Epileptic seizure is one of the most chronic neurological diseases that instantaneously disrupts the lifestyle of affected individuals. Toward developing novel and efficient technology for epileptic seizure management, recent diagnostic approaches have focused on developing machine/deep learning model (ML/DL)-based electroencephalogram (EEG) methods. Importantly, EEG’s noninvasiveness and ability to offer repeated patterns of epileptic-related electrophysiological information have motivated the development of varied ML/DL algorithms for epileptic seizure diagnosis in the recent years. However, EEG’s low amplitude and nonstationary characteristics make it difficult for existing ML/DL models to achieve a consistent and satisfactory diagnosis outcome, especially in clinical settings, where environmental factors could hardly be avoided. Though several recent works have explored the use of EEG-based ML/DL methods and statistical feature for seizure diagnosis, it is unclear what the advantages and limitations of these works are, which might preclude the advancement of research and development in the field of epileptic seizure diagnosis and appropriate criteria for selecting ML/DL models and statistical feature extraction methods for EEG-based epileptic seizure diagnosis. Therefore, this paper attempts to bridge this research gap by conducting an extensive systematic review on the recent developments of EEG-based ML/DL technologies for epileptic seizure diagnosis. In the review, current development in seizure diagnosis, various statistical feature extraction methods, ML/DL models, their performances, limitations, and core challenges as applied in EEG-based epileptic seizure diagnosis were meticulously reviewed and compared. In addition, proper criteria for selecting appropriate and efficient feature extraction techniques and ML/DL models for epileptic seizure diagnosis were also discussed. Findings from this study will aid researchers in deciding the most efficient ML/DL models with optimal feature extraction methods to improve the performance of EEG-based epileptic seizure detection.

1. Introduction

Epileptic seizure is a well-known chronic neurological and noncommunicable disease, occurring in 4% to 16% of organ recipients and affecting between 60–70 million people worldwide [1]. Epilepsy can be observed at any age, with a higher incidence in infants and the elderly. Every year, around three million people are affected by this disease...
An epileptic seizure is a sudden abnormality in the brain’s electrical activities, manifesting as excessive discharges of neuronal networks in the cerebral cortex and affecting the whole body [2]. It should be noted that the prediction of a seizure is hard, and for some patients, there may be hundreds of seizures in only one day, which may cause irreversible damage to the brain. Therefore, the timely detection and treatment of epilepsy are of great significance to control the development of the disease and improve the life quality of the patients. The most common causes include the shortage of oxygen during childbirth, malformations of organs, and low blood pressure [3, 4]. EEG (Electroencephalogram) is a method that records the neural electrophysiological activity of the brain by applying several electrodes over the subject’s head with some criteria. EEG with different waveforms reflects different frequencies. By comparing, clinicians can diagnose some diseases related to the neural system. Several studies about epilepsy monitoring have been carried out based on electroencephalography (EEG) [5, 6], magnetoencephalography (MEG) [6], positron emission tomography (PET) [7], single-photon emission computed tomography (SPECT) [8], functional magnetic resonance imaging (fMRI) [5], electrocorticography (ECoG) [9], and functional near-infrared spectroscopy (fNIRS) [9]. Compared to other techniques used in epilepsy, EEG signal devices are portable and economical, with their recordings being time-domain, and they can be transformed into frequency domain. EEG signals are produced by ionic currents from the variations in voltage coming from the brain’s neurons, which show the brain’s electric activity and are widely used in epileptic seizure detection [10, 11].

As shown in Figure 1, neuro-experts have categorized seizures based on the symptoms into two major categories, partial and generalized [4, 12]. A partial seizure can be defined by its symptoms, mainly caused by the affecting on the cerebral hemisphere.

Moreover, a partial seizure can also be divided into two main groups: simple-partial and complex-partial. In the simple-partial, the person looks conscious and can generally communicate, while in the complex-partial, the patients behave abnormally, get confused, and typically act by chewing and mumbling. A generalized seizure also has two main parts. Nonconclusive seizure is diagnosed by obvious motor signs, while conclusive seizures are difficult to diagnose for having no motor signs. The person can only stare and not make additional motions or moments [12, 13]. In the epileptic seizure detection task, the neurologists analyze and diagnose the information reflected from EEG signals, such as the waveform, frequency, and amplitude, since EEG signals in a seizure will manifest some special indications like spikes. However, realizing the efficient detection of epilepsy seizures is frequently a time-consuming and exhausting task with the high possibility of human error, relying on clinicians’ visual inspection. To be more specific, the limitations of manual epilepsy diagnosis can be listed as follows:

(1) It requires the physicians to have plenty of experience in clinical diagnosis and professional skills, making it more subjective and possible for misdiagnosis. Besides, different clinicians may draw an inconsistent conclusion over the same EEG signals based on their experience [4].

(2) EEG signals are weak electrophysiological signals, which means they are easily interfered with by noises and have a sharp decrease in their signal-to-noise ratio (SNR). EEG signals submerged in noise might have some changes in their waveform and make it difficult to diagnose [12].

(3) The amount of EEG signals used to make a diagnosis of epilepsy is large. In the clinical setting, the EEG signals are usually recorded synchronously with video signals to help diagnose using some behavior indications, which further increases the clinicians’ workload. It takes clinicians at least 16 hours to go through the EEG signals of the patients and make the diagnosis [11]. In clinical setting, the interruption of reviewing EEG signals and the heavy work load tremendously affect the clinician’s judgments on the signals, which may cause misdiagnosis [13].

Based on the aforementioned limitation, finding a technique to solve those problems is worthwhile and important. With artificial intelligence (AI) development, computer-based prediction techniques, including machine/deep learning classifiers, may alleviate these challenges. In recent years, machine/deep learning techniques have been widely used in the clinical diagnosis of diseases, especially in the application of epileptic seizures. These machine/deep learning techniques greatly free the clinicians from the heavy workload, significantly improve the diagnosis efficiency, and provide an objective and accurate diagnosis. Moreover, the number of studies in this area using machine/deep learning (ML/DL) keeps growing rapidly.

The keywords “EEG,” “Epilepsy,” “Epileptic Seizures,” “Deep Learning,” and “Machine Learning” were exploited to search articles. The keywords were searched in several citation databases, including IEEE, PubMed, Elsevier, Springer, Wiley, and ArXiv. In addition, Google Scholar was also utilized for further search. Figure 2 shows the number of articles that have been accepted into each citation database. It has been noticed that IEEE, Elsevier, and Springer citation databases included the most accepted articles. Initially, 400 accepted research articles were found in search engines. After keywords and title searches in each citation database, 200 articles were found.

Furthermore, full-text searches were conducted manually to select the best-accepted articles for review, 150 best potential articles were presented for the comprehensive review, and 50 articles were excluded. The first excluded criterion was the non-English articles. While the second excluded criterion represents the articles without availability of the performance metrics (accuracy, pre, sens, and spec), as shown in Figure 3.

In this paper, the main contribution is divided into four parts and is discussed as follows:

(1) We have accomplished a comprehensive review of the three key dimensions. Firstly, the analysis of the statistical features and extraction methods of EEG...
signals in epilepsy seizures were achieved. Secondly, a systematic review of machine/deep learning models was conducted, including their performance, limitations, and associated challenges in epilepsy seizure datasets. Thirdly, we investigated the performance achieved by machine/deep learning models based on the logical results during adequate detection.

(2) Throughout the research, we have found that a random forest model is more effective and efficient than other classifiers based on the adequate detection, and the random forest model handles high dimensional of the dataset and retrieves sensible information.

(3) For further analysis, we have selected the time-domain feature extraction method with 9-statistical features (standard deviation, kurtosis, skewness, energy, line length, entropy, mean, mode, and Hurst) because they help the machine/deep learning models to retrieve

Figure 1: The illustration of seizure types and their subtypes.

Figure 2: The proportions of accepted paper for the review using different citation database.
relevant knowledge and the best logical result (accuracy of 98–100%).

(4) The comprehensive review will help the researchers identify and use the most efficient machine/deep learning models with statistical feature extraction methods to improve the research in epileptic seizure detection.

The paper distributions are as follows: Section 2 shows a framework for seizure detection. Section 3 contains a detailed review of significant features and extraction methods, machine/deep learning models and challenges in seizure detection. Section 4 presents results and discussion.

2. Epilepsy Detection and Classification Process

The procedure for epilepsy seizure detection and classification is described as follows:

2.1. A Framework of Seizure Detection. We present a framework of seizure detection using an EEG seizure dataset in the given context. Four steps are needed to accomplish the seizure detection process, including data collection and preparation, feature extraction and selection, and machine/deep learning techniques to classify the seizure. The whole framework of epileptic seizure detection is given in Figure 4.

2.2. Data Collection. Firstly, one of the most important parts to achieve seizure detection is data collection. It can be obtained using an EEG monitoring device to collect the EEG signals of the brain. The EEG monitoring device locates the EEG cap on the scalp area presented in 10–20 international systems [14]. The monitoring device records the electrical signals from different electrodes or channels connected with wires to the scalp’s surface with various voltage and spatial information [15]. Moreover, these noisy EEG signals have been carefully investigated and monitored by the neuro-expert and categorized into ‘seizure’ and ‘non-seizure’ states.

2.3. Data Transformation. Data transformation is a difficult step after data collection, which converts the raw EEG signal data into a table format of 2-D. However, this relevant information is not sufficient for analysis to identify seizures. Various features' selection and modalities are applied to give precise information about a seizure.

2.4. Dataset Preparation. After successfully transforming the dataset (data transformation process), the next step is the preprocessing data phase. It is a data mining technique that transforms raw data into a meaningful and understandable format, removing null values, data reduction, and data cleaning of EEG seizure datasets [16].

2.5. Publicly Available Datasets. Using a dataset is crucial for data scientists and experts as it permits them to evaluate their proposed model’s performance. Publicly accessible
Datasets are very important because they offer a benchmark to analyze the results by comparing each dataset. There are many online existing epilepsy-related datasets, and most of the recent research prefers to use the mentioned datasets, which are further illustrated as follows:

2.5.1. CHB-MIT—EEG Dataset. This dataset is generated at Children’s Hospital Boston and the Massachusetts Institute of Technology (CHB-MIT) [17, 18] and is publicly accessible on a PhysioNet server. The dataset contains 23 patients: 5 men aged between 3 and 22 years and 17 girls aged from 1.5 to 19 years. Each patient has numerous seizure and nonseizure recording files in European data format (.edf).

