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A Detailed Analysis of EEG Signal Processing in E-healthcare Applications and Challenges

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ABSTRACT: Brain is the most essential part of the human body. It conveys a lot of information to other parts of the body. In e-healthcare brain health is a widely noticed area. In the biomedical field, people find the brain-related disorders by using the EEG electrode. The EEG electrodes are located on the scalp and transmit the captured signal to the computer or mobile device. EEG is a technology that is used to find the abnormalities of the human brain such as sleep, gaze, gait, cognition, voice acoustics, etc., This paper presents a brief review of EEG artifacts, applications, classification methods and challenges in e-healthcare.

KEYWORDS: e-Healthcare, EEG (Electroencephalography), Artifacts, Classification.

I. INTRODUCTION

The human brain consists of billions of neurons. The human body's internal and external behaviors are controlled and coordinated by the human brain. Usually, brain signals are captured by PET, CT, MRI, fMRI, and MEG. These devices have captured the images and signals of the brain. EEG is a technique to investigate the human brain's signals. EEG acquires the signals in the waveform. These waves are categorized as (Table 1) delta, theta, alpha, beta, and gamma [1,3,4]. These waves are categorized, based on the frequency range. The special qualities of EEG are non-dangerous, effortless, result less, and exact understandings of some mind issues, for example, epilepsy, cerebrum tumor, mind injury, cognitive decline, Alzheimer's, discourse issue, cerebrum demise, or trance state and chemical imbalance. The medical researcher can use these signals based on analysis with different states. The medical researchers can able to have better understanding of behavioral characteristics of the complex structure of the brain and its functions by EEG signals [1]. The raw EEG signals are combined with some artifacts. Artifacts are similar to signals. Some disordered signals are called artifacts. To detect artifacts are a challenging task [7]. Based on EEG signal frequencies for different states of artifacts are present such as eyeball rotation, head movement, heartbeat, eye blinks, sweating, muscle contraction, eye open, eye close, finger clenching, power failure, electrode failure, ventilation, and low power supply, etc [1,3].

Table 1. EEG Signal Brain Frequency Range

Waves	Frequency Range	Description
Delta	0.1 – 4 HZ	Sleep stage
Theta	4 – 8 HZ	Deep relaxed state and meditation
Alpha	8 – 13 HZ	Wakeful but stress-free state
Beta	13 – 30 HZ	Energetic thinking
Gamma	30 – 100 HZ	Combination of two senses

This paper is proposed as segment II, discusses about the related work, artifacts are clarified in segment III, segment IV, portrays application and challenges, V clarifies different strategies and conclusion of the paper is segment VI.

II. RELATED WORK

Satheesh Kumar and Bhuvanewari [1], have presented an EEG signal state and categorization of the human body. EEG has various waves and frequencies such as delta, theta, alpha, beta, and gamma. These signals are used to find human psychological states. EEG collects the records in various waveforms in a specific frequency.

Deepa [2] et al, have explained the RPCA method (Revised Principal Component Analysis) for predicting the signal in the state of open or close condition. This EEG analysis is implemented in the MATLAB platform. This system helps to find the defects in the cognitive task of the brain by matching the patient's EEG signal.

Bhuvanewari and Satheesh Kumar [3], to find the activity and specific disorder location of the brain. An EEG signal has some artifacts (noise). This artifact has detected and removed by some methods of PCA (Principal Component Analysis) and ICA (Independent Component Analysis) is used to found the artifact detection and removal.

Srimathi [4] et al, have discussed revolution of IoT technology by locating the abnormalities of the human brain, which is done by the data acquisition, data transmission, and cloud processing states. In the cloud, processing states use the three tiers of protection such as device security, connection security, and cloud security.

Bhuvanewari and Satheesh Kumar [5], have represented the SVM (Support Vector Machine) technique and classification and also focused on the role of SVM in EEG signal analysis. Kwang Suk Park and Toshiyo Tamura [6], have focused on future e-healthcare smart biosensor technologies, such as artificial intelligence, 5G wireless communication. Bhuvanewari and Satheesh Kumar [7], discussed on PCA methods of artifact detection and removal in EEG signal analysis.

