Chapter 1

Introduction

Epilepsy is one of the most common neurological diseases that affects 50 million people worldwide [8, 9]. It causes recurrent seizures, an involuntary movement resulting from abnormal electrical discharges in specific neuronal cells [10, 11]. It is observed that 50.0% of epileptic patients experience vigorous seizures. These occurrences are categorized as focal (partial) or generalized seizures. While generalized seizures happen when this aberrant activity affects both hemispheres, including their cortical and subcortical structures, focal seizures relate to abnormal activity in one or more defined brain areas. This condition typically affects 0.5%–1% of the population, and 30%–40% of those affected develop pharmacoresistant forms [12]. Seizures negatively influence patients as they experience seizure-related uneasiness to varying degrees in their regular routines. Epilepsy can lead to significant physical and psychosocial difficulties and consequently has a significant impact on the quality of life of patients [13]. Epileptic patients are in greater danger of accidents and wounds because of seizure-related occurrences alone [14]. These seizures usually begin instinctively without any external factors or stimulation. The unpredictable nature of epilepsy, such as the time duration of a seizure, the time of occurrence, the degree of intensity, and others, makes it undeniably challenging for patients to

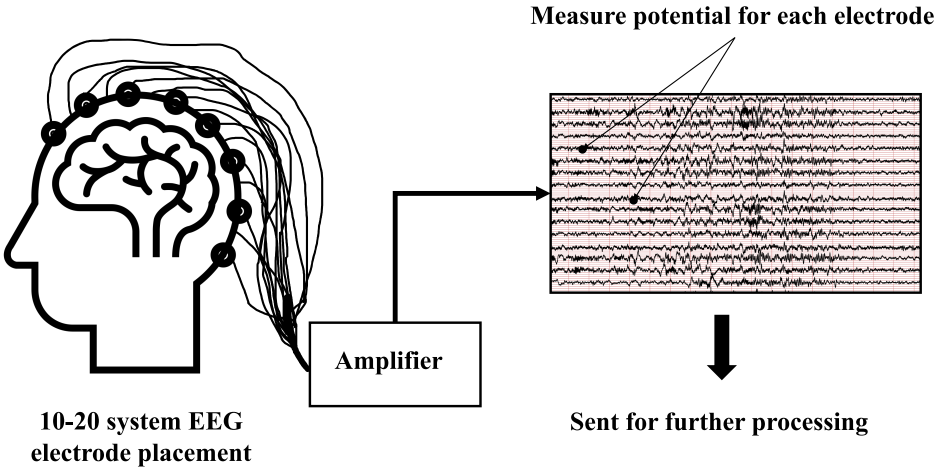

Figure 1.1: An electroencephalogram recording setup.

perform ordinary tasks. A timely diagnosis of epilepsy enables the patients and their caregivers to provide them with on-time medical support [15–18]. An EEG is a recording of brain activity and is of significant help in diagnosing epilepsy.

During this painless test, small sensors are attached to the scalp to pick up the electrical signals produced by the brain. These signals are recorded by a machine and are looked at by a doctor [19]. The determination of epilepsy from the EEG signals is a time-consuming activity. The hand-operated Epileptic Seizure (ES) classification process requires an entire day to recognize post-ictal, inter-ictal, and pre-ictal patterns from the EEG signals [16–18, 20, 21]. The predetermination of ESs enhances the lifetime of epileptic victims in various circumstances as it generates an alarm before the onset of a seizure event. These alarms provide enough time to take proper measures, adopt new treatment techniques, and set up new procedures to comprehend the idea of the disease more readily. The early determination of these seizures before they happen will be helpful for the patients to go for on-time medical treatment and enable the on-time application of the preventive therapies [22]. An alarm is generated when recognizing the pre-ictal state as it indicates the onset of a prospective seizure [16–18, 20, 21, 23]. Most of the seizure classification and prediction methods are Patient-Specific (PS), as the EEG signals