2.5.2. Bonn University—EEG Dataset. This dataset is split into five files (A–E) and includes 100 single-channel recordings. Each file has a record of 23.6 s, while all the signals have equal 128 channels recorded using 10–20 international electrodes system [19].

2.5.3. Kaggle—EEG Dataset. The EEG dataset is part of the American Epilepsy Society’s epileptic seizures detection challenge. It includes intracranial EEG signals from five dogs and two people who had 48 seizures spanning 627 hours. The EEG signals of dogs were recorded using 16 implanted electrodes, which were sampled at 400 kHz. In comparison, the EEG signals of patients 1 and 2 were recorded using 15 deep electrodes and 24 subdural electrodes, sampled at 5 kHz [20].

2.5.4. Fribourg—EEG Dataset. This EEG dataset contains invasive EEG signals from 21 patients with refractory focal epilepsy monitored at the University Hospital of Fribourg’s epilepsy center before surgery. The signals were collected during presurgical epilepsy monitoring. The intracortical grid, strip, and depth electrodes were used to provide direct recording from the focal area, reduce artifacts, and achieve a higher signal-to-noise ratio (SNR) [21].

2.5.5. Bern Barcelona—EEG Dataset. The Barcelona database was compiled by the Bern Hospital’s brain department in Barcelona, including intracranial EEG recordings from individuals who have focal epilepsy. Subjects were followed for many days without the use of antiepileptic medications to evaluate whether they were having seizures or needed surgery. The signals were collected using intracortical electrodes from AD-Tech, with one additional reference electrode located between the PZ and FZ positions [22].

2.5.6. Zenodo—EEG Dataset. This dataset has multichannel EEG recordings of 79 human neonates recorded at Helsinki University Hospital, with an average recording length of 74 minutes. Three experts documented 460 seizures, 39 neonates were found to have seizures, and 22 neonates were seizure-free [23].

Table 1 contains a list of the additional information for each dataset. Figure 5 shows the number of each dataset used in epileptic seizures detection based on ML/DL techniques.

2.6. Feature Extraction and Selection Techniques Applied in Epilepsy Seizure Detection. Feature extraction is considered a core component of any pattern recognition system [24]. It
is mainly because the feature extraction process often adopts a mathematically driven algorithm that helps extract relevant information mostly from a raw dataset to better characterize the pattern of interest at any given point in time. In many cases, integrating a feature extraction component in a pattern recognition system often leads to a better performance in accurately distinguishing various patterns of interest and yielding such results faster than the direct usage of the raw data [24]. Therefore, it is necessary to adopt a feature extraction technique, and at the same time, choose the best technique since there are several kinds of features for characterizing physiological signals, and selecting efficient statistical features is required when facing a challenging task.

Fundamentally, there are two ways in which features are often extracted from the EEG signal of interest, namely handcrafted and automatic extraction. The handcrafted extraction features are multivariate [27] and univariate in both frequency and time domains. In contrast, automatic features include mean [28], kurtosis, skewness, entropy [28], Horthy parameters, statistical moments, and variance [29]. Meanwhile, the most commonly adopted feature that is widely implemented in EEG signal characterization includes time-domain (TD), time-frequency domain (TFD), frequency domain (FD), fourier transform (FT), discrete wavelet transform (DWT), and continuous wavelet transform (CWT)-based features [30]. Abbasi et al. introduced wavelet scalograms (WSs) feature extraction techniques with DL

| Dataset          | Recording          | No. of seizure | Sampling frequency | Times | No. of patients |
|------------------|--------------------|----------------|--------------------|-------|-----------------|
| CHB-MIT [18, 19] | Scalp EEG          | 163            | 256                | 844   | 22              |
| Bonn [20]        | Surface and IEEG   | NA             | 173.61             | 39 m  | 10              |
| Freiburg [22]    | IEEG               | 87             | 256                | 708   | 21              |
| Kaggle [21]      | IEEG               | 48             | 400/5 KHz          | 627   | 5 dogs, 2 patients |
| Zenodo [23, 24]  | Scalp EEG          | 460            | 256                | 74 m  | 79 neonatal     |
| Bern Barcelona [22] | IEEG            | 3750           | 512                | 83m   | 5               |

Table 1: Presents full description of publicly available EEG dataset datasets for epilepsy seizure detection.

Figure 5: Represents various datasets in different studies for epilepsy seizure detection using ML/DL techniques.
models to detect HI brain injury and got satisfactory results [31]. Logesparan et al. [32] used various statistical feature extraction methods on EEG datasets but concentrated on only two features, “relative power” and “line length,” which produced better performance in seizure detection. Amin et al. [33] introduced tritime domain approaches for features selection with statistical features, namely line length, frequency, and energy in epilepsy seizure detection. Q hey used CHB-MIT and BONN datasets to test the detection accuracy and reached 93–99% by calculating F-score, sensitivity, and specificity.

Besides, many researchers implemented a single feature in epileptic seizure detection [34–36]. For example, Guo et al. [37] tested a single feature “line length” with machine learning classifiers ANN to classify EEG signal recordings, and the accuracy was 95.6%. Koolan et al. [34] introduced “line length” as a feature to detect seizures with a specificity of 85% and a sensitivity of 84%. Some researchers used a single feature, “line length,” while others applied many convenient features. However, many researchers have utilized other statistical features, which resulted in lesser accuracy (%) and more computational time (sec).

After feature extraction, one of the essential tasks is choosing a collection of informative, small, and compact features that have improved discriminating power. These features serve as the basic blocks for tasks, such as detection, classification, and regression, in biomedical signal processing. They are also one of the most important stages in the data analysis process. Indeed, features are a novel way of representing data, and they may be binary, categorical, or continuous. For example, characteristics, such as the patient’s age, health condition, family history, electrode location, or EEG signal descriptors may be considered (voltage, frequency amplitude, phase, etc.). Therefore, it is suggested that the polynomial-based methods are used before applying machine-learning models to derive low-dimensional features. Usually, polynomial features aim to create/add new input features based on the existing features. The “degree” of the polynomial is used to control the number of features added, e.g., a degree of 3 will add two new variables for each input variable.

Different polynomial-based methods are available and may be used to decrease computation time and make more effective use of computer resources, which helps them become more popular [44]. Various efficient linear and nonlinear dimensionality reduction methods for feature selection in EEG-based epileptic seizure detection are shown in Table 2.

3. Comprehensive Review of Efficient ML/Deep Learning Classifiers

Various pieces of literature have introduced machine/deep learning models for epileptic seizure detection using EEG signals datasets [45, 46] with statistical features methods and nonlinear parameters. In machine/deep learning models [47–53], random forest classifier (nonblack-box) and support vector machine (SVM), k-nearest neighbor (K-NN), artificial neural networks (ANN), convolutional neural network (CNN), recurrent neural networks (RNN), and autoencoder (AE) (“black-box”) are considered for review because of their remarkable performances in seizure detection.

3.1. Black-Box Classifiers in Seizure Detection

3.1.1. Convolutional Neural Network (2D-CNN). CNN is a popular deep learning classifier to predict and diagnose medical diseases [54]. Initially, CNN was used for image classification [55]. However, recent 1D-CNN has been
modified to two-dimensional architectures, broadly used to apply epileptic seizures and to process the EEG signal. Table 3 presents a review of recent works that adopted 2D-CNN models to predict an epileptic seizure.

1D-CNN architecture is also a suitable choice for processing brain activity signals. Because 1D-CNN architecture requires less number of parameters; therefore, its detection time is less than 2D-CNN architecture but have worst classification performance. Therefore, 1D-CNN and 2D-CNN are capable of the diagnosis of epileptic seizures. Figure 7 shows the seizure detection accuracies of the various kinds of literature-implemented 2D-CNN models [66–68].

### 3.1.2. Recurrent Neural Networks (RNNs)

The sequential datasets, including videos, texts, and signals, have some characteristics, such as great length and variable, which is hard for a simple deep learning model to process [69]. RNNs model is widely used to overcome these challenges. RNNs are competitive models for processing biomedical signal data and receiving satisfactory results. The following section reviews RNN models commonly used in epileptic seizure detection with their corresponding accuracies.

The LSTM model was introduced after the RNNs drawbacks, short-term memory, and vanishing gradient [70–72]. Various pieces of literature using LSTM in seizure detection are available. Golmohammadi et al. [70] presented a 2-layer LSTM model and SoftMax function to evaluate the data and achieved 90% accuracy. The research of [73] demonstrated a 3-layer LSTM architecture model for classification and got satisfactory results, while the literature of [74] evaluated two hybrid models, GRU and LSTM, with the activator function. One of the layers is fully connected with a sigmoid activator in this network. The studies in [71–74] used 10 different architectures of RNN with 31 layers and got the best accuracy (95%). Table 4 and Figure 8 present a review of recent works that adopted LSTM-RNN models to predict an epileptic seizure.

### 3.1.3. CNN_RNN

It is competent to use two models for more accurate diagnosis and prediction of epileptic seizures, such as CNN-RNN architecture. The structure of RNN helps process sequential data (time-series processing). In the literature of [82], they applied various preprocessing schemes and used a modified CNN-LSTM with 13 layers along with the sigmoid activation function in their last layers with 91% accuracy. Roy et al. [83] introduced a hybrid architecture CNN-RNN to achieve the best results. Their first experimental works consist of 1-D with a 7-layer hybrid model of CNN-GRU, and the second work has 3-D and CNN-GRU hybrid architecture. An extended study by Ravi Prakash et al. [84] implemented four deep learning architectures, and the accuracy of these experiments achieved 90.60%. Table 5 and Figure 9 presented hybrid architectures (CNN-RNN) applied in different literature on epileptic seizures and their corresponding accuracies.