Qing Zhang [8] et al, have presented the spot hat or elastic headband of EEG connected with acquisition sensors, signal processing chip, and Bluetooth, which is used to daily monitor on brain health. This paper also focuses on continuous recording of early warning and classification algorithms of intelligent SVM.

Bhuvanewari and Satheesh Kumar [9] et al, have focused on decision rules of consensus and majority rule in the classification of epilepsy data set and also described statistical linear feature extraction methods of RMT, variance, and linear prediction coefficient.

Bill Byrom [10] et al, have focused on an automatic EEG pathology detection system based on deep learning. The Spatio-temporal representation forms of the EEG signals are the CNN (Convolutional Neural Network). This CNN models have a shallow and deep model.

Musaed Alhussein [11] et al, have focused on the wearable and mobile applications that measure electrical brain activity directly and related to brain functions such as sleep, gaze, gait, cognition, and speech acoustical analytics.

Ramani Kannan [12] et al, have presented an ear-EEG wearable device. Normally the patients hesitate to show their disorder or illnesses to the public due to wearable devices such as head-mounted EEG devices. Due to this reason, this paper has focused on developing an ear-EEG, which is a wearable EEG device using the shelf components to record the EEG signal from the ear and display the captured brain signals in the software. Human emotions play an important role.

Mouhannadali [13] et al, have focused on human emotions such as decisions, planning, anger, sadness, happiness, fear, reasoning, and other human mental states. Patient mental states are captured from biosensors such as EEG signals of Ambient Assisted Living (ALL). This paper has achieved to modify energy, wavelet entropy, and the classifiers are SVM, Quadratic Discriminant Analysis, and k-nearest neighbour. This approach is tested based on the 'DEAP' method using four electrodes of the EEG database.

Jie Wan [14] et al, have defined the WISE (Wearable IoT cloud based Health) monitoring system. This wearable sensor embedded with the human body monitors the functions of heartbeat, body temperature, and blood pressure. There are components of the WISE body area network (W-BAN), the WISE cloud (W-cloud), and the WISE users have gathered these signals.

Karthikeyan and Manikandan [17], have focused on SWT (Stationary Wavelet Transform) and ANN (Artificial Neural Network) for the detection of brain tumor and brain disorders. SWT technique separates the EEG signals such as low and high signals. The separated signals are classified by ANN, whether the EEG signals are normal or brain tumors.

III EEG ARTIFACTS AND DETECTION

An artifact is a noise. Recording EEG signals have some noise that is contaminated with those signals. That is called artifacts. Artifacts are divided into two types. Physiological or Internal Artifacts occur from eyeball rotation, head movement, heartbeat, eye blinks, sweating, and muscle contraction. Non-Physiological or External Artifacts occur due to faults like power failure, electrode failure, ventilation, and low power supply.

PCA performs [3], without losing any informations of the high dimensional data which is reduced by reduction techniques. ICA performs on non-brain signals like head movement, gaze, gait, eye blink, and eyeball rotation. SVM is used to classify the EMG, EOG, and clean EEG. Feature Extraction in SVM depends on component location, spectral information, and time-series information. Ocular artifact is detected and remove by the regression-based method of the adaptive filter and ARMAX modelling. In an adaptive filter, the coefficients are adjusted and calculated using the Recursive Least Square (RLS) algorithm. ARMAX uses a linear subtraction model [3].

SVM has some classifiers such as Least Square Support Vector Machine which is used to detect seizure and non-seizure activity. Power Spectrum Method is used to find the mental disorder of the brain. The adaptive filter and Spectral method analyze and detect the tumor in the brain. Emotion-based detection is done by the SVM technique [5].

