methods for feature extraction and classification. Conventional techniques, such as statistical parameters, wavelet analysis, and entropy analysis, have been widely employed, with SVM being the most commonly used standalone technique, while hybrid techniques have also been extensively investigated. On the other hand, there has been a noticeable shift towards deep learning approaches, particularly from 2014 onwards, with an increasing percentage of published articles focusing on deep learning models. Researchers have demonstrated the effectiveness of deep learning algorithms, such as convolutional neural networks (CNNs) and long short-term memory (LSTM) networks, in automatically detecting and classifying epileptic seizures. The surge in attention towards deep learning models reflects a growing interest in exploring the potential of these advanced techniques. Overall, the this research provides a comprehensive overview of the evolving landscape of epileptic seizure detection and classification, shedding light on the increasing adoption of deep learning models, the challenges within the field, and the significance of standardization in ensuring accurate and reliable comparisons across studies.

Afrakhteh, Sajjad & Mosavi, M. (2020) [3], in their research study, revealed, the integration of Evolutionary Algorithms (EA) with Common Spatial Patterns (CSP) has been shown to markedly enhance system precision. This hybrid approach significantly outperforms the use of CSP alone. The combination of EA and CSP not only boosts the accuracy of the system but also introduces a higher degree of complexity. This finding underscores the trade-off between achieving superior precision and managing the increased computational demands associated with the integrated method.

Saidi, Afef & Ben Othman, Slim & Kacem, Wafa & Ben Saoud, Slim. (2018), [4] In their paper while analysing the EEG Signal to detect Epileptic Seizure, discussed the development and implementation of a system for detecting epileptic seizures through the analysis of electroencephalogram (EEG) signals. The work is organized into six sections, covering related works in the field, the proposed method, system design and implementation, architecture optimization, implementation results, and conclusion. The authors describe the challenges of epileptic seizure detection and propose an approach based on a classification algorithm, AntMiner+, and its implementation on the Xilinx ZC702 embedded board. They discussed the system's functionality, including EEG signal recording, data preprocessing, feature extraction, and classification. The authors present the details of the hardware and software design, as well as the optimization of memory occupation for the program. The paper also includes experimental results, such as filtering and wavelet decomposition, and the implementation of the classification model using the AntMiner+ algorithm, achieving an accuracy of 98.9%. The authors conclude by highlighting the contributions of their work and proposing future improvements, such as the implementation of more classification methods like ANN or SVM. The paper provides a comprehensive overview of the development and implementation of an EEG signal analysis system for epileptic seizure detection. The authors detail the proposed method, system design, and architecture optimization, followed by the presentation of implementation results and conclusions. Their work demonstrates the successful execution of the system on an embedded board, achieving accurate classification results for epileptic seizures. The paper also suggests potential directions for future research, such as the incorporation of more complex classification methods to further enhance the system's capabilities.

Paul, Yash. (2018) [5] asserted that Epilepsy is a chronic disease that affects more than 2% of the world's population, with 85% of patients in developing countries. A seizure is a short-term abnormality in the electrical activity of the brain that causes physical symptoms such as decreased concentration and memory. Approximately one-third of patients experience recurrent seizures despite treatment with various antiepileptic drugs. The number of people aged 65 and over in the EU is expected to increase from 16.4% (2004) to 29.9% (2050), while other countries are also expected to see further increases by 2050.), empirical type decomposition and rational function technology. The aim of this review is to present the latest methods and techniques that can contribute to future research in epilepsy research. Seizures are generally divided into generalized or localized and localized or localized. An automatic epilepsy diagnosis machine needs to be developed to prevent many dangers that epilepsy patients may encounter. Because capturing electrical signals from the brain (iEEG) is dangerous and requires expertise, most research is done using scalp electroencephalography. Domains: time domain, frequency domain, wavelet domain (time-frequency), empirical mode decomposition (EMD), and rational transformation domain. Most discussion techniques are non-invasive and use sensitivity, specificity, and vulnerability to measure performance. The article also discusses the use of other biomedical signals such as the electrocardiogram (ECG), electrocorticogram (ECoG), or different combinations of signals to detect seizures. The effectiveness of epilepsy detection depends on parameters such as the transformation process, selection of features, separation, size, type of window or main wavelet, decomposition level of the first light red, and optimization algorithm. The article also tries to determine which parameters are relevant to the algorithm to improve the current epilepsy diagnostic method.

