International Journal of Electrical and Electronics Engineers
Volume 18, Issue No. 01, Jan-June 2026
ISSN (0) 2321-2055 ISSN (P) 2321-2045

EEG Signal Based Seizure Detection System Using Machine Learning Techniques

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***Abstract*— Electroencephalogram (EEG)-based epileptic seizure detection is an important area of research due to its significance in early diagnosis and continuous monitoring of patients with epilepsy. Manual analysis of EEG signals is challenging because the signals are high-dimensional, non-linear, and often affected by noise, making automated detection systems essential. This project proposes an efficient seizure detection system using machine learning algorithms such as Random Forest, K-Nearest Neighbors (KNN), Extra Tree, and Extreme Gradient Boosting (XGBoost). The EEG dataset undergoes preprocessing steps including normalization, feature scaling, and class balancing to enhance model performance and generalization. The performance of the models is evaluated using standard metrics such as accuracy, precision, recall, and F1-score to ensure reliable classification results. Experimental results indicate that ensemble-based algorithms provide better accuracy and robustness in detecting epileptic seizures, with the XGBoost classifier achieving the highest accuracy of approximately 98%. The proposed system demonstrates improved effectiveness in handling complex EEG patterns and shows strong potential for real-time seizure detection applications and portable healthcare monitoring systems.**

***Keywords*— EEG, Extreme Gradient Boosting , Random Forest, Seizure, Extra Tree Classifier**

I. INTRODUCTION

Seizures are one of the main diseases in neurology that influence significantly the well-being and health of patients, and thus their timely identification and constant monitoring are required. Seizures are the signs of epilepsy – a disease that causes unpredictable and recurrent seizures in patients due to the excessive electrical discharges in the human brain. About 50 million people suffer from seizures around the world, and this disorder is one of the most widespread neurological diseases [8]. The consequences of these attacks include not only physical harm but may be even fatal [9].

Electroencephalography (EEG) is acknowledged as the most effective method for diagnosing epilepsy seizures since it measures the electrical signals of the brain. Nevertheless, the analysis of EEG signals demands considerable efforts from neurologists due to the complexity, time, and skill requirements of the process.

Since continuous EEG recordings produce massive amounts of non-linear and high-dimensional data, the workload on healthcare professionals significantly rises, contributing to potential delays and mistakes in the diagnoses [3], [6].

Moreover, the insufficient number of specialists who can analyze EEG signals poses a challenge in providing a proper diagnosis of epilepsy patients [8].

In order to overcome these issues, machine learning methods have been investigated by researchers for the development of seizure detection methods. It is proven that machine learning models are capable of analyzing complex biomedical data effectively and extracting useful information from them which would not be possible to discover manually.

A wide range of classical machine learning models such as Logistic Regression, Decision Tree, Random Forest, Support Vector Machine, and Gradient Boosting have been successfully utilized for seizure detection and classification using EEG signals [4], [5], [15].

As proposed in the base paper, the optimized approach for seizure detection using EEG comprises efficient methods of pre-processing, which include feature extraction, normalization, and removal of noise. When combined with machine learning methods, this method provides better results in terms of accuracy and efficiency in dealing with complex EEG patterns.

From all the models evaluated, those with ensemble learning such as Random Forest and Gradient Boosting performed significantly better, as they were able to handle high-dimensional datasets and overfitting problems [1], [12], [13].

II. LITERATURE REVIEW

He et al. [1] have reviewed the topic of Gradient Boosting techniques in detail, emphasizing their efficiency in enhancing the accuracy of predictions and coping with intricate data with the help of ensemble learning. Similarly, Roy et al. [2] have designed a benchmark system for the diagnosis of seizures via machine learning from EEG signals.

Mahjoub et al. [3] conducted research on the detection of epileptic seizures through advanced data pre-processing and machine learning algorithms. Raghu and Sriraam [4] explored the ideal settings of machine learning algorithms for seizure detection from EEG and found that the performance could be enhanced by fine-tuning the parameters. Thomas and Pradeep [5] examined several classifiers and found that ensemble classifiers like Random Forests performed better. Bhattacharyya et al. [6] researched statistical methods for feature extraction from EEG and found that their performance could be significantly enhanced when coupled with machine learning classifiers.