### 3.1.4. Autoencoders (AEs)

Autoencoder (AE) is an unsupervised machine learning model that presents different input parameters and works with the function (compression, de-compression) coupled with a neural network [88, 89]. The pieces of literature [45, 46, 90, 91] used multilayer autoencoders (MAE) to hybridize EM-PCA methods to reduce the dimensions for classification. They also implemented a genetic algorithm (GA), and the experimental results indicated an accuracy of up to 92.78%. Sharathappriya et al. [92] used stacked denoising AE (SDAE), which consisted of three layers of architecture. Qiu et al. [93] also introduced denoising sparse AE (DSpAE) and reported 95% accuracy. The study in [94] consisted of automated EEG with a machine learning-based system. This system has several parts: the first part extracted linear predictive cepstral coefficients (LPCC) as signal features. After that, three paths were used for accurate detection. They proposed SpAE to extract the feature from EEG, and SVM was used for the classification. Sharma et al. [48] achieved average accuracy up to 93.92%. Table 6 presented AE in seizure detection and performance metrics, and an illustration of the authors of various literature with their accuracies was shown in Figure 10.

### 3.1.5. Conventional ML (ANN, SVM, KNN)

Based on their significant performances, SVM, ANN, and KNN have also been applied in various domains [73, 104], especially in

| Feature selection methods | Description |
|---------------------------|-------------|
| [38] principal component analysis (PCA) | It was implemented to compress highly correlated features into a lower-dimensional subspace and use in various pattern recognition applications, including EEG signal classification |
| [39] T-distributed stochastic neighbor embedding (t-SNE) | Used to decrease the dimensionality of nonlinear data with a high-dimensionality of complexity to a lower-dimensional subspace. It is extensively utilized to present large amounts of high-dimensional biological data |
| [40] kernel principal component analysis (KPCA) | Used to handle the problem of nonlinear dimensionality reduction and useful for data compression using electroencephalogram (EEG) signals |
| [41] independent component analysis (ICA) | Process multivariate data representing the vast database samples as EEG signal is composed of various random signals |
| [42] locally linear embedding (LLE) [43] generalized discriminant analysis (GDA) | One of the most frequently utilized methods for extracting the nonlinear features uses the EEG signal. GDA is a highly effective method for extracting the nonlinear features of EEG signal data because generalized discriminants are calculated by mapping the training data in large dimensions of space using a kernel function |

**Table 2: Efficient polynomial-based methods for the features selection of EEG epileptic seizure detection.**
processing brain signal datasets. Various relevant works listed here on seizure detection used different classifiers. Most of the research articles preferred hybrid models. Dorai and Ponnambalam [105] proposed a hybrid model using SVM and KNN to classify these EEG epochs into seizure and nonseizure types. Birjandtalab et al. [106] implemented a Gaussian mixture model (GMM) to diagnose epileptic seizure detection. They achieved satisfactory results of accuracy and an F-measure of 85.1%. This experimental work addressed the class imbalance issue in the given dataset. A detailed review of SVM, ANN, and KNN in seizure detection is shown in Table 7. The literature of [119] recommended ANN classifiers on the EEG brain activity dataset with time-frequency domain features. The implemented classifiers accurately classify the signals into “nonseizure” and “seizure” with 95% accuracy. They used the EEG dataset class combination from A to E. The proposed study by Satapathy et al. [120] applied two models, SVM and neural networks (“black-box” approaches), to the EEG dataset for seizure detection. The outcomes of the given models indicated that

| Authors | Machine-learning approaches | Feature selection methods | Dataset | Performance metrics | Limitations | Accuracy (%) |
|---------|-----------------------------|--------------------------|---------|---------------------|-------------|--------------|
| Bizopoulos et al. [56] | SoftMax, standard networks | 2D and 3D phase space presents the intrinsic mode and functions | BONN | Overall accuracy | Low detection accuracy | 85.30 |
| Antoniades et al. [57] | LR, 2D-CNN | Time-domain | BONN | Overall accuracy | — | 87.50 |
| Park et al. [58] | SoftMax, 2D-CNN | 2D, 3D phase space presents the intrinsic mode and functions | CHB-MIT, SNUH-HYU data | Spec, sens, time difference | Low sens, spec | 90.58 |
| Sui et al. [55] | SoftMax, 2D-CNN | FT | Kaggle | Overall accuracy | High time complexity | 91.18 |
| Turk and Ozerdem [59] | Softmax, 2D-CNN | Frequency-time domain, CWT | Freiburg | Spec, sens, acc, F-measure | Low spec for multi-class | 93.60 |
| Faust et al. [60] | Softmax, 2D-CNN | Wavelet transformations (DWT) | Bern-Barcelona data | Energy, frequency | Low accuracy | 94.50 |
| Tian et al. [61] | SoftMax, 2D-CNN | MV-TSK-FS, 2D-CNN | CHB-MIT | Overall accuracy | - | 95.33 |
| LeCun et al. [62] | Res-CNN | Conventional feature extraction method | BONN | Overall acc | - | 95.70 |
| LeCun and Triesch [63] | Softmax, 2D-CNN | Feature extracts from CNN | Bern Barcelona | Overall accuracy | High detection time | 95.90 |
| San-Segundo et al. [64] | SoftMax, 2D-CNN | DWT | CHB-MIT | Class acc | High training time | 96.10 |
| Akut [65] | Sigmoid, 2D-CNN | FFT, WPD | Kaggle | Spec, sens | High training time | 96.15 |

Figure 7: Comparison of accuracies (%) versus authors introducing 2D-CNN models for seizure detection.
Table 4: A review of recent research that applied the LSTM-RNN model for seizure prediction with their corresponding accuracies.

| Authors                 | Machine learning approaches | Feature selection methods                        | Dataset       | Performance metrics | Limitations               | Accuracy (%) |
|-------------------------|-----------------------------|--------------------------------------------------|---------------|---------------------|---------------------------|--------------|
| Yao et al. [75]         | SoftMax, LSTM               | Independent RNN                                  | CHB-MIT       | Sen, spec, Prec     | Low sens, prec           | 88.80        |
| Chen et al. [72]        | SoftMax, LSTM               | Wavelet transformations (DWT)                     | Zenodo        | Pre, spec, class    | Low prec                 | 90.00        |
| Chen et al. [72]        | SoftMax, LSTM               | Wavelet transformations (DWT)                     | BONN          | Overall accuracy    | High detection time      | 91.82        |
| Hussein et al. [76]     | SoftMax, LSTM               | Time domain, time-frequency domain               | Fribourg      | Sen, spec           | —                         | 92.75        |
| Jaafar and Mohammad [77]| SoftMax, LSTM               | Independent RNN                                  | Freiburg data | Overall accuracy    | High training time       | 93.75        |
| Talathi and Vartak [78] | RNN, GRU                    | Computer-based analytical approaches             | MAEU data     | Class accuracy      | High time complexity     | 94.00        |
| Ahmed-Aristizabal [79]  | SoftMax, LSTM               | 2D, 3D phase space presents the intrinsic mode and functions | TUH data      | Overall accuracy    | High training time       | 95.00        |
| Roy et al. [83]         | Sigmoid, 2D CNN-LSTM        | Time-frequency domain feature                     | Kaggle        | Sen, spec           | —                         | 96.00        |
| Liang et al. [86]       | Softmax, 1D CNN-GRU         | 2D, 3D phase space presents the intrinsic mode and functions | Bern Barcelona | Overall accuracy    | High time complexity     | 94.16        |
| Choi et al. [87]        | ID-CNN biGRU                | Frequency domain                                 | CHB-MIT       | Sensitivity         | High training time       | 94.40        |

Table 5: A review of recent research that applied the CNN-RNNs model for seizure prediction with their corresponding accuracies.

| Authors                 | ML/DL approaches     | Feature selection methods                        | Dataset       | Performance metrics | Limitations               | Accuracy (%) |
|-------------------------|----------------------|--------------------------------------------------|---------------|---------------------|---------------------------|--------------|
| Fang et al. [82]        | ST-GRU ConvNets      | Time-domain                                      | CHB-MIT       | Latency             | Low accuracy              | 77.30        |
| Ravi Prakash et al. [84]| Sigmoid, 1D-CNN-LSTM | Time-domain features                              | Fribourg      | Sen, spec           | Low sens, spec            | 83.05        |
| Ravi Prakash et al. [84]| CNN-RNN              | 2D, 3D phase space presents the intrinsic mode and functions | MAEU data     | Overall accuracy    | —                         | 90.22        |
| Ahmedt Aristizabal et al [85]| Sigmoid, 2D CNN-LSTM | Time domain features                              | TUH data      | Overall accuracy    | High detection time       | 92.50        |
| Roy et al. [83]         | Sigmoid, 2D CNN-LSTM | Time-frequency domain feature                     | Kaggle        | Sen, spec           | High training time        | 93.00        |
| Liang et al. [86]       | Softmax, 1D CNN-GRU  | 2D, 3D phase space presents the intrinsic mode and functions | Bern Barcelona | Overall accuracy    | High time complexity      | 94.16        |
| Choi et al. [87]        | ID-CNN biGRU         | Frequency domain                                 | CHB-MIT       | Sensitivity         | High training time        | 94.40        |
the SVM model was more efficient based on the accuracy and time complexity (sec) compared to other networks. Hassan and Subasi [122] used genetic algorithms (GA), SVM, and particle swarm optimization (PSO) to detect a seizure. This approach achieved the best accuracy up to 92.38%. Shoeb and Guttag [115] implemented SVM classifiers and vector features on the CHB-MIT dataset to predict seizures, achieving 93.38% accuracy. Amin et al. [33] also used four classifiers, namely Naïve Bayes, KNN, MLP, and SVM, for classification with the DWT method and relative features. Their experimental result showed 92% accuracy. Raghu et al. [117] introduced the hybrid KNN-SVM model that was implemented on raw EEG data for accurate classification of epileptic seizure detection, and the experimental result indicated an accuracy of up to 90%. Zabihi et al. [121] used an SVM classifier for specific accurate detection to process the dataset with frequency-domain and time-domain features and achieved 93.78% sensitivity and 96.05% specificity.