Supervised learning algorithms have been widely used in the early detection of epileptic events. These algorithms require labeled training data, where EEG signals are annotated with information about the presence or absence of seizures. Common supervised learning techniques include support vector machines (SVM), decision trees, and neural networks. Support Vector Machines (SVM): SVMs have been employed to classify EEG segments as preictal (before a seizure) or interictal (between seizures). Studies have shown that SVMs can achieve high accuracy when feature extraction techniques are galvanized with techniques comprising wavelet transforms **(Shoeb & Guttag, 2010).** [6]

(Zeng, Wei & et al 2023) [7] is trying to develop a new method that can detect seizures using electroencephalogram (EEG) signals. Researchers developed a deep neural network (DNN) model while extracting features of EEG input from raw data. Deep maps derived from hierarchically placed layers in convolutional networks are fed into different types of shallow classifiers to detect anomalies. Reduce the size of feature maps using principal component analysis (PCA). The of the study reveals that the proposed method is both efficient and robust and outperforms other state-of-the-art methods. A widely used test uses a 10-fold cross-validation strategy to show nearly 100% accuracy for binary and multi-class classification. The results also demonstrate that the model can also be used in medicine. EEG signals recorded using metal electrodes provide information about the state of the brain and can be used to diagnose seizures in a non-invasive and cost-effective manner. Traditionally, diagnosis was based on visual inspection and data analysis of electroencephalogram data by certified medical professionals; This is a tedious, subjective and error-prone process. To solve this problem, many tools ranging from signal processing to artificial intelligence have been rapidly developed and used in recent years. Diagnosis of epilepsy using EEG has two stages: isolation and classification. In the first stage, a large number of characteristics created by the quartet of time, frequency, time-frequency and nonlinearity are combined. Time-frequency domain analysis methods such as time-frequency dispersion and wavelet transform are used to analyze the time-varying properties of EEG signals. In the field of nonlinearity, complex measures are proposed to account for the nonlinearity of EEG signals. Machine learning algorithms such as neural networks and logistic regression have been applied to extract EEG signal features. Various classifiers have been used to identify these activities, including naive Bayes, multilayer perceptron, k-nearest neighbors, and support vector machines.Neural Networks: Deep learning models, particularly convolutional neural networks (CNNs) and recurrent neural networks (RNNs), have demonstrated significant potential in seizure prediction. CNNs are effective in extracting spatial features from EEG data, while RNNs capture temporal dependencies **(Thodoroff, Pineau, & Lim, 2016).**

1.4 Unsupervised Learning

Unsupervised learning approaches do not require labelled data and are useful for detecting novel patterns in EEG signals. Clustering algorithms and anomaly detection methods fall under this category. Clustering: Techniques like k-means clustering have been used to group EEG data into clusters representing different brain states. This can help identify transitions leading to seizures **(Mirowski et al., 2009).** [8]

Anomaly Detection: Autoencoders and other neural network-based anomaly detection methods have been applied to identify unusual EEG patterns that precede seizures **(Golmohammadi et al., 2018).** [9]

1.5 Data Types and Feature Extraction

The effectiveness of ML algorithms in seizure prediction largely depends on the quality and type of data used. EEG signals are the most commonly utilized data type, but other sources such as functional MRI and genetic data are also explored.

EEG Signals: EEG data provides a direct measure of brain activity, making it highly relevant for seizure prediction. Features such as amplitude, frequency, and wavelet coefficients are extracted from EEG signals to train ML models.