In eye blink artifact removal, the various methods are available. The suitable methods are Blind Source Separation (BSS) and Regression Technique. PCA and ICA are part of BSS. EMD (Empirical Mode Decomposition) is the most powerful extraction tools to remove eye blink artifacts [19]. In this EMD, eye blink artifact is eliminated from EEG signals by utilizing the method of EMD and ICA (Figure 1). EMD-ICA are measured using the different eye blink and removes that artifact by converting artifact to signal ratio and signal to noise ratio. Compared with other techniques, EMD-ICA processing time is very less [19].

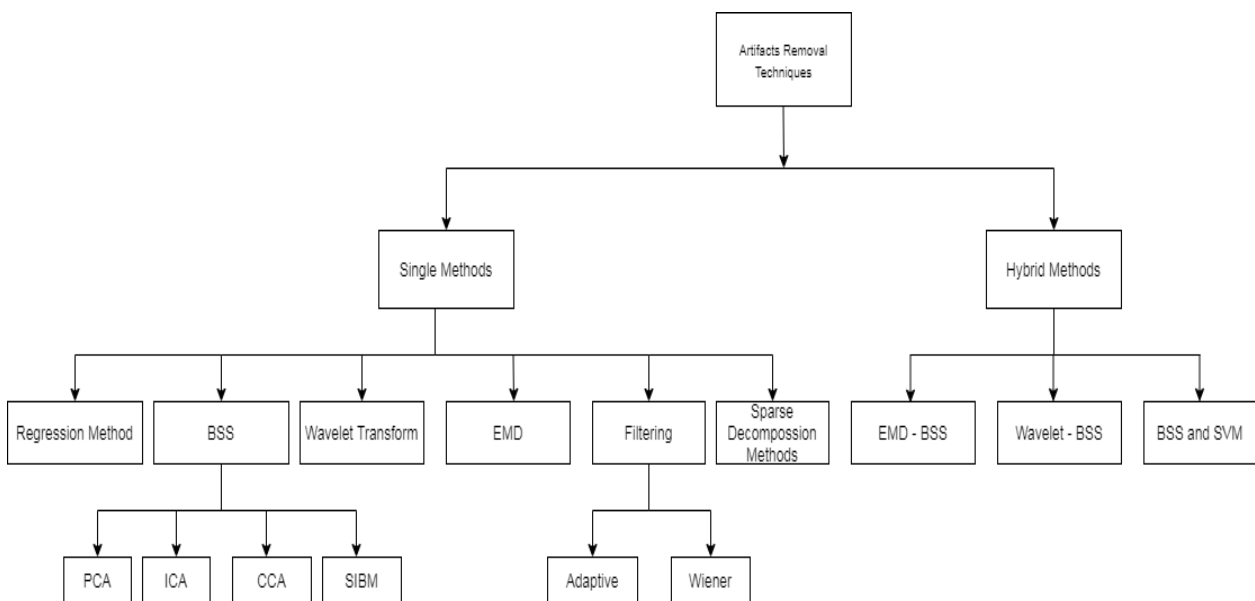


Figure 1. Artifacts Removal Classification



Ocular artifacts are contaminated with EEG data by eye movement, eye open, eye close, and eye blinks which is recorded by EEG activity. Ocular signals are recorded by the EOG (Electrooculogram). EEG signals are contaminated with the EOG. Muscle artifacts are measured by EMG (Electromyogram). EMG artifacts are caused by stretch, subject talks, sniffs, muscle proximity, and swallows. EMG is difficult to remove. ICA is the best method for removing EMG artifact. Cardiac artifacts are raised due to electrodes, are placed on or near a blood vessel. Cardiac artifacts are measured by ECG (Electrocardiogram) [21].

IV. APPLICATIONS OF EEG IN E-HEALTHCARE

EEG technique is discriminating the normal and abnormal brain signal by using several methods. The several applications are reviewed in this section. The features of the epilepsy, brain death or coma, brain tumor, and sleep disorders are discussed in the table 2 [15,16,17,18,22].

