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Comprehensive survey on EEG analysis for detecting brain disorders

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Abstract

Electroencephalography (EEG) enlighten about the state of the brain i.e. about the electrical activity of the brain. The electrical activity measured as voltage at different points of brain act as basis of EEG. These signals are generally time-varying and non-stationary in nature. These signals can be scrutinized using various signal processing techniques. In this paper, few statistical approaches to analyze EEG data are discussed. The EEG is a medical modality that plays crucial roles in detecting, displaying and recording electrical activity in the brain. This paper reviews the analysis method of EEG signal for common diseases like Epilepsy, Brain Injuries, Alzheimer 's disease and schizophrenia. Fast Fourier Transform, Short Time Fourier Transform (STFT) and event-related potential (ERP) are some of the techniques used in analyzing EEG signal.

Keywords*— EEG; Epilepsy; Brain Injuries; Alzheimer's disease; schizophrenia*

I. Introduction

Signal processing of electroencephalogram (EEG) is a field that has drawn significant attention in the last years. As a result, numerous EEG processing methodologies have been presented in the literature. One of the most popular field in EEG signal processing is the epilepsy detection and classification. The EEG is a useful tool in brain abnormality diagnosis. It is a non-invasive, portable, and relatively inexpensive technique that detects tiny electrical impulses at electrodes placed on the scalp as neurons communicate with each other. EEG bands have been found to be useful in detecting, monitoring, and treating a variety of brain disorders, including epilepsy.

Being one of the most common neurological disorders [1], epilepsy has been the focus of hundreds of EEG analysis studies. About one-third of the total diseases in developing countries results from brain disorders such as epilepsy, schizophrenia, and brain injuries. An abrupt change from the typical pattern of EEG is often associated with these disorders. A highly trained neurologist is required to analyse EEG signals as they are easy to misinterpret. However, timely diagnosis and treatment of brain disorders is possible and can make a difference.

This situation urgently calls for development of an accurate algorithm, which can be used for EEG-based detection of brain disorder and monitoring of brain function with minimal human intervention.

II. Eeg Signal Processing

The raw EEG signals are contaminated by artifacts caused by different sources. As these artifacts may misinterpret the brain activity and misdiagnosis of brain disorder, it's important to remove these artifacts first. Researchers have developed many techniques for artifact removal, including regression-based methods, component-based methods and adaptive filtering methods and also use of notch filter. Fig 1 shows processing steps [8].

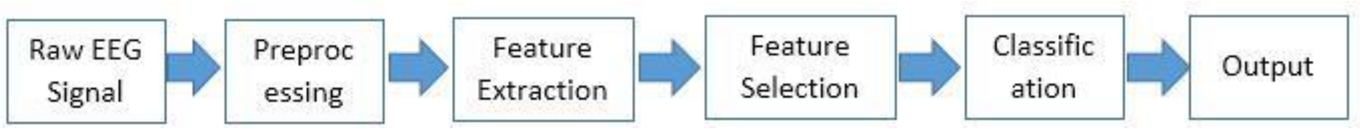

Fig. 1 EEG Signal Processing

After the elimination of the artifacts, the significant features of the EEG signals are extracted & selected. The feature extraction and selection techniques are important to identify certain properties that can effectively be used in classifying the EEG signals[2]. There are several approaches used in feature extraction including time domain analysis, frequency-domain analysis and time-frequency domain analysis. The features such as minimum, maximum, mean, standard deviation and energy are commonly used in time-domain analysis. The disadvantages of time-domain approach are high sensitivity of the selected features and the demand for higher storage capabilities. In frequency-domain analysis, EEG signals are first transformed into frequency domain using Fast Fourier Transform (FFT) and Wavelet transforms. In some cases if it is not enough to provide

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signal characteristic for classification using only frequency information, time frequency analysis is used for improving classification accuracy. [11]

The EEG spectral analysis depends on sub-bands frequencies. Researchers have mainly used wavelet transform (WT) and time-frequency distributions (TFD) to analyse the EEG spectral patterns. However, although spectral analysis is a well-known approach, with numerus studies including spectral characteristics in the features extracted from the EEG, the importance of the frequency sub-bands that are used to analyse the signal has never been thoroughly investigated in the literature. It is medically established that brainwaves are divided based on their frequency into several sub-bands, being delta (1–4 Hz), theta (4–8 Hz), alpha (8–13 Hz), beta (13–30 Hz) and gamma (30–80 Hz). Thus, several researchers roughly focus on these sub-bands, with the technical limitations that the analysis technique imposes (i.e. WT).