Imaging Data: Functional MRI (fMRI) and magnetoencephalography (MEG) offer additional insights into brain activity. Combining EEG with imaging data can enhance the accuracy of seizure prediction models **(Douw et al., 2010).** [10]

1.6 Performance Metrics

Evaluating the performance of ML-based seizure prediction models involves several metrics, including accuracy, sensitivity, specificity, and false prediction rate (FPR).

- **Accuracy**: Measures the overall correctness of the model's predictions.
- **Sensitivity:** Indicates the model's ability to correctly identify preictal states.
- **Specificity:** Reflects the model's ability to recognize interictal states.
- **False Prediction Rate (FPR):** The rate at which the model incorrectly predicts a seizure.

Thodoroff et al. (2016) [11] achieved high sensitivity and specificity with deep learning models. However, the challenge of high false prediction rates and the need for extensive computational resources remain significant hurdles.

(Karpov, Oleg & et el., 2023) [12] in their research titled "Evaluation of Unsupervised Anomaly Detection Techniques in Labelling Epileptic Seizures on Human EEG" discusses the application of unsupervised anomaly detection algorithms in the labelling of epileptic seizures on electroencephalograms (EEG). The study highlights the challenges associated with traditional machine learning approaches in processing EEG data due to the artefacts caused by head movements and eye blinks, and the rare nature of epileptic seizures, making their diagnostics in hospital settings complex. The authors suggest using unsupervised anomaly detection algorithms to address these challenges as they require minimal pre-processing. The study evaluates the performance of outlier detection algorithms in detecting seizures, showing promising results with 100% recall, albeit with precision barely exceeding 30%. The authors propose that the outlier detection algorithms could be used for rapid analysis of EEG to save time and effort for experts.

This study elucidates about the visual search methods, including one-class support vector machine (OCSVM), k-nearest neighbor (kNN), local nearest neighbor (LNND), local outlier factor (LOF), and isolated forest (IF). Includes evaluation. The authors tested these algorithms using EEG data from patients diagnosed with partial-onset epilepsy and found that the four learned components of the LNND explained 90% of the spectral power variance in the frequency of 1-30 Hz, achieving the best performance-based approach. especially when combined with principal component analysis (PCA). The impact of separation. Research has shown that spatial patterns affect the distance between clusters and that approximate separation can predict algorithm performance. These findings provide good insight into the effectiveness of the most accurate detection methods for detecting epilepsy and demonstrate the potential of remote methods in carrying out these studies in an intensive manner. The results of this study are consistent with modern studies that propose new methods to detect epilepsy in EEG signals using different monitoring methods of machine learning. This study provides a comprehensive evaluation of non-visual anomaly detection techniques in human EEG epileptic seizures, demonstrating the potential of remote methods to accomplish this task, particularly in combination with PCA. These findings provide insights into the development of efficient and effective computer-based tools for epilepsy diagnosis, with the potential to reduce the burden of interpretation and improve patient care.

1.7 Conclusion

Epilepsy, characterized by recurrent and unprovoked seizures, significantly impacts the high priority enriched quality of life for millions of individuals globally. Traditional methods for seizure detection, primarily reliant on EEG and clinical observation, are limited by their accuracy, real-time monitoring capabilities, and the complexity of data interpretation. The advent of machine learning (ML) has revolutionized epilepsy research, offering new possibilities for early detection and prediction of epileptic events. ML algorithms, particularly supervised learning models like support vector machines (SVMs), neural networks, and deep learning techniques such CNNs and RNNs, have confirmed noteworthy probability in accurately forecasting seizures by analysing vast and complex EEG data. These models can identify subtle patterns and biomarkers that precede seizures, enabling timely and personalized interventions that can mitigate the impact of seizures on patients. Future work should focus on improving model interpretability, standardizing data protocols, and ensuring the generalizability and scalability of ML models.

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