

A SURVEY ON CONVOLUTIONAL NEURAL NETWORKS FRAMEWORKS ON ELECTROENCEPHALOGRAPHY DATA**Sneha Mishra^{1*} and Umesh Chandra Jaiswal²**

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ABSTRACT

The inception of learning was through neural networks. ANN has ushered into many fields providing solutions for critical solutions, particular in medical and health care systems. Brain neurological disorder is epilepsy; electroencephalograph is the tool to study it. EEG recordings consume lot of time and they are with uncertain frequencies. Only experts can study and diagnose epilepsy perfectly, even uncertainty rules over into ambiguities. Deep Learning has solutions to solve on the data with multivariate, temporal, uncertainty in nature. EEGs are obtained as signal data as frequency graphs from the electro-encephalography devices, digitized into images. Feature extraction and classification is the most challenging on EEG signal datasets. In this paper, a survey on EEG data sets, analyses method and contributions of CNN in EEG signal data analysis have been discussed, to provide direction for the researchers to handle the most challenging problems.

Keywords: Electroencephalography, Convolutional Neural Networks, Deep Learning

INTRODUCTION

As per World Health Organization (WHO), around the count of fifty million in the affected multitude suffer by epilepsy and each year a lakh and eighty thousand cases are recorded, amongst of three quarters of the subjects do not have medical assistance. A neurological ailment of the brain sources frequent seizures unpredictably into abnormal consequences. Frequent occurrence of seizures in a subject causes amnesia, mild depression, persistent headache, coma and even death [39]. In toto of the population around the world 70% of the subjects are adults and 30% are children. Low oxygen levels during the birth, head injuries, brain tumors and abnormal intake of sodium and blood sugar leads to untoward conditions of epilepsy. In certain conditions amongst the major group of 70%, reason for the occurrence is not discovered, particularly for the children.

The dawn of big data analytics blended with machine learning [31][41][43] fortified the world as data and knowledge driven entity. Computational power used to parse and analyze the data depends on the complexity of data representation. Substantially atypical activity of the brain, project electrical signals [67] by neurons, recorded by electro-encephalography, a latent understanding of human behavior through brain sub-conscious acts. Recording, analyzing and interpreting EEG signal data have been a creative challenge for the researchers in brain computer interface [2].

EEG and EEG Data

EEG has complex forms of representation of data. Artificial Intelligence and Machine learning [31][41][43] exceptionally becomes accountable for developing many methods and algorithms for the cause of understanding, analysis and presentation of the EEG data. Early to the inventions of artificial intelligence and machine learning, the clinicians used to script algorithms to extract valuable information from EEG signals [11][15][27][57][67]. The Machine Learning [31][41][43] with Deep Learning [40][45] has a potential to deal dynamic problems with complex data forms demonstrably.

Epilepsy holds fourth position in neurological disorders in the world. A routine scalp electroencephalography [19][29][32][49][62] has to be explored as a fundamental test for diagnosing epilepsy. Interictal Epileptiform Discharges (IEDs) [29][47][51] are considered to be the latent proofs with spiky morphological characteristics from the background activities can detect the early stage of epilepsy than time invariant ictal and seizure, which are and time consuming to diagnose.

The best of the standards for diagnosing epilepsy is identifying IEDs with visual inspection. This can be achieved by experts, which may consume much time, cumbersome and a conditionally subjective process. Therefore, an automated development of the IEDs detection process shall be augmented with approaches said in the consensus of literatures such as mimetic analysis, neural networks, wavelet-transforms, template-matching and parametric modeling [43][44][47][51]. In the recent years, the methods and automated frameworks developed using CNN has showcased a top positional appearance in achieving higher efficiency in epilepsy detection [32][33][34], diagnosis and monitoring. The monitoring of EEG signal data mainly vests with the methods of seizure detection, classification [8] and IED detection.

EEG signal data processing comprises of electrical signal recordings of brain to decode the behavior and activity of the brain. It is almost equally estimating the relationship between the signals and the activity of the brain. EEG signal data contain complex patterns with blend of noise and combinations of raw artifacts, where usually the input is a raw data represented as a wavelet or frequencies graph [7][11]. Readings of the recordings are EEG, a multichannel [14], multivariate [25] representation of various characteristics with dynamic correlations, which usually differs amongst the subjects. The periodical traits in the recordings of electroencephalography of the subjects are drawn into four periods [32][33][34]: *interictal*, *pre-ictal*, *seizure* and *post-ictal*.