III. Brain Disorders

A. Epilespsy

The Epilepsy is one of the most common neurological diseases in the world affecting more than 50 million individuals. Epilepsy is a neurological disorder which is caused by firing (excess voltage) of neurons in the brain. The occurrence of an epileptic seizure is unpredictable There are multiple methods of measuring brain activity, both invasive and non-invasive. [2] EEG is the primary diagnostic tool for epilepsy and is most frequently used for epileptic seizure onset detection. This is essentially due to its good resolution in space-time as compared to other techniques. Epilepsy, one of the most common neurological conditions characterized by epileptic seizures, is the second most common neurological disorder behind stroke, according to the World Health Organization (WHO). Seizures may occur, regardless of the circumstances or host attributes. Patients with epilepsy suffer from sudden and unforeseen seizures, during which they are unable to protect themselves and are vulnerable to suffocation, death, or injury due to fainting and traffic accidents. To date, this disease is mainly treated with medications and surgery; no cure exists, and treatments with anticonvulsants are not completely efficacious for all of types of epilepsy. Epilepsy can be classified into two types: Partial and Generalized seizures. In partial seizure, particular area of brain is involved. In Generalized seizures, Whole brain is involved. EEG is one of the diagnostic methods to detect abnormalities of the brains electrical activity. Existence of epilepsy can be detected from EEG signals by calculating the spikes. Epilepsy has three states: ictal, preictal and post ictal. Ongoing seizure period is called ictal. Pre seizure period is called pre ictal state. After seizure the period of EEG is called post ictal.

B. Brain Injury

Traumatic brain injury (TBI) is a leading cause of acquired epilepsies. Traumatic Brain Injury (TBI) is recognized as an important cause of death and disabilities after an accident. The availability a tool for the early diagnosis of brain dysfunctions could greatly improve the quality of life of people affected by TBI and even prevent deaths. The TBI diagnosis is obtained using discriminant analysis based on quantitative EEG (qEEG) features extracted from data recordings after the automatic removal of artifacts. Traumatic brain injury (TBI) is caused by an external force that damages the brain. This brain dysfunction results as possible physical, cognitive, social, emotional, and behavioral effects on the subject1. The severity of the injury ranges from mild to severe as well as the associated impacts on the quality of life of the person with TBIReactive astrocytes have long been associated with seizures and epilepsy in patients, particularly after focal/lesional brain injury. However, most TBIs also include non-focal, diffuse injuries. Areas with atypical astrocytes are larger in animals that later developed seizures suggesting that this response may be one root cause of epileptogenesis after diffuse TBI. There is an ongoing need for continuous, bedside-available, preferably non-invasive tools for reliable prediction of neurological outcome in traumatic brain injury (TBI) patients. A prediction model for patient outcome after TBI might provide realistic information to caregivers to inform relatives about expectations. Besides, better outcome prediction could assist in reliable quantification and classification of TBI severity to support clinical decision-making. Electroencephalography (EEG) is a non-invasive bedside-available measure of cortical activity and is particularly useful in sedated or comatose patients [5]. Continuous EEG (cEEG) is often part of the multimodal monitoring in TBI patients at the ICU, where it is mainly used for the detection of (non-convulsive or electrographic) seizures.

