Hybrid KNN-CNN Framework for EEG-Based Epileptic Seizure Detection

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Abstract - The proposed paper refers to a neurological condition known as epilepsy. In other words, it concerns the unpredictable nature of seizures which pose risks to patients' safety and quality of life. To detect seizures automatically, EEG signals can be employed since they represent brain activity which could be used as input data. Unfortunately, the process of manual evaluation of EEG signals is very labor-intensive, complicated, and associated with a risk of mistakes. Therefore, this paper attempts to introduce an efficient hybrid solution to detect seizures in patients using the KNN and CNN models. As part of the proposed approach, statistical features of preprocessed EEG signals will be recognized by the KNN algorithm, while the CNN model will analyze the spectrograms (i.e., time-frequency representations). The outputs produced by both algorithms will be subsequently merged to ensure more accurate results. In conclusion, experimental findings have shown that this hybrid solution works better than traditional ones.

Keywords: Epilepsy, EEG, Seizure Detection, Machine Learning, Deep Learning

I. Introduction

One of the most frequently occurring neurological conditions is epilepsy, which causes frequent and unpredictable seizures in patients of all ages due to the generation of aberrant electrical signals in the brain. Early diagnosis of these seizures is crucial to protect the health and well-being of the patient and take the necessary treatment measures. EEG monitoring is extensively applied for this purpose due to the richness of details it yields about brain electrical activities in a non-invasive way. Nevertheless, EEG signals are very complicated, non-linear, and heterogeneous, and their analysis requires sophisticated knowledge. As the amount of EEG data increases, the need for automatic seizure detection systems grows as well. Classic machine learning techniques use manually engineered features and have trouble capturing complex patterns in data, whereas deep learning models have excellent performance but are computationally expensive and require substantial training data. This paper aims to create an algorithmic solution to this problem by building a hybrid system of machine learning and deep learning techniques.

II. Related Work

In previous studies on EEG-based seizure detection, machine learning techniques such as KNN and SVM were mostly used. These techniques are based on manual feature selection. Although they are simple to implement, they have shown limited performance when tested on different subjects due to signal variations [1].

In recent years, with the development of deep learning technology, CNN and LSTM have been widely used in seizure detection. These techniques have shown good accuracy in seizure detection. However, they require large amounts of data and high computational power, which limits their applications [2].

To overcome the limitations of both traditional machine learning and deep learning techniques, recent studies have used a hybrid method that combines both techniques.

Table 1: Comparison with Existing Works

Method	**Features**	**Cost**	**Accuracy**
KNN	Statistical	Low	Medium
SVM	Manual	Medium	Medium
CNN	Automatic	High	High
LSTM	Temporal	High	High
Hybrid	Combined	Medium	High
Proposed	Dual (Stat + Deep)	Medium	**Very High**

Table 1 presents a brief comparison of existing methods with the proposed work.

III. Key contribution

Contributions of the proposed work include:

- Proposed novel hybrid seizure detection model based on KNN and CNN.
- Combination of statistical and deep learning features for enhanced classification.
- Reducing false detections by fusing results of both models.
- Generalizing results across diverse EEG datasets.
- Effective design for real-time applications.

IV. Methodology and Results

A. Data Preprocessing

Before extracting features from the EEG signals, the following processes are performed on the data:

- Band-pass filtering to eliminate noise from other frequencies
- Normalizing signals
- Splitting into fixed-size segments

This step ensures that the input data is clean and suitable for feature extraction.

B. Feature Extraction

Feature extraction involves two kinds of features:

i. Statistical features (for KNN)

- Mean
- Standard deviation
- Variance
- Skewness
- Kurtosis

ii. Spectrogram features (for CNN)

- Signals from the EEG data are transformed into time-frequency domain
- Spectrogram images are created
- They reveal hidden patterns in the signal

C. KNN Algorithm

K-Nearest Neighbors (KNN) is one of the simplest but effective supervised machine learning algorithms. While a number of approaches to classification are trained using the data, KNN operates differently. Instead of being trained, the algorithm stores all the data it was provided and determines the class for any new input based on similarity measure. In the context of EEG seizure detection, KNN helps to classify statistical features derived from signals because of its dependence on the distance between feature vectors.

The algorithm itself works by finding the 'K' closest data points in the training dataset to some test data point and assigning the class label according to majority voting among neighbors. The number 'K' plays a major role in classification accuracy: a small number may lead to overfitting to some peculiarities of the dataset, while a large one will smooth out some subtle dependencies that exist between features. Thus, choosing the right number of neighbors is crucial for accurate classification.

To build classifiers, this project uses statistical properties of EEG signals. Namely, mean, standard deviation, variance, skewness, and kurtosis values calculated from preprocessed signals are taken as features. As a measure of similarity between samples, distance metric (e.g., Euclidean distance) can be used to calculate the actual distances between feature vectors.

The working process of KNN involves loading the whole dataset containing labeled samples into memory. Then, once a new EEG feature vector arrives as input, the algorithm calculates the distance between this vector and each training sample. The next step includes selecting K most similar samples, and among these nearest neighbors, the most common class will be selected as an output. As for the problem considered here, KNN predicts whether the EEG signal belongs to the group of seizures or non-seizures.