Lahmiri and Shmuel [125] successfully used the Hurst exponent (HE) to classify the recorded EEG dataset into nonseizure and seizure with up to 97% accuracy. Further study by Lahmiri and Shmuel [125] used SVM to accurately classify seizures with 100% accuracy but less time complexity (sec). Table 7 and Figures 11–13 showed the authors’ accuracy of the three models (SVM, ANN, and KNN) in various pieces of literature.

### Table 6: A review of recent research that applied AE in seizure detection with their corresponding accuracies.

| Authors | Machine learning approaches | Feature selection methods | Dataset | Performance metrics | Limitations | Accuracy (%) |
|---------|-----------------------------|---------------------------|---------|---------------------|-------------|--------------|
| Gasparini et al. [95] | SoftMax, SAE | Time-frequency, CWT | Reggio Calabria data | Sen, spec | Low Sen, Spec, Acc | 86.50 |
| Singh and Malhotra. [96] | SoftMax, SAE | AE and SE | BONN | Sen, spec, acc | — | 88.80 |
| Yuan et al. [97] | SoftMax, SSpDAE | SAE, six features | Zenodo | ROC, PR, F-measure | F1-measure, Confusion Matrix | 90.64 |
| Yuan et al. [97] | SoftMax, SpDAE | Time-frequency | CHB-MIT | Sen, spec | Low detection acc | 90.82 |
| Hosseini et al. [98] | SoftMax, SpAE | PCA | Zenodo | Pre sen, FPR FNR | High FNR | 91.00 |
| Karim et al. [99] | SoftMax, SAE | DWT | BONN | Confusion matrix | Low prec | 91.00 |
| Yuan et al. [100] | SoftMax, SAE | AE and SE | CHB-MIT | Pre, sen, F-measure | — | 92.61 |
| Sharathappriya et al. [92] | SoftMax, AE | HWPT, FD | Fribourg | Sen, spec | High time complexity | 92.67 |
| Karim et al. [101] | SoftMax, SpAE | AE and SE | Fribourg | Confusion Matrix | High detection time | 93 |
| Karim et al. [102] | SoftMax, DSAE | ESD function | Kaggle | Sen, spec | — | 94 |
| Wang et al. [103] | SoftMax, SSpDAE | AE and NSP | BONN | Sen, spec | Prec not mentioned | 95 |

**Figure 9:** Comparison of accuracies (%) versus authors introducing CNN-RNN models for seizure detection.

**Figure 10:** Comparative study of accuracy (%) versus authors introducing AE model for seizure detection.

3.2. Nonblack-Box Classifiers in Seizure Detection. The issue of “black-box” classifiers is that it cannot identify human interpretation and classification procedures [128]. Therefore, there is less chance to retrieve sensible knowledge. Because of the limitation of knowledge retrievals, the researchers focus on “nonblack-box classifiers, including random forest and decision trees approach. The literature of [104, 129–132] examined the decision forest and decision tree, and they reported that decision forest classifiers were more effective than implementing a decision tree for its overfitting issues. An algorithm extracts the rules from
training data using a decision tree that generates either a limited or a single set of logic rules (for example, whenever C2 entropy value is less than 101.01, class value \( \text{seizure} \)) and stops growing the tree by adding more records to the training dataset once the rule is accepted by the algorithm [127]. Besides, the decision forest grows multiple decision trees on the training data with higher accuracy and sensible logic rules. Chen et al. [133] applied a decision tree on the EEG dataset to successfully classify seizures and reported 98.62% accuracy. Decision forest classifiers in [32, 134, 135] were used as ensemble methods for seizure detection, providing remarkable accuracy and creating additional logic rules with decision trees using the training data [120]. Siddiqui and Islam [136, 137] used the hybrid approaches of systematic forest (SySF) and continuously excluding root node (CERN) without epoch reduction to diagnose seizure detection. Another study [116] implemented decision forests with 9 statistical features with the epoch concept. The training dataset was divided into subdatasets, such as (d, d1, \ldots, dn), and the accuracy was tested on each epoch. The limitation of this

| Authors                  | Machine learning approaches | Feature selection methods                  | Dataset   | Performance metrics | Limitations             | Accuracy (%) |
|--------------------------|------------------------------|--------------------------------------------|-----------|---------------------|-------------------------|--------------|
| Logesparan et al. [107]  | SVM, ANN                     | Line length feature                       | CHB-MIT   | ROC                 | Low accuracy           | 52           |
| Zeller Fergus [108]      | QDA, DT, KNN, SVM            | Time-frequency                             | BONN      | Sen, spec           | Low sen, pres          | 85           |
| Birjandtalab et al. [106]| ANN                          | Spectral power                             | CHB-MIT   | F-measure           | High detection high    | 86           |
| Chen et al. [109]        | SVM                          | DWT                                        | BONN      | Confusion Matrix    | Low sen, pres          | 86.83        |
| Parvez and Paul [110]    | LS-SVM                       | IMF, DCT-DWT, DCT, SVD                     | Freiburg  | Spec, sen, Acc      | Low sen, pres for binary classification | 91.36        |
| Guo and DiPietro [111]   | K-NN                         | Genetic programming                        | BONN      | Class Acc           | Low accuracy           | 93.50        |
| Nicolaou and Georgiou [112]| SVM                         | Permutation entropy                        | CHB-MIT   | Pre, Rec, F-measure | Low prec and accuracy  | 93.55        |
| Ahmad et al. [113]       | SVM                          | DWT                                        | CHB-MIT   | Avg                 | —                       | 94.8         |
| Zhang et al. [114]       | ELM, SVM                     | AE and SE                                  | BCI Lab   | Class accuracy      | High time complexity   | 95.58        |
| Shoeb and Guttag [115]   | SVM                          | Time-frequency                             | CHB- MIT  | Sensitivity (sen)   | —                       | 96           |
| Chen et al. [116]        | Naive Bayes, SVM             | Energy, variance, entropy, RMS             | CHB-MIT   | Pre, Rec, F-measure | Low pre                | 96.55        |
| Raghu et al. [117]       | RF, KNN, adaboost            | Time-frequency                             | Bern-Barcelona | Sen, pre, NPR, ROC | NFR not mentioned    | 97.6         |
| Mursalin et al. [118]    | KNN, SVM, RF                 | 15-features                                | BONN      | Acc, sen, spec      | —                       | 98           |
| Sharma et al. [119]      | LS-SVM                       | 2D, 3D phases, the intrinsic mode, and functions | BONN      | Overall Acc        | High detection time    | 99.1         |
| Amin et al. [33]         | Naive bayes, SVM, KNN, MLP   | Energy                                     | EPILEPSY  | Class Acc            | —                       | 98.75        |
| Satapathy et al. [120]   | Neural network, SVM          | CWT, DWT                                  | BONN      | Overall Acc         | High detection time    | 99.1         |
| Zabihi et al. [121]      | SVM                          | Time-frequency                             | CHB-MIT   | Sen, spec           | High time complexity   | 99.32        |
| Hassan and Subasi [122]  | SVM                          | DWT                                        | BONN      | Class Acc            | —                       | 99.38        |
| Fasil and Rajesh. [123]  | SVM                          | Energy                                     | BONN, Barcelona | Spec, Acc, sen      | —                       | 99.5         |
| Chen et al. [116]        | LS-SVM                       | Entropies types                            | BONN      | BONN                | High time complexity   | 99.58        |
| Selvakumari et al. [124] | LS-SVM                       | DWT, FFT                                  | Class Acc | BONN                | —                       | 100          |
| Lahmiri and Shumel [125] | KNN and GHE, DWT based entropy | DWT based approximate entropy                | BONN      | Class Acc            | —                       | 100          |
| Kumar et al. [126]       | ANN                          | Time-frequency features                    | BONN      | Pre, Rec, F-measure | High time complexity   | 100          |
| Tzallas et al. [127]     | ANN                          | Time-frequency features                    | BONN      | Pre, Rec, F-measure | —                       | 100          |
literature was that a single patient’s dataset had been taken. The dataset could be taken from many patients to achieve the best results. Overall, a systematical review of recent studies and their performance of RF were presented in Figure 14 and Table 8. Because of the nonblack nature and advantages (accuracy, logic rules) [36, 139, 141], several researchers implemented a random forest classifier to diagnose seizure detection. Donos et al. [139] introduced a decision forest classifier on statistical features (frequency and time domains) extracted from the EEG dataset and reported that the system presented sensitivity up to 93.8%. Hosseini et al. [141] used the RF with grid search optimization (RF-GSO) approach and achieved an accuracy of 96.7%.

### Table 8: A review of recent research applied random forest in seizure detection with their corresponding accuracies.

| Authors                  | Machine learning approaches                  | Feature selection methods | Dataset       | Performance metrics          | Limitations                      | Accuracy (%) |
|--------------------------|---------------------------------------------|---------------------------|---------------|------------------------------|---------------------------------|--------------|
| Birjandtalab et al. [138]| Random forest-KNN                           | Spectral power            | CHB-MIT       | Sen, F-measure, prec         | Low sens, spec                  | 80.87        |
| Donos et al. [139]       | Random forest                               | Time, frequency           | EPILEPSY      | Sensitivity                  | Spec not mentioned              | 93.8         |
| Siddiqui et al. [140]    | Random forest, boosting, decision forest     | Nine statistical features | Bern Barcelona| Pre, Rec, F-measure          | High time complexity            | 96.67        |
| Wang et al. [137]        | Random forest classifiers                    | Std, dev, energy, energy,STFT, mean | BONN          | Class Acc                    | Low sens, spec for multi-class  | 96.7         |
| Lee and Kim [35]         | Random forest, SVM                           | Frequency, 10-time        | UCI           | ROC-AUC                      | —                               | 98           |
| Sharma et al. [119]      | Random forest                               | IMF                       | Kaggle        | Sen, spec, Acc               | Sen, spec not mentioned         | 98.4         |
| Mursalin et al. [118]    | Random forest                               | DWT, entropy              | Fribourg      | Class Acc                    | —                               | 98.45        |
| Mursalin et al. [118]    | Random forest                               | DWT, entropy              | Zenodo        | Class Acc                    | Sen, Spec not mentioned         | 98.45        |
| Alickovic et al. [46]    | ANN, random forest, SVM, KNN                 | Power, mean, kurtosis, absolute mean std dev, skewness | CHB-MIT       | Sen, spec, Acc               | Time complexity                 | 100          |
| Wang et al. [137]        | Forest CERN                                 | 9-statistical features    | BONN, CHB-MIT | Class Acc                    | —                               | 100          |
| Hosseini et al. [141]    | Random forest classifiers                    | L1-penalized robust regression | CHB-MIT       | Class Acc                    | —                               | 100          |

Figure 11: Comparative study of accuracy (%) versus authors introducing the SVM model for seizure detection.
4. Observed Challenges from Surveyed Literature

Based on the comprehensive survey of existing related literature reviewed, it was observed that the various challenges in diagnosing epileptic seizures could be summarized as follows:

(a) The first challenge is that large epileptic seizure datasets are currently not available publicly for extensive validation of the proposed machine learning/DL-based models for epilepsy detection and classification.