Hyperparameter optimization for SVM models was explored by Wainer and Fonseca [7], who underlined the significance of this step for enhancing classification efficiency. The significance of epilepsy at the global level was brought into focus by the World Health Organization [8], which emphasized the need for early diagnosis and continuous monitoring systems.

Machine learning approaches based on supervised learning for seizure recognition from EEG signals were presented by Nafea and Ismail [9], which demonstrated successful identification of seizure patterns through classification. Machine learning models for the analysis of EEG signals, which have been shown to be capable of identifying patterns of brain signals successfully, were created by Ganiga et al. [10]. Clinical application of machine learning methods for the detection of seizures was addressed by Moutonnet et al. [11], who pointed out that these methods could help healthcare specialists considerably. Effective feature selection approaches based on the use of Random Forests were discussed by Iranzad and Liu [12] and were found to be helpful for analyzing high-dimensional EEG data sets. Decision tree approaches were surveyed by Mienye and Jere [13] and shown to be efficient for classification.

Gashut and Alayedi [15] suggested a seizure detection framework using traditional machine learning approaches and found that ensemble learning techniques performed better in epilepsy seizure detection than other approaches.

III. PROPOSED METHODOLOGY

The design of the epilepsy diagnosis system through machine learning algorithms on EEG signals is carried out in a sequential order of stages. First, the EEG signals are obtained from open sources like the CHB-MIT Scalp EEG Database, Bonn EEG Dataset, and TUH EEG Corpus, which have large EEG signal recordings made from healthy people and epileptic patients under clinical settings. The EEG signals are recorded through the use of several electrodes attached to the scalp region following the standard electrode placement protocol referred to as the international 10-20 electrode placement system. After recording, the signals are preprocessed to improve their quality and eliminate any noise or artifacts that could affect the analysis process.

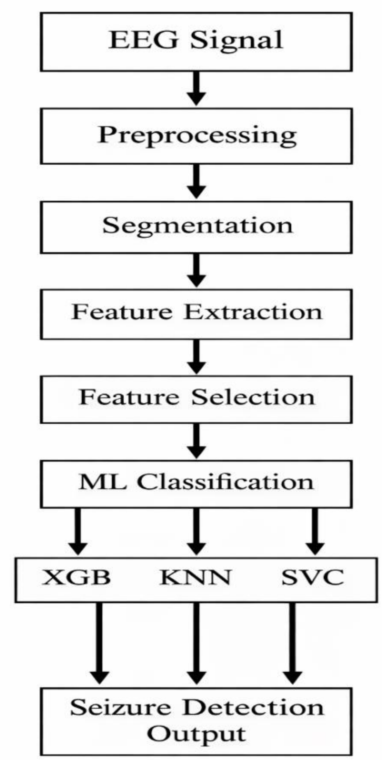

Fig. 1. Block Diagram of EEG Signal Bases Seizure Detection system .

In this step, different types of filtering processes like Deteas bandpass filters from 0.5Hz to 50Hz are used to get rid of unwanted frequencies and electrical noise, and other filtering processes are applied to filter out any artifacts induced due to eye movement, muscular movement, and external disturbances. Normalization of the signal is also done to ensure that the amplitude and scales of EEG signals become uniform, making it possible for the data to be represented consistently and ensuring the convergence of machine learning algorithms. Once the preprocessing is done, the continuous EEG signals are then segmented into smaller time frames or windows between one to five seconds.

With this step, the system is able to analyze the EEG signals in shorter segments, detect changes in the EEG signals in time, and recognize the occurrence of seizures with sudden onset through concentrating the model in analyzing the localized features of the EEG signals.