Table 2. EEG Signal Applications and Features

Applications	Detection Method	Features
Epilepsy	Convolutional Neural Network (CNN)	Time and Frequency Domain
Brain Death or Coma	Canonical Correlation Analysis (CCA)	Power Spectral Density
Brain Tumor	Artificial Neural Network (ANN)	Back Propagation Network and General Regression Network
Brain Injury	Machine Learning Method	Fourier Transform or Wavelet Transform
Speech Disorder	Machine Learning Method	Hidden Markov Model
Seizure	Parametric Spectrum Estimation, Machine Learning	Wavelet Domain

EEG has played an essential role in the application of BCI (Brain Computer Interface). In object controlling application, EEG can control various objects. There are wheelchair, robotic arms, and moving robots. In object recognition, EEG can apply the vehicle control task and gaze classification approach. EPR lie detector can find the liar. EEG can also record emotions from different users and voice signals from familiar and non-familiar. EEG is also applied in the field of drowsiness detection studies. EEG is used to recognize human preferences such as predict like/dislike response from a customer, human choice for products, movies, and designs [22].

V. EEG SIGNAL CLASSIFICATION

EEG signal classification is the very challenging task in e-Healthcare. In recent decades the EEG signal classification has various feature extraction approaches. This paper has reviewed various EEG classification approaches which are Pattern Recognition, Deep Learning and Artificial Neural Network. This three approaches has various methods are used to classify the EEG signal.

In Pattern Recognition approach [23], discussed classifiers such as SVM (Support Vector Machine), MLP (Multi-layer Perception), KNN (K-Nearest Neighbors) and Naïve Bayes (NB).

Support Vector Machine (SVM)

SVM classifiers separate the signals by classes such as hyper plane minimal and hyper plane maximal using kernel trick techniques training data which are, linearly separated [13]. SVM is classified [5], into three types namely Linearly

Separable, Linearly Inseparable and Non Linearly Separable. Linearly Separable is a high dimensional data classified into two groups,

$$Y = \{ +1, -1\} \tag{1}$$

Linearly Inseparable has produced high dimensional datasets with erroneous data that represented by ‘ε’ Non Linearly Separable transformed sample data into higher dimensional mapping function, $\phi(x_j)$. Kernel function, $K(x_i, x_j)$.

Multilayer Perceptron (MLP)

MLP is a neural network based techniques. It comprises of three consecutive layers, that is input, hidden and output layers respectively. Hidden layer is intermediate between the input and output layer and it is used to transmit the input data to output layer [23].

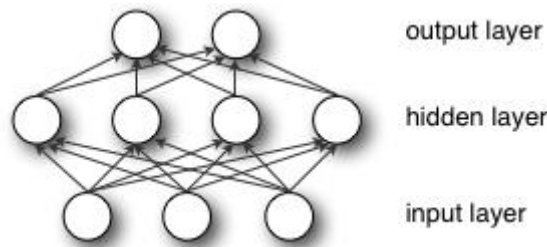


Figure 2. Artificial Neural Network

Hidden layer function,

$$f: R^D \rightarrow R^L$$

D – Input Vector Size

X and L – Output Vector Size

Matrix notation,

$$f(x) = G \left(b^{(2)} + W^{(2)} \left(s \left(b^{(1)} + W^{(1)} x \right) \right) \right) \tag{2}$$

$b^{(1)} + b^{(2)}$ - Bias Vector

$W^{(1)} + W^{(2)}$ – Weight Matrices

G and s – Activation Functions.

Naïve Bayes (NB)

Based on Bayes’ theorem data signals are classified by simple and efficient probabilistic classification. It is the most sophisticated method. Small amount of training data can be classified by using NB method with parameters. NB modes are maximum probability algorithm and probability distribution function [23].