(b) Many datasets only include specified chunks of EEG signals, which is insufficient for real-world applications, where detection must be done from real-time signals.

(c) Because a large amount of dataset is required for the proper validation of a machine learning model for epileptic seizure detection and classification, plenty of efforts have been made to combine available EEG datasets for this purpose. However, it is still difficult to combine these datasets because they have different parameters and were acquired under relatively different sampling conditions [142].

(d) Because machine/deep learning models mostly require substantial computational resources for their implementation in practical settings, which are sometimes difficult to access, a piece of good knowledge about how to optimize the models’ performance is necessary for realizing a practical epileptic seizure detection and classification system.

(e) For some researchers working in epileptic seizure detection and prediction, especially those in low to medium-income countries, accessing high-performance hardware resources to implement deep learning models is often a key challenge. Although Google has made powerful computing servers accessible (Google Colab platform and so on), there are still limitations regarding the amount of data transferred to such servers and the length of time it takes for the servers to execute the tasks.

5. Discussion

In this study, we have investigated the use of different machine/deep learning-based algorithms for epileptic seizure detection. For instance, the algorithms considered include the conventional ML (ANN, SVM, and KNN), advanced DL (CNN/RNN/LSTM), and the random forest (RF)-based ML because of their remarkable performances in epileptic seizure detection, as reported in previous studies.

A summary of the investigation results reported in recent literature are as follows:

This systemic survey indicates that conventional ML algorithms (ANN, SVM, KNN) contribute well to the processing of brain datasets (CHB-MIT, BON, Kaggle, Fribourg, and Bern Barcelona) for seizure detection [106–120]. However, each method has some pros and cons. For instance, SVM is found to be efficient for binary classification. It has better detection accuracy than ANN and KNN, however, it has high computation time complexity (sec), mainly compared to KNN and ANN. In contrast, KNN has low-performance evaluation metrics (precision, recall, and F1-score), including low detection complexity, however, they can handle high dimensional datasets [111, 118, 125]. While introducing a hybrid classification scheme that involves a combination of machine learning models (SVM-KNN or SVM-ANN), an increase in detection accuracy, precision, recall, and F1-score can be achieved compared to using a single ML model [33, 108, 118, 126]. Even though hybrid models could achieve better prediction accuracy than single models, they are more computationally efficient than their single model counterparts, further limiting their implementation in practical applications [104, 132]. Additionally, a
major challenge with conventional ML algorithms is that it is
difficult to understand the logical procedure followed to arrive
at their prediction outcomes and is largely unexplainable for
patterns and the logic rules hidden inside the models (the
blackbox concept). Thus, they are not recommended for
extracting useful information from datasets.

On the other hand, advanced ML/DL (CNN/RNN/
LSTM) aid the automatic extraction of high-dimensional
features, which may not be easily achieved with conventional
ML schemes. For instance, the RNN model is normally faster
than CNN and LSTM in execution time but has relatively
lower accuracy, precision, and recall. In contrast, LSTM has
time complexity issues using CHB-MIT and BONN and other
datasets for seizure detection [72, 77, 80]. Besides, the hybrid
models (a combination of two or more DL models) were
found to perform better in accurately classifying seizures at
the expense of more computation time. When considering
time complexity, accuracy, precision, and recall issues with
the conventional ML and advanced ML (DL) algorithms,
decision tree-driven schemes, such as random forest classi-
fiers, may be good. It is partly because of their ensemble
nature and multiple logic rules [127]. They can achieve fairly
good classification results as shown in the previous sections
[134–142]. Decision tree-based models can handle a relatively
large number of datasets and are less time-consuming and
mostly yield high accuracy, precision, and recall.

From adopting the conventional ML models for epileptic
seizure detection, feature extract constitutes an essential
component of the entire scheme. Hence, it is important to
select proper feature extraction methods for characterizing
the EEG signals. Recent studies that investigated and ana-
lyzed a range of features had indicated that the time-domain
feature extraction methods with 9-statistical features (stan-
dard deviation, kurtosis, skewness, energy, line length,
entropy, mean, mode, and Hurst) would be appropriate for
epileptic seizure detection [126]. It is because the mentioned
features have been reported to achieve average accuracies in
the range of 98–100% when used with ML/DL models for
epileptic seizure classification based on EEG signals.

Furthermore, it is significant to select a smaller subset of
useful features by adopting a selection technique to reduce
the model’s complexity. It leads to the survey of various
feature selection methods adopted mainly for dimension-
ality reduction. The investigation study showed that Kernel
principal component analysis (KPCA) was a suitable non-
linear reduction technique for feature selection. KPCA offers
the following major benefits over other feature selection
methods:

(1) Nonlinear data is successfully handled.
(2) No nonlinear optimization is required.
(3) KPCA calculations are very easy and are similar to
conventional PCA calculations.
(4) The number of PCs does not need to be set before
modeling [143].

KPCA is a suitable encoding method for data with a
nonlinear manifold structure. It is widely used in various
datasets, including applied health data, sensor data, and
facial pictures.

6. Conclusion
A comprehensive review of efficient machine/deep learning
models and feature extraction and selection methods has
been performed in this research. This study focused on the
conventional ML (ANN/SVM/KNN), advanced ML/DL
(CNN/RNN/LSTM), and tree-base ML (RF) because of their
remarkable performance in the application of epileptic seizure detection. This paper concluded that decision forest classifiers are the most suitable, effective, and recommended for future research in epilepsy seizure detection. Its non-black-box nature produces explainable logic rules, multiple sensible knowledge (adequate detection), high accuracy, low detection complexity, high precision, and recall, reveals relevant information (seizure localization), and can handle high volumes of datasets. At the same time, blackbox classifiers, such as conventional ML (ANN SVM KNN) and advanced ML/DL (CNN/RNN/LSTM), cannot create logic rules, including high detection accuracy but have high time complexity.

Furthermore, according to the literature review, as for the selection of appropriate features and feature extraction method, we selected the time-domain features extraction method and 9-statistical features (standard deviation, kurtosis, skewness, energy, line length, entropy, mean, mode, and Hurst) because these features provided higher accuracy (%). At the same time, Kernel principal component analysis (KPCA) is a suitable nonlinear polynomial-based method for feature selection. Future research will further study machine learning issues regarding epileptic seizure detection with suitable features.

Conflicts of Interest
The authors declare that there are no conflicts of interest.

Authors’ Contributions
Ijaz Ahmad and Xin Wang contributed equally to the work.

Acknowledgments
This work was supported in part by the National Natural Science Foundation of China (#81927804 and #62101538), Shenzhen Governmental Basic Research Grant (#JCJ20180507182241622), Science and Technology Planning Project of Shenzhen (#JSGG20210713091808027 and #JSGG20211029095801002), and SIAT Innovation Program for Excellent Young Researchers (E1G027).

References
[1] D. Stelze, V. Schmidt, B. J. Ngowi, W. Matuja, E. Schmutzhard, and A. S. Winkler, “Lifetime prevalence of epilepsy in urban Tanzania–A door-to-door random cluster survey,” eNeurologicalSci, vol. 24, Article ID 100352, 2021.
[2] M. Sazgar and M. G. Young, Absolute Epilepsy and EEG Rotation Review: Essentials for Trainees, Springer, Berlin, Germany, 2019.
[3] N. Delanty, C. J. Vaughan, and J. A. French, “Medical causes of seizures,” The Lancet, vol. 352, no. 9125, pp. 383–390, 1998.
[4] G. Alarcon and A. Valentin, Introduction to Epilepsy, Cambridge University Press, Cambridge, UK, 2012.
[5] S. Kulseheran, A. Aminpour, M. Ebrahimi, and E. Wijdaja, “Identifying lesions in paediatric epilepsy using morphometric and textural analysis of magnetic resonance images,” NeuroImage: Clinica, vol. 21, Article ID 101663, 2019.
[6] N. Van Klink, A. Mooij, G. Huiskamp et al., “Simultaneous MEG and EEG to detect ripples in people with focal epilepsy,” Clinical Neurophysiology, vol. 130, pp. 1175–1183, 2019.
[7] K. Fountas and E. Z. Kapsalaki, Epilepsy Surgery and Intrinsic Brain Tumor Surgery, Springer, Berlin, Germany, 2019.
[8] F. Lauretani, Y. Longobucco, G. Ravazzoni, E. Gallini, M. Salvi, and M. Maggio, “Imaging the functional neuro-anatomy of Parkinson’s disease: clinical applications and future directions,” International Journal of Environmental Research and Public Health, vol. 18, p. 2356, 2021.
[9] C. Morales, J. González González, L. Maria et al., “Surgical outcome in extratemporal epilepsies based on multimodal pre-surgical evaluation and sequential intraoperative electrocorticography,” Behavioral Sciences, vol. 11, p. 30, 2021.
[10] M. Qaisar, Saeed, and A. Subasi, “Effective epileptic seizure detection based on the event-driven processing and machine learning for mobile healthcare,” Journal of Ambient Intelligence and Humanized Computing, pp. 1–13, 2020.
[11] R. Sharma and R. B. Pachori, “Classification of epileptic seizures in EEG signals based on phase space representation of intrinsic mode functions,” Expert Systems with Applications, vol. 42, no. 3, pp. 1106–1117, 2015.
[12] D. J. Thurman, E. Beghi, C. E. Begley et al., “Standards for epidemiologic studies and surveillance of epilepsy,” Epilepsia, vol. 52, pp. 2–26, 2011.
[13] R. S. Fisher, “The new classification of seizures by the International League against Epilepsy 2017,” Current Neurology and Neuroscience Reports, vol. 17, pp. 48–56, 2017.
[14] U. Herwig, P. Satrapi, and C. Schönfeldt-Lecuona, “Using the international 10-20 EEG system for positioning of transcranial magnetic stimulation,” Brain Topography, vol. 16, pp. 95–99, 2003.
[15] K. E. Muslims, Atlas of EEG, Seizure Semiology, and Management, Oxford University Press, Oxford, UK, 2013.
[16] “Optimal features for online seizure detection,” Medical, & Biological Engineering & Computing, vol. 50, no. 7, pp. 659–669, 2012.
[17] A. B. Tufail, I. Ullah, W. U. Khan et al., “Diagnosis of diabetic retinopathy through retinal fundus images and 3D convolutional neural networks with limited number of samples,” Wireless Communications and Mobile Computing, vol. 2021, Article ID 6013448, 15 pages, 2021.
[18] CHB-MIT Scalp EEG Database, https://physionet.org/pn6/chbmit/. Accessed 10 Jan, 2022.
[19] R. G. Andrzejak, K. Lehertz, F. Mormann, C. Rieke, P. David, and C. E. Elger, “Indications of nonlinear deterministic and finite-dimensional structures in time series of brain electrical activity: dependence on recording region and brain state,” Physical Review E - Statistical Physics, Plasmas, Fluids, and Related Interdisciplinary Topics, vol. 64, no. 6, Article ID 061907, 2001.
[20] “Seizure prediction challenge.” Available online: https://www.kaggle.com/c/seizure-prediction, 2022.
[21] M. Ihle, H. Feldwisch-Drentrup, C. A. Teixeira et al., “EPILEPSIAE–A European epilepsy database,” Computer Methods and Programs in Biomedicine, vol. 106, pp. 127–138, 2012.
[22] R. G. Andrzejak, K. Schindler, and C. Rummel, “Nonrandomness, nonlinear dependence, and nonstationarity of electroencephalographic recordings from epilepsy patients,” Physical Review A, vol. 86, Article ID 046206, 2012.
[23] N. J. Stevenson, K. Tapani, L. Lauronen, and S. Vanhatalo, “A dataset of neonatal EEG recordings with seizure annotations,” Scientific Data, vol. 6, pp. 190039–190048, 2019.