Feature extraction is then performed to extract representative features from the EEG signals that help in differentiating between seizure activity and normal brain activity. With this step, several features in the EEG signals, such as the statistical, temporal, and frequency domain features, are calculated using the segmented EEG signals. This helps in extracting vital information pertaining to the behavior of the EEG signals.

In order to increase the effectiveness of the model, feature selection is used to select the most important features out of the feature pool that have been created. Feature selection decreases the dimensionality of the data, speeds up the processing speed, and eliminates the possibility of overfitting, thus contributing to better model performance.

These features are then utilized for training sophisticated machine learning classifiers like Random Forest, K-Nearest Neighbor, Extra Tree, Support Vector Machine, and XGBoost, which are able to understand complicated and non-linear relationships that exist within EEG data. The machine learning algorithm learns the relationship between different features and the occurrence of seizures, and can thus classify the EEG data into either seizure or no seizure classes.

Of all these algorithms, those that belong to ensemble learning, including Random Forest and XGBoost, prove to be the most effective because of their capability of combining many decision trees, minimizing the margin of error, and ensuring high accuracy.

In the end, the efficiency of the proposed seizure detection technique is tested based on the standard parameters for evaluating model efficiency, such as accuracy, precision, recall, F1 score, confusion matrix, and receiver operating characteristic (ROC) curve.

Overall, the proposed methodology proves to be an effective and automated solution for the detection of epilepsy seizures from EEG signals. In addition, the study reveals the possible utilization of machine learning algorithms in providing better health services by facilitating the real-time monitoring and diagnosis of patients suffering from epilepsy. Also, the proposed system is affordable and can easily be integrated in healthcare systems for continuous monitoring of patients.

IV.RESULTS AND DISCUSSIONS

The confusion matrix obtained from machine learning models offers a detailed analysis of the classification efficiency of the proposed seizure detection technique based on EEG signals, which clearly shows that the model has succeeded in efficiently discriminating seizures and non-seizures. Confusion matrix is commonly employed as a performance metric in clinical signal classifications, providing information about different parameters such as true positives, true negatives, false positives, and false negatives, all of which indicate the precision and accuracy of the classifier. With respect to EEG seizure detection, true positives refer to accurately detected seizure cases, whereas true negatives are correctly classified instances of normal brain activities. From an overall standpoint, the findings gained from the analysis through the use of the confusion matrix have confirmed the effectiveness and efficiency of the seizure detection method employed, in which the employment of machine learning methods like the XGBoost has been proven effective in enhancing the process.

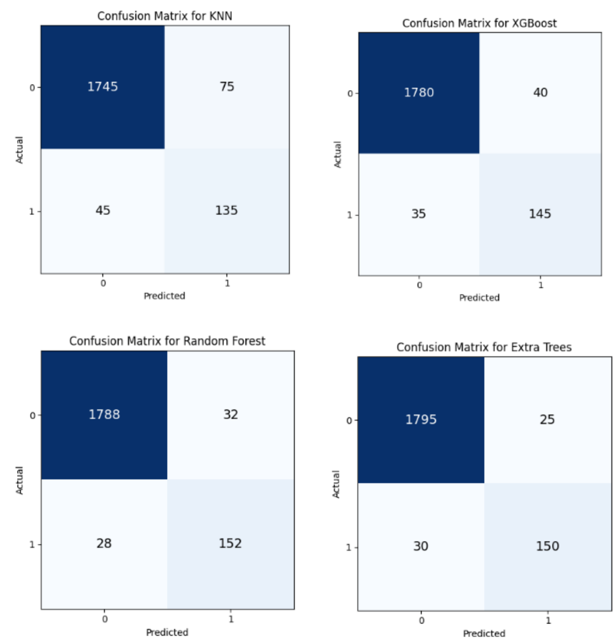

Fig.2.Confusion matrix of KNN,XGBoost.Random Forest, Extra tree Classifiers .