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C. Alzheimer's Disease

Alzheimer's disease (AD) is a progressive neurodegenerative disorder, which is associated with cognitive impairment, behaviour disorders and memory loss, among others. AD is the most common cause of dementia, with an estimated 60–80% of cases. In 2018, 50 million people worldwide were coexisting with some type of dementia. This number is expected to be more than tripled by 2050, rising to 152 million. AD can be considered a highly disruptive disorder, not only for patients, but also for families and caregivers, being the main cause of dependence and disability for older people. AD is particularly costly for the society, reaching a global economic burden of about US$ 1 trillion per year in 2018. Three major effects of AD on EEG have been observed: slowing of the EEG, reduced complexity of the EEG signals, and perturbations in EEG synchrony. Alzheimer's disease (AD) is a neuro-degenerative disease, the most common form of dementia, third most expensive disease and sixth leading cause of death. It affects more than 10% of people over age 65, nearly 50% of people older than 85, and it is estimated that the prevalence of the disease will triple within the next 50 years. While no known cure exists for Alzheimer's disease, a number of medications are believed to delay the symptoms (and perhaps causes) of the disease. The progression of the disease can be categorized in four different stages. The first stage is known as Mild Cognitive Impairment (MCI), and corresponds to a variety of symptoms — most commonly memory loss — which do not significantly alter daily life. Between 6 and 25% of people affected with MCI progress to AD every year. The next stages of Alzheimer's disease (Mild and Moderate AD) are characterized by increasing cognitive deficits, and decreasing independence, culminating in the patient's complete dependence on caregivers and a complete deterioration of personality (Severe AD)

D. Schizophrenia

Schizophrenia is an organic brain disease, which affects approximately one in 100 people at some time during their lives. Schizophrenia is a mental disorder, which is characterized by a wide spectrum of disturbances when performing several tasks. These disturbances should be explained independently of the specific task, in initial states, i.e., before performing the task or at rest. Schizophrenia is associated with disorders in the lobes and areas of the brain, which are responsible for information processing, temporary memory and executive functions. The diagnosis of schizophrenic spectrum disorders and other psychotic disorders is challenging. The scientific community is constantly working to integrate the latest clinical and scientific advances in the field of psychiatry into diagnostic and statistical manuals. Neurobiological studies of schizophrenia have made it possible to sum various data to confirm this approach. Promising and capable young adolescence or early adulthood people are often devastated by Schizophrenia and transforming them individuals who requires a high degree of care and support throughout their lives. Schizophrenia disrupts the brains ability to perceive and interpret reality to think and to feel. Schizophrenia has nothing to do with split personality or multiple personality or bipolar disorder. Schizophrenia has long bewildered psychiatrists and terrified the layperson, seeming to appear without warning to devastate developing minds poised on the threshold of adult life. Schizophrenia is basically the condition when a person starts having difficulties in interpreting reality. They confuse their perceived thoughts with the actual happenings. A person with schizophrenia will show a sudden but significant change in his or her behaviour as well as symptoms like delusions, hallucinations, abnormal speech, extremely erratic behaviour, an absence of emotional responsiveness, in appropriate emotional reactions, impoverished speech and a potentially dangerous loss of the desire or ability to care for himself or herself.

IV. Discussions

The All of these disorders have one common characteristics of EEG signal which is abnormality in waveform.

In the development of our patient specific seizure detection method, the objective has been to increase both the sensitivity and the specificity of the seizure detection algorithm as well as to reduce the detection delay. Muhammad Sohaib used dynamic mode decomposition (DMD), a data-driven dimensionality reduction technique, originally used in fluid mechanics, as an instrument for epileptic seizure detection from scalp electroencephalograph (EEG) data. The proposed algorithm has been tested over a thousand hours of EEG data from two different datasets, the CHB-MIT dataset, and the KU Leuven dataset, giving sensitivity values of 0.87 and 0.88, respectively, and specificity values of 0.99 for both datasets. Prabhapreet Kaur designed a system using wavelet decomposition method and different training algorithms to train the neural network for classification of the EEG signals

The system was tested and compared with Support Vector Machine (SVM) classifier. The system was tested and compared with Support Vector Machine (SVM) classifier. The system accuracy comes out to be 99.97%. [14]