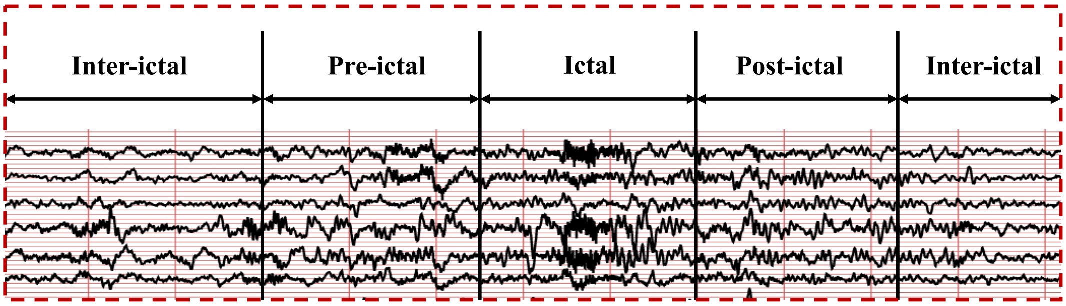

Figure 1.2: Various stages in an EEG Signal when a seizure occurs [1, 2].

are diverse and vary across patients due to the variety of seizure patterns and positions. Here, the term PS systems refers to those research works where techniques are evaluated by training the classifier on individual patient information and presenting a patients-wise analysis of the approach. Also, whenever an EEG recording is taken, it tends to get contaminated with various artifacts. These artifacts, also called noise, can be of various types. Both physiological and non-physiological artifacts can interfere with accurate readings during EEG tests. Artifact Removal (AR) is essential for improving EEG data quality, interpretability, and clinical relevance, which can have important implications for understanding brain function and diagnosing neurological disorders.

1.1 Problem Statement

The need for an automated epilepsy management system makes it essential that such a system fits every individual to a certain degree and is responsive whenever an episode is about to occur. Designing such a seizure monitoring system is a challenging task for researchers as well as practitioners. Therefore, **the main focus of this work is to improve ES detection and prediction by optimizing the classifiers' parameters and giving the patient prior information about upcoming seizures. Further, this work also develops techniques to remove artifacts identified in the acquired EEG signal and generate an elaborate feature space that captures the**

varying nature of EEG signals and their characteristics.

1.2 Motivation

The motivation for this work came from a lot of observations in the domain of ES classification and prediction. After going through the literature, it was inferred that PS methodologies are tailor-made to fit the specifications of the patient's condition, and the seizure properties vary with patients and duration. It is challenging to capture the varying characteristics of the information obtained from these signals and learn them to attain the desired performance. The existing techniques need to be more generalized, and appropriate modifications should be made with the new data available. It is essential to have an elaborate feature space to express the seizure characteristics for the classification and their prediction. DL methods have shown promising potential for executing classification and prediction tasks on EEG signals. Many works have converted the raw EEG signals into images without focusing on the properties of these data sets. As a result, valuable temporal information of the EEG signal is lost [24]. Also, the variation in the raw EEG signal length affects the proper image representation. The existing techniques require a significantly large architecture that works directly on the raw signal. Thus, substantial computational resources are needed to train many parameters and hyperparameters, which add an overhead to tuning these parameters and hyperparameters. Many techniques do not consider any preprocessing or post-processing methods that may increase prediction accuracy, such as AR and enhancing the image quality. Additionally, EEG signals are quite sensitive to noise. The addition of artifacts to these signals during recording makes it even more challenging to interpret them. The emergence of portable systems that utilize Single-Channel EEG (SC-EEG) has revolutionized real-time medical observation systems and Brain-Computer Interface (BCI), especially in non-clinical and indoor settings. The artifacts mentioned above can easily become a part of the EEG signals being recorded in such settings [25]. Only a few countable works provide methodologies for EEG signals of epileptic patients. The variety of artifacts these techniques handle is also limited, as some cater to only individual artifact types. Certain denoising techniques necessitate the presence of either an artifact reference channel or an initial calibration process [25]. It is almost always theoretically implied by most of these works that denoising will eventually improve the quality of signals and will become fit for classification and prediction purposes.