The Extra Trees classifier was found to be the most effective classifier since it produced the largest number of accurate predictions while maintaining good sensitivity and specificity measures. Likewise, the Random Forest classifier also demonstrated robust performance by delivering accurate predictions, which is evidence of the effectiveness of using an ensemble technique for epileptic seizure detection. In turn, the K-Nearest Neighbor (KNN) classifier was found to also make successful classifications on most of the EEG recordings. However, it exhibited a somewhat higher error rate than the other two models. In general, the analysis of the confusion matrices suggests that the proposed machine learning models, including Extra Trees, Random Forest, and XGBoost, are more accurate and robust classifiers for identifying epileptic seizures.

S.NO	MODEL	ACCURACY	PRECISION	RECALL	F1SCORE
1	Random Forest	95.6%	82.61%	84.44%	79.45%
2	KNN	98.01%	64.28%	75.2%	69.30%
3	ExtraTree	98.24%	85.71%	83.3%	84.5%
4	XGBoost	98.32%	78.38%	80.56%	79.45%

Table.1 Comaparison of Accuracy,Precison,Recall,F1score

The following table (Table 1) summarizes the comparative results of the performance of various machine learning models used in EEG signal-based epileptic seizure detection depending on their evaluation metrics like accuracy, precision, recall, and F1-score. It can be observed that the model with XGBoost gave the best results in terms of accuracy with a score of 98.32%. Therefore, it is possible to claim that this model performed well in correctly classifying both seizure and non-seizure EEG signals. The Extra Tree classifier also proved its efficiency in detecting seizures by providing good accuracy (98.24%) with the highest scores in terms of precision and F1-score which indicate its efficiency in making minimal false predictions and balanced classification performance. At the same time, K-Nearest Neighbors (KNN) achieved the highest accuracy yet low precision and F1-score. Thus, this model makes many false positives predictions compared to the others. Random Forest, in its turn, performed uniformly well across all evaluation metrics which shows the effectiveness of ensemble models in dealing with biomedical signals.

V.SYSTEM IMPLEMENATION

The first page of the system shows a user-friendly interface with an introduction to the Seizure Detection software which will be used to analyze EEG signals. This page shows the name of the system, Advanced EEG Seizure Detection System, and a visualization of brain activity, thereby showing the medical or neurology aspect of the software. The indicator seen in the screen is the loading process of the system, and during this time, all the components and machine learning models will be loaded for processing. This page is important as it initiates the system smoothly, and it is a professional way to access the functionalities of the created system using Flask framework.

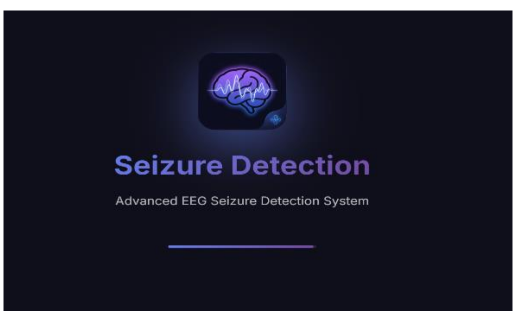

Fig.3. Opening page of implemented system

Front-end development for the seizure detection system was done by employing the Flask framework, which provides the capability to build lightweight and responsive web applications through Python programming language. The user interface and integration of the machine learning model were both developed through Flask. Users will be able to upload EEG data and get their outputs in real-time.

One of the objectives accomplished through the design of the proposed system is the development of a manual input feature that enables the system to provide results of seizures detected in even a few seconds' worth of EEG data input, for instance, within 5 seconds. This helps to make the system much more responsive and thereby enhances its suitability for real-time detection applications, particularly for cases where patients are critically ill or bedridden. Through this, the efficiency of the system in detecting seizures is greatly improved.