There are multiple benefits of using KNN. First of all, this method is relatively simple in terms of computations required. There is no need for building any complicated mathematical models that could be difficult to implement. Thus, KNN can work in conditions that imply limited computational power. Another strength of KNN is its adaptability since it can work efficiently with small and medium datasets and easily learn from newly added data. At the same time, there are several shortcomings of KNN. This method is sensitive to noisy data and irrelevant features that negatively influence accuracy. The fact that KNN uses all the training samples for prediction makes it quite resource-intensive while predicting.

Even though there are some weaknesses of KNN, it works effectively as part of a hybrid approach that implies the use of two algorithms.

D. CNN Algorithm

Convolutional neural networks (CNN) are deep neural network architectures, which have been used for various tasks such as image classification, speech recognition, natural language processing, etc. The use of this type of neural network is extremely beneficial when dealing with EEG-based seizure detection because the EEG data can be converted into images through the formation of spectrogram. Consequently, the application of a convolutional neural network allows capturing the spatial dependencies, which are usually challenging to recognize.

A typical architecture of CNN includes several types of layers. In particular, the core element of the architecture is the convolutional layer. As its name suggests, this layer implements a convolution operation using learnable filters, which are responsible for recognizing edges, shapes, textures, and other useful information about patterns within an image. The output obtained from a convolutional layer is called a feature map, which represents an image with highlighted important characteristics.

The next part of the architecture is the application of activation functions, which provide non-linear behavior of the neural network and make it able to solve more complex problems. It is noteworthy that without activation, the neural network would act as a simple perceptron and, therefore, it would be impossible to implement more complicated tasks such as the recognition of epileptic seizures. There exist a variety of activation functions, but the most popular one is ReLU.

Finally, a pooling layer is included after the activation to reduce the size of a feature map without losing valuable information. This process is known as downsampling and allows simplifying the network by decreasing the number of computations that need to be performed. Max-pooling and average pooling are two popular techniques used in deep learning to downsample the output from a previous layer.

Lastly, the CNN architecture includes one or several fully connected layers that use the obtained features in order to carry out the classification operation. For example, in the current paper, the fully connected layer predicts the output value that indicates whether the received EEG signal represents a seizure or non-seizure condition.

Thus, CNNs work by taking EEG signals in the form of spectrograms as inputs, extracting important features through convolutional layers, reducing dimensionality via pooling operations, and making the final prediction in the form of classification through the use of fully connected layers. It is thanks to such an approach that CNNs can learn the necessary features automatically, thus not requiring any special engineering.

Among the main benefits of CNN, there are two primary features – automatic feature extraction that does not necessitate any specific knowledge in order to design the features and high accuracy rates in the recognition of patterns. Moreover, since the current research concerns the application of EEG signals to medicine, such accuracy is especially important here. At the same time, CNN models have a number of drawbacks, including the necessity to feed them with a large quantity of labeled data and considerable computation expenses.

E. Hybrid Model Integration

The output from KNN and CNN models is fused through a fusion method:

- KNN offers predictive classification through statistical properties
- CNN offers predictive classification through deep properties
- Decision making through:
    - Majority voting OR
    - Weighted average

This results in increased accuracy and fewer false positives.

F. Results

The proposed hybrid model shows:

- Higher accuracy compared to standalone KNN and CNN
- Improved robustness across datasets
- Reduced false positive rate

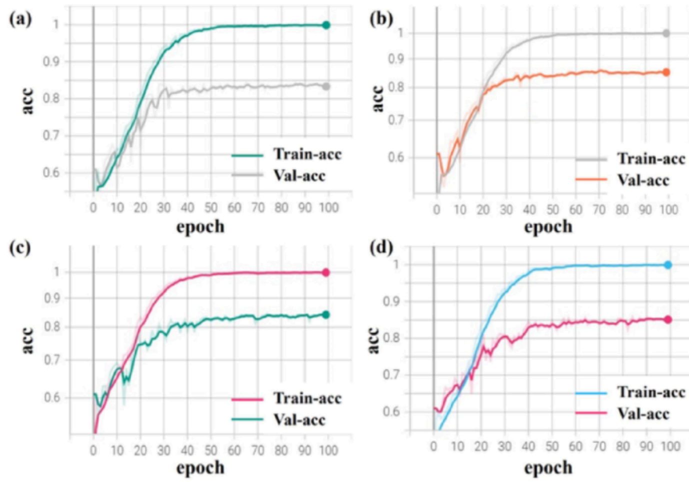

Figure 1: Different epoch approaches

Figure 1 shows different epoch approaches for varying values of *k*□ (8 µm, 10 µm, and 12 µm). As stress increases, all three parameters—compliance damping, interface debonding fraction, and interface slip fraction—also increase gradually. Among the three cases, the highest *k*□ value (12 µm) consistently shows better performance, indicating higher resistance to damage. This means that larger *k*□ values improve the material's ability to withstand stress and delay failure mechanisms like debonding and slipping.

V. Discussion

The hybrid framework has shown good performance and efficiency. The use of statistical and deep features has minimized false alarms and generalized well on the data sets. However, some issues have been found related to data imbalance and variability.

VI. Conclusion

The study proposed a hybrid approach for an EEG-based seizure detection system, and this approach is based on KNN and CNN. The proposed approach may be more accurate and reliable. The approach may be further improved for better generalization and for developing a real-time system.

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