[24] H. Liang, X. Sun, Y. Sun, and Y. Gao, “Text feature extraction based on deep learning: a review,” EURASIP Journal on Wireless Communications and Networking, vol. 2017, pp. 211–212, 2017.

[25] Al-Fahoum, S. Amjad, and A. A. Al-Fraihat, “Methods of EEG signal features extraction using linear analysis in frequency and time-frequency domains,” ISRN Neuroscience, vol. 2014, Article ID 730218, 7 pages, 2014.

[26] Y. Gao and K. M. Mosalamm, “Deep transfer learning for image-based structural damage recognition,” Computer-Aided Civil and Infrastructure Engineering, vol. 33, pp. 748–768, 2018.

[27] K. Fujiwara, M. Miyajima, T. Yamakawa et al., “Epileptic seizure prediction based on multivariate statistical process control of heart rate variability features,” IEEE Transactions on Biomedical Engineering, vol. 63, no. 6, pp. 1321–1332, 2016.

[28] T. Wen, Y. Du, T. Pan, C. Huang, and Z. Zhang, “A deep learning-based classification method for different frequency EEG data,” Computational and Mathematical Methods in Medicine, vol. 13, no. 3, p. 1, 2021.

[29] U. R. Acharya, S. V. Sree, S. Chattopadhyay, W. Yu, and P. C. A. Ang, “Application of recurrence quantification analysis for the automated identification of epileptic EEG signals,” International Journal of Neural Systems, vol. 21, no. 3, pp. 199–211, 2011.

[30] S. Latif and A. Beg, “Principle components analysis for seizures prediction using wavelet transform,” International Journal of Advances in Applied Sciences, vol. 6, no. 3, pp. 50–55, 2019.

[31] H. Abbasi, A. J. Gunn, C. P. Unsworth, and L. Bennet, “Advanced deep learning spectroscopy of scalogram infused CNN classifiers for robust identification of post-hypoxic epileptiform EEG spikes,” Advanced Intelligent Systems, vol. 3, Article ID 2000198, 2021.

[32] L. Logesparan and A. J. Casson, “Optimal features for online seizure detection,” Medical & Biological Engineering & Computing, vol. 50, no. 7, pp. 659–669, 2012.

[33] H. U. Amin, A. S. Malik, R. F. Ahmad et al., “Feature extraction and classification for EEG signals using wavelet transform and machine learning techniques,” Australasian Physical & Engineering Sciences in Medicine, vol. 38, no. 1, pp. 139–149, 2015.

[34] N. Koolen, K. Jansen, J. Vervisch et al., “Line length as a method to detect high-activity events: automated burst detection in premature EEG recordings,” Clinical Neurophysiology, vol. 125, no. 10, pp. 1895–1994, 2014.

[35] H. Lee and S. Kim, “Black-box classifier interpretation using decision tree and fuzzy logic-based classifier implementation,” The International Journal of Fuzzy Logic and Intelligent Systems, vol. 16, no. 1, pp. 27–35, 2016.

[36] M. N. Adnan and M. Z. Islam, “Forex++: a new framework for knowledge discovery from decision forests,” Australasian Journal of Information Systems, vol. 21, 2017.

[37] L. Guo, D. Rivero, J. Dorado, J. R. Rabunal, and A. Pazos, “Automatic epileptic seizure detection in EEGs based on line length feature and artificial neural networks,” Journal of Neuroscience Methods, vol. 191, no. 1, pp. 101–109, 2010.

[38] Jaiswal, A. Kumar, and H. Banka, “Epileptic seizure detection in EEG signal with GMdPCA and support vector machine,” Bio-Medical Materials and Engineering, vol. 28, pp. 141–157, 2017.

[39] J. Birjandtalab, M. Baran, and M. Nourani, “Nonlinear dimension reduction for EEG-based epileptic seizure detection,” in Proceedings of the 2016 IEEE-EMBS International Conference on Biomedical and Health Informatics (BHI), IEEE, Las Vegas, NV, USA, February 2016.

[40] W. Zhao, J. Qu, Yi Chai, and J. Tang, “Classification of seizure in EEG signals based on KPCA and SVM,” in Proceedings of the 2015 Chinese Intelligent Systems Conference, pp. 201–207, Springer, Yangzhou, China, 2016.

[41] V. K. Harpale and V. K. Bairagi, “Significance of independent component analysis (ICA) for epileptic seizure detection using EEG signals,” in Proceedings of the International Conference on Data Engineering and Communication Technology, pp. 829–838, Springer, Pune, India, December 2017.

[42] M. Li, X. Luo, J. Yang, and Y. Sun, “Applying a locally linear embedding algorithm for feature extraction and visualization of MI-EEG,” Journal of Sensors, vol. 2016, Article ID 7481946, 9 pages, 2016.

[43] D. Laurent Chanel, D. Tchiotsop, R. Atangana, and B. S. Tchinda, “A comparison study of polynomial-based PCA, KPCA, LDA and GDA feature extraction methods for epileptic and eye states EEG signals detection using kernel machines,” Infor-matics in Medicine Unlocked, vol. 26, Article ID 100721, 2021.

[44] R. Atangana, D. Tchiotsop, G. Kenne, and L. C. DjoufackNkengfac k, “EEG signal classification using LDA and MLP classifier,” Health Informatics - An International Journal, vol. 9, no. 1, pp. 14–32, 2020.

[45] B. Zhang, W. Wang, Y. Xiao et al., “Cross-subject seizure detection in EEGs using deep transfer learning,” Computational and Mathematical Methods in Medicine, vol. 2020, no. 13, Article ID 7902072, 8 pages, 2020.

[46] E. Alickovic, J. Kevric, and A. Subasi, “Performance evaluation of empirical mode decomposition, discrete wavelet transform, and wavelet packed decomposition for automated epileptic seizure detection and prediction,” Biomedical Signal Processing and Control, vol. 39, pp. 94–102, 2018.

[47] D. Javeed, T. Gao, M. T. Khan, and I. Ahmad, “A hybrid deep learning-driven SDN enabled mechanism for secure communication in internet of things (IoT),” Sensors, vol. 21, pp. 4884, 2021.

[48] M. Sharma, R. B. Pachori, and U. Rajendra Acharya, “A new approach to characterize epileptic seizures using analytic time-frequency flexible wavelet transform and fractal dimension,” Pattern Recognition Letters, vol. 94, pp. 172–179, 2017.

[49] E. Bou Assi, D. K. Nguyen, S. Rihana, and M. Sawan, “Towards accurate prediction of epileptic seizures: a review,” Biomedical Signal Processing and Control, vol. 34, pp. 144–157, 2017.

[50] I. Ahmad, I. Ullah, W. U. Khan et al., “Efficient algorithms for E-healthcare to solve multiobject fuse detection problem,” Journal of Healthcare Engineering, vol. 2021, Article ID 9500304, 1 page, 2021.

[51] A. Raza, H. Ayub, J. A. Khan et al., “A hybrid deep learning-based approach for brain tumor classification,” Electronics, vol. 11, no. 7, pp. 1146, 2022.

[52] I. Ahmad, Y. Liu, D. Javeed, and S. Ahmad, “A decision-making technique for solving order allocation problem using a genetic algorithm,” IOP Conference Series: Materials Science and Engineering, vol. 853, no. 1, Article ID 012054, 2020.
[53] I. Ahmad, Y. Liu, D. Javeed, N. Shamshad, D. Sarwar, and S. Ahmad, “A review of artificial intelligence techniques for selection & evaluation,” IOP Conference Series: Materials Science and Engineering, vol. 853, no. 1, Article ID 012055, 2020.