1.3 Objectives

The following are the primary objectives that were aimed throughout this research work:

- To remove noise or artifacts efficiently from EEG signals once they are obtained from epileptic patients
- To make the application of the above denoising technique flexible to be implemented in domains other than epilepsy
- To develop an automated system that classifies EEG signals as seizures or non-seizures
- To develop a feature space that efficiently encodes the characteristics and patterns identified in the EEG signal
- To improve the performance of existing DL architectures using optimization techniques
- To develop an automated alarm system that warns an epilepsy patient of the upcoming seizure and its onset

1.4 Contributions

This section provides the essential contributions made in this thesis. A literature review on methods for analysis of EEG signals used for classification and prediction tasks has been discussed. This thesis discusses issues, challenges, and gaps related to these techniques. Various research problems are identified using the discussion.

- **Denoising of EEG signals of epileptic patients using Bidirectional Stochastic LSTM:** This work has proposed an architecture that combines the framework of a BLSTM and the learning mechanism of a BSCN. This novel architecture has been utilized to denoise EEG signals of epilepsy patients. This technique has been able to handle multiple types of noises, like Electrocardiography (ECG), Electromyography (EMG), Electrooculography (EOG), and PowerLine Interference (PL). Through experimentation, it has been reported that the novel denoising technique efficiently improves the classification and prediction accuracy of ESs. The proposed technique has also been implemented on a sleep data set to prove the flexibility of domain adaptation.

- **Epileptic Seizure Classification using Battle Royale Search and Rescue optimization-based Deep LSTM:** This work proposes a DL-based approach to mitigate the problem of PS seizure classification models. As proof of principle, a general data set has been designed and developed to train the classifier based on non-specific patient information. A feature augmentation approach has been presented to handle the data scarcity issue in EEG data sets. As proof of concept, various advanced signal processing techniques were employed to enrich the quantity of data. Consequently, a hybrid feature space has been generated to capture the potential non-linear patterns for seizure classification to improve performance. This work has presented an optimized DL model based on the defender and the Team Leader (TL) characteristics to identify a better solution with a fast convergence rate.

- **An Intelligent Optimized Deep Learning Model to Achieve Early Prediction of Epileptic Seizures:** This work has proposed an approach to forecast the occurrence of a seizure episode and raise the alarm for it. This was achieved by training the classifier to find the optimal SPH and achieve early prediction. This work has addressed the issue of PS seizure prediction models by putting forth a DL-based solution. A broad input set has been created and prepared as a proof of concept to train the classifier using generic patient data. As proof of concept, the data scarcity issue of EEG data sets has been alleviated by providing a feature augmentation strategy that employs several adaptive signal decomposition algorithms to enhance the quantity of data. A hybrid feature space has been created to boost performance and capture potential non-linear patterns for seizure classification. This study provides an improved optimization-based DL model based on the steps taken during a criminal investigation and the dynamics of a group that has lost a comrade.

1.5 Scope of the Work

- EEG databases considered are for epilepsy patients only.
- All the studies and experiments have been conducted on all the patients of these data sets.

1.6 Organization of the Thesis

This thesis is arranged into six different chapters. A brief description of the chapters is as follows:

Chapter 1 is the introduction of the domain explored in this research work along with its contributions.

Chapter 2 provides a summary of the importance of ES prediction and details the literature survey of various approaches for seizure detection and occurrence prediction. A comparative analysis of these approaches has been done to find the research gap.

Chapter 3 presents the work done for denoising EEG signals using a novel architecture.

Chapter 4 discusses the contribution done for the detection of ESs by using an elaborate feature space and optimization technique that tunes the parameters of a DL model.

Chapter 5 proposes a novel architecture for the early prediction of ES occurrences through the use of DL techniques.

Chapter 6 concludes the work by summarizing the main findings of the works done herein and future directives to extend the research work.