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Bruno Albert, Jingjing Zhang designed a portable decision support system called EmerEEG, in which the TBI diagnosis is obtained using discriminant analysis based on quantitative EEG (qEEG) features extracted from data recordings after the automatic removal of artifacts. [7] The proposed algorithm computed the TBI diagnosis on the basis of a model extracted from clinically labelled EEG records. The system evaluations have confirmed the speed and reliability of the processing algorithms as well as the system's ability to deliver accurate diagnosis. The developed algorithms have achieved 79.1% accuracy in removing artifacts, and 87.85% accuracy in TBI diagnosis. Oleksii Shandra1 & Alexander R. Winemiller used mice of both sexes in a model of repetitive mild/concussive closed-head TBI, which only induce diffuse injury, to test the hypothesis that astrocytes respond uniquely to diffuse TBI and that diffuse TBI is sufficient to cause post-traumatic epilepsy. Astrocytes did not form scars and classic astrogliosis characterized by up regulation of glial fibrillary acidic protein was limited. Surprisingly, an unrelated population of atypical reactive astrocytes was characterized by the lack of glial fibrillary acidic protein expression, rapid and sustained down regulation of homeostatic proteins and impaired astrocyte coupling. After a latency period, a subset of mice developed spontaneous recurrent seizures reminiscent of post traumatic epilepsy in human TBI patients. Seizing mice had larger areas of atypical astrocytes when compared to non-seizing mice suggesting that these atypical astrocytes might contribute to epileptogenesis after diffuse TBI. In another approach, the development of the automatic TBI diagnosis algorithm is based on advanced EEG signal processing and machine learning techniques. The pre-processing step of the algorithm enables the automatic removal of artifacts and nose, avoiding the need for a time-consuming manual inspection and removal of data segments. The diagnosis is computed using supervised machine learning based on clinical data. The system operator is then provided with an assessment of the possible patient's traumatic brain injury.

Sachin M. Elgandelwar and Vinayak K. Bairagi focused spectral and signal complexity measures through which such early findings can possibly be improved. Power spectral and nonlinear features, which have been utilized for classification of Alzheimer disease subjects (ADS) from the normal healthy subject (NHS) [13]. The main aim of this research article is to study the power and nonlinear analysis for the finding of AD to consider as a probable biomarker to recognize AD subject and normal healthy subject. Relative power (RP) was independently calculated from various EEG bands which indicate the slowing of EEG signals acknowledge the Alzheimer disease subjects. EEG seems an attractive brain imaging modality for diagnosing AD, since EEG recording systems are relatively inexpensive and (potentially) mobile. Moreover, in contrast to most other non-invasive brain imaging methods, EEG has high temporal resolution, and may therefore contain crucial information about abnormal brain dynamics in AD patients. In particular, three major effects of AD on EEG have been observed: slowing of the EEG, reduced complexity of the EEG signals, and perturbations in EEG synchrony.

Any abnormalities in neural architecture and physiology associated with schizophrenia may directly or indirectly affect the basic nonlinear properties of brain systems. Symptoms of schizophrenia, such as formal mental disorders and disturbing the sequence or flow of thinking, are dynamic. This suggests a violation of non-linear processes, such as state transitions in cortical systems. C.J. Stam have described the role of nonlinear analysis methods as "the application of nonlinear dynamics to electroencephalography opens up several new prospects for studying normal and impaired brain function and develops in the direction of a new interdisciplinary field of nonlinear brain dynamics". The proposed method of visual analysis of EEG allowed them to compare the interaction between the activities of brain regions. This approach makes it possible to evaluate the symmetry of activity on the basis of topographic images, [15] to localize the activity centres and to correlate the activity of interaction between hemispheres by means of cross-correlation analysis.

V. Conclusions

The EEG is used as the analyzing tool of diseases, classification and rehabilitation. The methodologies of the analyzing diseases also differ according to the diseases. Some of the technique to analyses EEG waveform is using time-frequency pre-processing while others use focal wave to detect the active side in the EEG signal. More research and development needs to be done to improve the usage of the EEG. It can be concluded that EEG plays its role as a detection tool to detect the disease in the early stage, rehabilitation, classification or as an assistive tool for the patient according to the needs of the diseases.

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