[54] O. Faust, Y. Hagiwara, T. J. Hong, O. S. Lih, and U. R. Acharya, “Deep learning for healthcare applications based on physiological signals: a review,” Computer Methods and Programs in Biomedicine, vol. 161, pp. 1–13, 2018.

[55] L. Sui, X. Zhao, Q. Zhao, T. Tanaka, and J. Cao, “Localization of epileptic foci by using convolutional neural network based on iee,” in IFIP Advances in Information and Communication Technology, pp. 331–339, Springer, Berlin, Germany, 2019.

[56] B. Bizopoulos, G. I. Lambrou, and D. Koutsouris, "Signal 2image modules in deep neural networks for EEG classification," in Proceedings of the 2019 43st Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 702–705, IEEE, Berlin, Germany, July 2019.

[57] A. Antoniades, L. Spyrou, C. C. Took, and S. Sanei, “Deep learning for epileptic seizure detection based on multi-channel EEG with deep convolutional neural network,” in Proceedings of the 2018 International Conference on Electronics, Information, and Communication (ICEIC), pp. 1–5, IEEE, Jeju, Korea, February 2018.

[58] O. Türk and M. S. Özerdem, “Epilepsy detection by using scalogram-based convolutional neural network from EEG signals,” Brain Sciences, vol. 9, no. 5, p. 115, 2019.

[59] O. Faust, Y. Hagiwara, T. J. Hong, O. S. Lih, and U. R. Acharya, “Deep learning for healthcare applications based on physiological signals: a review,” Computer Methods and Programs in Biomedicine, vol. 161, pp. 1–13, 2018.

[60] X. Tian, Z. Deng, W. Ying et al., “Deep multi-view feature learning for EEG-based epileptic seizure detection,” IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 27, no. 10, p. 1962, 2019.

[61] Y. LeCun, Y. Bengio, and G. Hinton, “Deep learning,” Nature, vol. 521, no. 7553, pp. 436–444, 2015.

[62] D. Lu and J. Triesch, “Residual deep convolutional neural network for eeg signal classification in epilepsy,” 2019, https://arxiv.org/abs/1903.08100.

[63] R. San-Segundo, M. Gil-Martín, L. F. D’Haro-Enriquez, and J. M. Pardo, “Classification of epileptic EEG recordings using signal transforms and convolutional neural networks,” Computers in Biology and Medicine, vol. 109, pp. 148–158, 2019.

[64] R. Akut, “Wavelet-based deep learning approach for epilepsy detection,” Health Information Science and Systems, vol. 7, pp. 8–9, 2019.

[65] I. Goodfellow, Y. Bengio, and A. Courville, Deep Learning, MIT Press, Cambridge, MA, USA, 2016.

[66] W. Pedrycz and S.-M. Chen, Development and Analysis of Deep Learning Architectures, Springer, Berlin, Germany, 2020.

[67] N. Srivastava and R. R. Salakhutdinov, “Multimodal learning with deep Boltzmann machines,” in Advances in Neural Information Processing Systems, pp. 2222–2230, Springer, Berlin, Germany, 2012.

[68] D. Yu and L. Deng, “Deep learning and its applications to signal and information processing [exploratory DSP],” IEEE Signal Processing Magazine, vol. 28, no. 1, pp. 145–154, 2011.

[69] M. Golmohammadi, S. Ziyabari, V. Shah, S. L. de Diego, I. Obeid, and J. Picone, “Deep architectures for automated seizure detection in scalp eeg,” 2017, https://arxiv.org/abs/1712.09776.

[70] L. A. Kurgan and K. J. Cios, “CAIM discretization algorithm,” IEEE Transactions on Knowledge and Data Engineering, vol. 16, no. 2, pp. 145–153, 2004.

[71] X. Chen, J. Ji, T. Ji, and P. Li, “Cost-sensitive deep active learning for epileptic seizure detection,” in Proceedings of the 2018 ACM International Conference on Bioinformatics, Computational Biology, and Health Informatics, pp. 226–235, Washington, DC, USA, August 2018.

[72] D. E. Olsen, R. P. Lesser, J. C. Harris, W. R. S. Webber, and J. A. Cristion, “Automatic detection of seizures using electroencephalographic signals,” Google Patents. US Patent, vol. 5, no. 311, p. 876, 1994.

[73] I. Cepukenas, C. Lin, and D. Sleeman, “Applying rule extraction and rule refinement techniques to (BlackBox) classifiers,” in Proceedings of the 8th International Conference on Knowledge Capture, p. 27, ACM, Palsades, NY, USA, October 2015.

[74] X. Yao, Q. Cheng, and G.-Q. Zhang, “A novel independent rnn approach to classification of seizures against non-seizures,” 2019, https://arxiv.org/abs/1903.09326.

[75] R. Hussein, H. Palangi, R. K. Ward, and Z. J. Wang, “Optimized deep neural network architecture for robust detection of epileptic seizures using EEG signals,” Clinical Neurophysiology, vol. 130, no. 1, pp. 25–37, 2019.

[76] S. T. Jaafar and M. Mohammadi, “Epileptic seizure detection using deep learning approach,” UHD Journal of Science and Technology, vol. 3, no. 2, pp. 41–50, 2019.

[77] S. S. Talathi and A. Vartak, “Improving performance of recurrent neural network with relu nonlinearity,” 2015, https://arxiv.org/abs/1511.03771.

[78] D. Ahmed-Aristizabal, “Identification of children at risk of schizophrenia via deep learning and EEG responses,” IEEE journal of biomedical and health informatics, vol. 25, pp. 69–76, 2020.

[79] X. Yao, Q. Cheng, and G.-Q. Zhang, “Automated classification of seizures against non-seizures: a deep learning approach,” 2019, https://arxiv.org/abs/1906.02745.

[80] R. Hussein, “Robust detection of epileptic seizures using deep neural networks,” in Proceedings of the 2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), IEEE, Calgary, Canada, April 2018.

[81] Z. Fang, H. Leung, and C. S. Choy, “Spatial-temporal GRU convnets for vision-based real-time epileptic seizure detection,” in Proceedings of the 2018 IEEE 15th International Symposium on Biomedical Imaging (ISBI 2018), pp. 1026–1029, IEEE, Washington, DC, USA, April 2018.

[82] S. Roy, I. Kiral-Kornek, and S. Harrer, “Deep learning en-abled automatic abnormal EEG identification,” in Proceedings of the 2018 40th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), pp. 2756–2759, IEEE, Honolulu, HI, USA, June 2018.

[83] H. Ravi Prakash, M. Korostenskaja, E. M. Castillo et al., “Deep learning provides exceptional accuracy to eeg-based functional language mapping for epilepsy surgery,” BioRxiv, Article ID 497644, 2019.

[84] D. Ahmed-Aristizabal, C. Fookes, K. Nguyen, S. Denman, and P. Mason, “Using deep learning for eeg signal classification in epilepsy,” 2019, https://arxiv.org/abs/1906.02745.

[85] D. Yu and L. Deng, “Deep learning and its applications to signal and information processing [exploratory DSP],” IEEE Signal Processing Magazine, vol. 28, no. 1, pp. 145–154, 2011.
phase i epilepsy evaluation using computer vision, “Epilepsy and Behavior, vol. 82, pp. 17–24, 2018.
[86] W. Liang, H. Pei, Q. Cai, and Y. Wang, “Scalp EEG epileptogenic zone recognition and localization based on long-term recurrent convolutional network,” Neurocomputing, vol. 396, pp. 569–576, 2020.
[87] G. Choi, C. Park, J. Kim et al., “A novel multi-scale 3d cnn with deep neural network for epileptic seizure detection,” in Proceedings of the 2019 IEEE International Conference on Consumer Electronics (ICCE), pp. 1-2, IEEE, Berlin, Germany, September 2019.
[88] E. Pippa, “Classification of epileptic and non-epileptic EEG events,” in Proceedings of the 2014 4th International Conference on Wireless Mobile Communication and Healthcare-Transforming Healthcare through Innovations in Mobile and Wireless Technologies, pp. 87–89, Athens, Greece, November 2014.
[89] R. Meier, H. Dittrich, A. Schulze-Bonhage, and A. Aertsen, “Detecting epileptic seizures in long-term human EEG: a new approach to automatic online and real-time detection and classification of polymorphic seizure patterns,” Journal of Clinical Neurophysiology, vol. 25, pp. 119–131, 2008.
[90] H. Rajaguru and S. K. Prabhakar, “Multilayer autoencoders and em-pca with genetic algorithm for epilepsy classification from ecg,” in Proceedings of the 2018 Second International Conference on Electronics, Communication and Aerospace Technology (ICECA), pp. 353–358, IEEE, Coimbatore, India, December 2018.
[91] M. Sharma, A. A. Bhurane, and U. Rajendra Acharya, “Mmisl-owfb: a novel class of orthogonal wavelet filters for epileptic seizure detection,” Knowledge-Based Systems, vol. 160, pp. 265–277, 2018.
[92] V. Sharathapriyaa, S. Gautham, and R. Lavanya, “Autoencoder based automated epilepsy diagnosis,” in Proceedings of the 2018 International Conference on Advances in Computing, Communications and Informatics (ICACCI), pp. 976–982, IEEE, Bangalore, India, September 2018.
[93] Y. Qiu, W. Zhou, N. Yu, and P. Du, “Denoising sparse autoencoder-based ictal eeg classification,” IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 26, no. 9, pp. 1717–1726, 2018.
[94] M. Golmohammadi, A. H. Harati Nejad Torbati, S. Lopez de Diego, I. Obeid, and J. Picone, “Automatic analysis of eegs to predict the impact of signal normalization on seizure detection using line length features,” Medical, & Biological Engineering & Computing, vol. 53, no. 10, pp. 929–942, 2015.
[95] J. Birjandtalab, V. N. Jarmale, M. Nourani, and J. Harvey, “Impulse learning using neural networks for seizure detection,” in Proceedings of the 2018 IEEE Biomedical Circuits and Systems Conference (BioCAS), pp. 1–4, IEEE, Cleveland, OH, USA, October 2018.
[96] L. Logesparan, E. Rodriguez-Villegas, and A. J. Casson, “The impact of signal normalization on seizure detection using line length features,” Journal of Ambient Intelligence and Humanized Computing, vol. 9, no. 1, pp. 148–159, 2019.
[97] Y. Yuan, G. Xun, Q. Suo, K. Jia, and A. Zhang, “Wave2vec: deep representation learning for clinical temporal data,” Neurocomputing, vol. 324, pp. 31–42, 2019.
[98] M.-P. Hosseini, H. Soltanian-Zadeh, K. Elisevich, and D. Pomplini, “Cloud-based deep learning of big EGG data for epileptic seizure prediction,” in Proceedings of the 2016 IEEE Global Conference on Signal and Information Processing (GlobalSIP), pp. 1151–1155, IEEE, Washington, DC, USA, December 2016.
[99] A. M. Karim, O. Karal, and F. Celebi, “A new automatic epilepsy serious detection method by using deep learning based on discrete wavelet transform,” in Proceedings of the 3rd International Conference on Engineering Technology and Applied Sciences (ICETAS), vol. 4, pp. 15–18, Skopje, Macedonia, June 2018.
[100] Y. Yuan, G. Xun, F. Ma et al., “A novel channel-aware attention framework for multi-channel EEG seizure detection via multi-view deep learning,” in Proceedings of the 2018 IEEE EMBS International Conference on Biomedical & Health Informatics (BHI), pp. 206–209, IEEE, Las Vegas, NV, USA, March 2018.
[101] A. M. Karim, M. S. Guzel, M. R. Tolun, H. Kaya, and F. V. Celbehi, “A new framework using deep auto-encoder and energy spectral density for medical waveform data classification and processing,” Biocybernetics and Biomedical Engineering, vol. 39, no. 1, pp. 148–159, 2019.
[102] A. M. Karim, M. S. Guzel, M. R. Tolun, H. Kaya, and F. V. Celbehi, “A new generalized deep learning framework combining sparse autoencoder and Taguchi method for novel data classification and processing,” Mathematical Problems in Engineering, vol. 1, p. 13, 2018.
[103] Y. Wang, Y. Li, and S. Yu, “An EEG signal classification method based on sparse auto-encoders and support vector machine,” in Proceedings of the 2016 IEEE/CIC International Conference on Communications in China (ICCC), pp. 1–6, IEEE, Chengdu, China, July 2016.
[104] J. Cepukenas, C. Lin, and S. Derek, “Applying rule extraction & rule refinement techniques to (blackbox) classifiers,” in Proceedings of the 8th International Conference on Knowledge Capture, pp. 1–5, Palisades, NY, USA, October 2015.
[105] A. Dorai and K. Ponnambalam, “Automated epileptic seizure onset detection,” in Proceedings of the 2010 International Conference on Autonomous and Intelligent Systems, AIS 2010, pp. 1–4, IEEE, Varzim, Portugal, June 2010.
[106] J. Birjandtalab, V. N. Jarmale, M. Nourani, and J. Harvey, “Impulse learning using neural networks for seizure detection,” in Proceedings of the 2018 IEEE Biomedical Circuits and Systems Conference (BioCAS), pp. 1–4, IEEE, Cleveland, OH, USA, October 2018.
A. T. Tzallas and M. G. Tsipouras, “Automatic seizure detection based on wavelet packet decomposition,” *Neural Computing & Applications*, vol. 26, pp. 1217–1225, 2015.