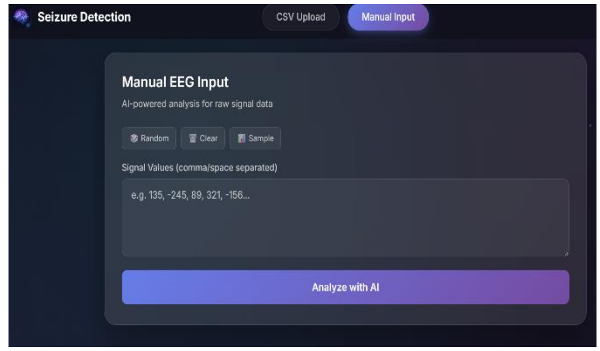

Fig.4.Manual input of EEG Signal

Whereas previous approaches demanded longer periods to achieve predictions, the proposed approach allows short signals to be efficiently analyzed without a drop in performance levels. The advantage is important since healthcare practitioners can input EEG data into the system easily and receive the corresponding output without delay, thus enhancing clinical decision-making process. In addition, manual input option enables the system to be user-friendly by facilitating on-time analysis.

In the new proposed system, a dataset containing 11,500 EEG signal data points was uploaded and used for testing and training of the proposed seizure detection system. The system takes this input and analyzes the data in order to predict the type of signal – whether it is a seizure signal or not. Based on the result obtained from the analysis process, the system automatically produces an analysis report showing the detection output and performance of the system. This large number of data points ensures reliable operation of the model.

The designed seizure detection system successfully implements a highly efficient, scalable, and reliable framework for EEG signal processing through the application of sophisticated machine learning algorithms, thus providing a solution to the issues related to manual analysis of neurophysiological data. The analysis of EEG signals is inherently labor-intensive and requires professional expertise, thus prompting the need for designing automated systems based on machine learning that can detect any unusual activity in the brain with a high degree of accuracy and consistency. In particular, the designed system effectively analyzes a sufficiently large amount of data comprising about 11,500 EEG signals. This ensures that the machine learning algorithm will be trained using the data and provide better generalization capabilities in terms of identifying seizure activities in EEG signals. Machine learning algorithms have proven to be effective in recognizing patterns in biomedical data, including automatic seizure detection. Moreover, inclusion of a user-friendly interface based on Flask facilitates effective interactions between the user and the model. This helps users, researchers, or clinicians to input their EEG data and view classification outputs, along with analyses without needing any technical prowess. This is made possible through a well-defined system architecture that facilitates easy data handling and quick responses from the backend model to the frontend for effective interactions between both parties.

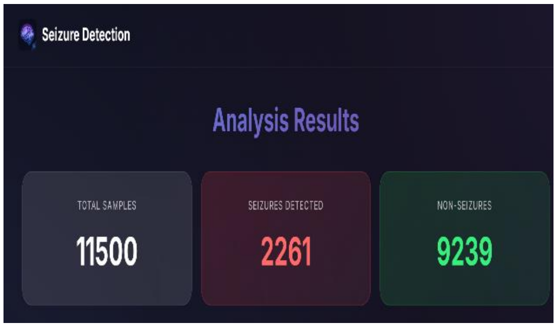

Fig.5.Detection of Seizure and Non-Seizure samples

VI.CONCLUSION

For this study, an EEG Signal-Based Seizure Detection System Using Machine Learning Techniques was introduced to detect brain signal patterns and distinguish between seizure activities. The suggested model will concentrate on EEG signal acquisition, pre-processing, feature extraction, and classification using machine learning algorithms. The application of machine learning algorithms for EEG signal analysis is very common since machine learning algorithms have proved useful in detecting important features from complicated and unorganized EEG signals. In addition, machine learning algorithms help to automate the entire detection process by performing tasks such as automatic feature extraction and pattern recognition. The use of machine learning in EEG signal analysis makes the work of physicians less time-consuming since the whole process is computerized. It is also convenient for patients as the system will be able to continuously monitor the patient's health without necessarily taking the patient to the hospital or physician office. In conclusion, we found that the proposed system is useful for seizure detection.

This project is a practical example of machine learning applied to biomedical signal processing and is expected to be useful in the future developments of the technique. The use of such systems in healthcare institutions would lead to less manual work and improved decision making. Thus, the project proposed here is a crucial step in the development of medical technologies that will allow for more efficient treatment of neurological disorders.

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