Bayes equ,

$$P(c|x) = \frac{P(x|c) P(c)}{P(x)} \tag{3}$$

$$P(c|X) = P(x_1|c) \times P(x_2|c) \times \dots \times P(x_n|c) \times P(c) \tag{4}$$

$P(c|X)$ – Posterior Probability, c – target, X – attributes

$P(c)$ – Prior Probability

$P(x|c)$ – Probability Predictor

$P(x|c)$ – Prior Probability Predictor



k-Nearest Neighbor (k-NN)

k-NN[9], produces good result for separating epilepsy signal from normal signals. KNN role has explained which helps to detect disorder signal from normal brain signals.

$$d(x_i, x_j) = \sqrt{\sum_{p=1}^n (a_p(x_i) - a_p(x_j))^2} \quad (5)$$

KNN has predicted the closest points in the test data by using distance function. The distance function are Euclidean, Mahalanobis, correlation, Spearman, Hamming and cityblock.

The classification performance is considered for accuracy, sensitivity, specificity and precision.

$$Accuracy = \frac{\text{Total number of correctly classified instances}}{\text{Total numbers of instances}} \times 100 \quad (6)$$

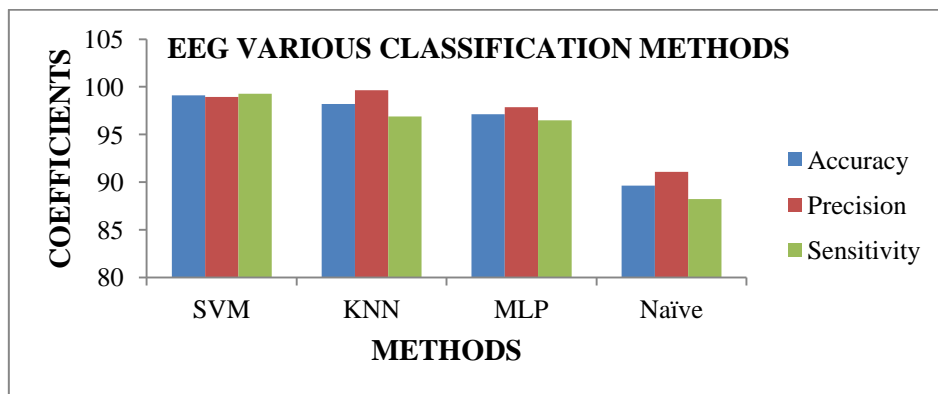
$$Sensitivity = \frac{\text{True Positive}}{\text{True Positive} + \text{Flase Negative}} \times 100 \quad (7)$$

$$Specificity = \frac{\text{True Positive}}{\text{True Negative} + \text{Flase Positive}} \times 100 \quad (8)$$

$$Precision = \frac{\text{True Positive}}{\text{True Positive} + \text{Flase Positive}} \times 100 \quad (9)$$

Table 3. EEG Signal Classification Based on Pattern Recognition Approach

Methods	Accuracy	Precision	Sensitivity	Specificity
SVM	99.11	98.93	99.28	98.93
KNN	98.21	99.64	96.88	99.63
MLP	97.14	97.86	96.48	97.83
Naïve	89.63	91.07	88.24	90.77



Based on pattern recognition progress to classify EEG signals utilizing SVM, MLP, NB and KNN. According to the table SVM and MLP classifiers yield 99.11% and 97.14% exactness. SVM is the most highest accuracy when compare

to other three methods. KNN and MLP classifiers have accomplished 98.21% and 97.14% correctness. Finally in this survey the mix of DWT and FDA and PCA techniques give better feature extraction approach for classification [23].

VI. CONCLUSION

Nowadays, the rapid growth of biosensor technology to determine the disorders in the brain is a very difficult challenge in the research area. In that point EEG is the most advanced technique, to detect the abnormality of the disabled signals in the brain. The signals are captured in the waveform and artifacts are removed from advanced methods like artificial intelligence, machine learning, and deep learning. This paper explains the EEG basics, various artifacts, applications, various classification methods in pattern recognition approach and also the challenges of EEG.

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