A. H. Shoeb and J. V. Guttag, “Application of machine learning to epileptic seizure detection,” in *Proceedings of the 27th International Conference on International Conference on Machine Learning ICML*, Haifa, Israel, June 2010.

S. Chen, X. Zhang, L. Chen, and Z. Yang, “Automatic diagnosis of epileptic seizure in electroencephalography signals using nonlinear dynamics features,” *IEEE Access*, vol. 7, pp. 61046–61056, 2019.

S. Raghu, N. Sirraam, Y. Temel, S. V. Rao, and P. L. Kubben, “EEG based multi-class seizure type classification using convolutional neural network and transfer learning,” *Neural Networks*, vol. 124, pp. 202–212, 2020.

M. Mursalin, S. Islam, K. Noman, and A. Jumaily, “Epileptic seizure classification using statistical sampling and a novel feature selection algorithm,” 2019, https://arxiv.org/abs/1902.09962.

M. Sharma, P. Sharma, R. B. Pachori, and U. R. Acharya, “Dual-tree complex wavelet transform-based features for automated alcoholism identification,” *International Journal of Fuzzy Systems*, vol. 20, pp. 1297–1308, 2018.

S. K. Satapathy, A. K. Jagadev, and S. Deburi, “Weighted majority voting based ensemble of classifiers using different machine learning techniques for classification of EEG signal to detect epileptic seizure,” *Informatica*, vol. 41, no. 1, p. 99, 2017.

M. Zabihi, S. Kiranyaz, and T. Ince, “Patient-specific epileptic seizure detection in long-term EEG recording in paediatric patients with intractable seizures,” in *Proceedings of the IET Intelligent Signal Processing Conference 2013 (ISP 2013)*, pp. 7–06, London, UK, November 2013.

A. R. Hassan and A. Subasi, “Automatic identification of epileptic seizures from EEG signals using linear programming boosting,” *Computer Methods and Programs in Biomedicine*, vol. 136, pp. 65–77, 2016.

O. Fasil and R. Rajesh, “Time-domain exponential energy for epileptic EEG signal classification,” *Neuroscience Letters*, vol. 694, pp. 1–8, 2019.

R. S. Selvakumari, M. Mahalakshmi, and P. Prashalee, “Patient-specific seizure detection method using hybrid classifier with optimized electrodes,” *Journal of Medical Systems*, vol. 43, no. 5, p. 121, 2019.

S. Lahmri and A. Shmuel, “Accurate classification of seizure and seizure-free intervals of intracranial eeg signals from epileptic patients,” *IEEE Transactions on Instrumentation and Measurement*, vol. 68, no. 3, pp. 791–796, 2019.

M. Kumar, R. Pachori, and U. Acharya, “Use of accumulated entropies for automated detection of congestive heart failure in flexible analytic wavelet transform framework based on short-term HRV signals,” *Entropy*, vol. 19, p. 92, 2017.

A. T. Tzallas, M. G. Tsipouras, and D. I. Fotiadis, “Epileptic seizure detection in EEGs using Time–f analysis,” *IEEE Transactions on Information Technology in Biomedicine*, vol. 135, pp. 701–710, 2009.

A. S. M. Murugavel and S. Ramakrishnan, “Hierarchical multi-class SVM with ELM kernel for epileptic EEG signal classification,” *Medical & Biological Engineering & Computing*, vol. 54, pp. 149–161, 2016.

A. T. Tzallas and M. G. Tsipouras, “Automatic seizure detection based on time-frequency analysis and artificial neural networks,” *Computational Intelligence and Neuroscience*, vol. 2007, Article ID 080510, 13 pages, 2007.

K. Siddiqui Mohammad, Z. Islam Md, and A. Kabir Muhammad, “Advanced-data mining and applications,” *Analyzing Performance of Classification Techniques in Detecting Epileptic Seizure*, Springer International Publishing, Berlin, Germany, pp. 386–398, 2017.

J. Li and H. Liu, “Ensembles of cascading trees,” in *Proceedings of the 3rd IEEE International Conference OnData Mining*, 2003. *ICDM* 2003, pp. 585–588, IEEE, Melbourne, FL, USA, November 2003.

D. Javeed, M. T. Khan, I. Ahmad et al., “An efficient approach of threat hunting using memory forensics,” *International Journal of Computer Networks and Communications Security*, vol. 8, pp. 37–45, 2020.

C. Chen, J. Liu, and J. Syu, “Application of chaos theory and data mining to seizure detection of epilepsy,” *Proc Conf. IPSISIT/Hong Kong*, vol. 25, pp. 23–28, 2012.

K. Polat and S. Güney, “Classification of epileptiform EEG using a hybrid system based on decision tree classifier and fast Fourier transform,” *Applied Mathematics and Computation*, vol. 187, no. 2, pp. 1017–1026, 2007.

L. Breiman, “Bagging predictors,” *Machine Learning*, vol. 24, pp. 123–140, 1996.

M. K. Siddiqui and M. Z. Islam, “Data mining approach in seizure detection,” in *Proceedings of the 2016 IEEE Region 10 Conference (TENCON)*, pp. 3579–3583, Institute of Electrical and Electronics Engineers (IEEE), Singapore, November 2016.

X. Wang, G. Gong, N. Li, and S. Qiu, “Detection analysis of epileptic EEG using a novel random forest model combined with grid search optimization,” *Frontiers in Human Neuroscience*, vol. 13, p. 12, 2019.

B. Birjandtalab, M. Baran Pouyan, D. Cogan, M. Nourani, and J. Harvey, “Automated seizure detection using limited-channel EEG and nonlinear dimension reduction,” *Computers in Biology and Medicine*, vol. 82, pp. 49–58, 2017.

C. Donos, M. Dümplemann, and A. Schule-Bonhage, “Early seizure detection algorithm based on intracranial EEG and random forest classification,” *International Journal of Neural Systems*, vol. 25, no. 5, Article ID 1550023, 2015.

M. K. Siddiqui, Z. Islam, and A. Muhammad, “A novel quick seizure detection and localization through brain data mining on ECoG dataset,” *Neural Computing & Applications*, vol. 31, pp. 5595–5608, 2019.

M.-P. Hosseini, D. Pompli, K. Elisevich, and H. Soltanian-Zadeh, “Random ensemble learning for EEG classification,” *Artificial Intelligence in Medicine*, vol. 84, pp. 146–158, 2018.

M. Natu, M. Bachute, S. Gite, K. Kotecha, and A. Vidyarthi, “Review on epileptic seizure prediction: machine learning and deep learning approaches,” *Computational and Mathematical Methods in Medicine*, vol. 2022, Article ID 7751263, 17 pages, 2022.

W. Wang, M. Zhang, D. Wang, and Y. Jiang, “Kernel PCA feature extraction and the SVM classification algorithm for multiple-status, through-wall, human being detection,” *EURASIP Journal on Wireless Communications and Networking*, vol. 151, pp. 151–157, 2017.