CNNs of deep learning [40][45] can be used to resolve the anomalies in the complex EEG signal data. Stober et al.[1] has advocated on rhythm stimuli of music from electro encephalograms, around 15 rhythms are classified belonging a genre of music, the CNN experimentation by Cecotti et al. [2] detected 16 characteristics from the EEG signal data analysis. CNN for EEG signal data analysis has been discussed various pioneer researchers, in this paper we analyze the basics on deep learning with some select articles that project the current state of the art methods to work on EEG signal data. Furthermore, limitations and advantages of CNN in EEG signal data analysis are discussed.

EEG Data Analysis

Quite a long duration and waits are required in epileptic seizures [52][54][55][56][59][60] to generate electroencephalography signals[57][67]. Visual investigation and analysis of recordings consume time and often leads to inefficient and inaccurate conclusions [42][47][51]. Noise characteristics meddle with the electroencephalograph signals becomes challenging separating from artifacts of time-domain frequency patterns [13][20]. Machine learning [15] [31] algorithms succeed in automatically detects and predicts the nature of the signals from raw forms of EEG signal data. In a dataset [35] referred from UCI, the data set represents various attributes in EEG as HB for Healthy Brain, EL for Epileptic Seizure [52] [54][55][56][59][60], EC for Eyes Closed, EOP for Eyes Opened, [35] etc.

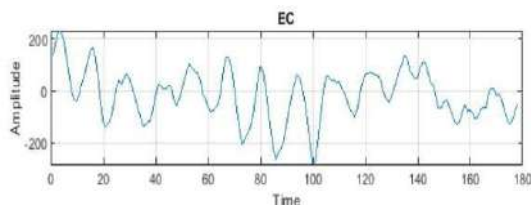


Fig. 1(a). EEG; eyes while closed

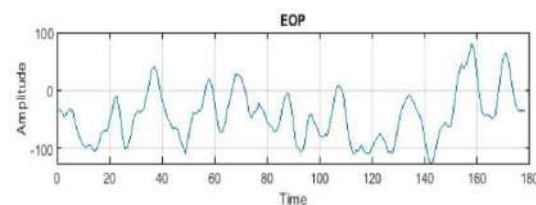


Fig. 1(b). EEG; eyes while opened

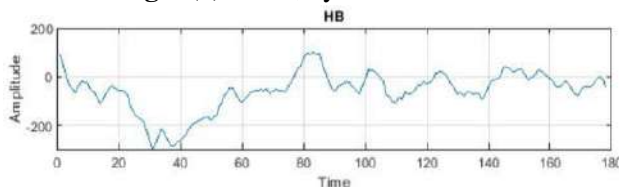


Fig. 1(c). EEG; of healthy brain

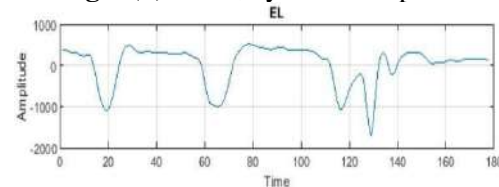


Fig. 1(d). EEG; of epileptic seizure

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A spectrogram-based data analysis [15], uses spectrogram of EEG [16] similarity of images live, coma and dead subjects is studied and further the time-domain [13] [20] signal is converted into discrete forms of spectrogram images which help deep learning methods [40][45] in EEG signal data classification.

The artifacts of EEG signals [57] mix with noise, thus they are referred to as raw. Channels and frequency bands are more often referred in EEG signals to classify emotions [3][4][6][7]. EEG signals are traced with multiple frequencies to detect the motor imagery skills and certain involuntary actions of hands [23][38]. Deep belief networks [46] are essentially applied for fast classification and detection [57] with most probable anomalies in measurements. Sleep stage detection [58] and coma stage detection is quite simple for the analysts, the EEG signal data is studied with frequencies. CNNs play vital role in understanding the cognitive skills, motor imagery skills, sleep stage skills and any kind of alcoholic prone brain states. Even the influence of noise has profound importance in the research of EEG data with deep convolutional neural networks, in Alzheimer's particularly. Bands of frequencies of noise can be observed and selective filtering methods can be applied for precision classification during training and testing processes of learning.

Systematic Literature Review

The consensus of literature with all propositions have been collected and considered for the review. The articles collected from most reliable digital sources; categorized, filtered and labeled using keywords. The combinations of the keywords that are applied to find the research articles include i) epilepsy, ii) epileptic diagnosis, iii) encephalography, iv) EEG, v) EEG signals, vi) EEG signal data, vii) periodic forms of epileptic seizures, viii) brain-computer interfaces, ix) CNN in EEG data analysis, x) EEG signal data interpretation, xi) EEG signal data images, xii) EEG data classification, xiii) CNN in diagnosis of epilepsy.

Keyword Groups in Systematic Literature Survey

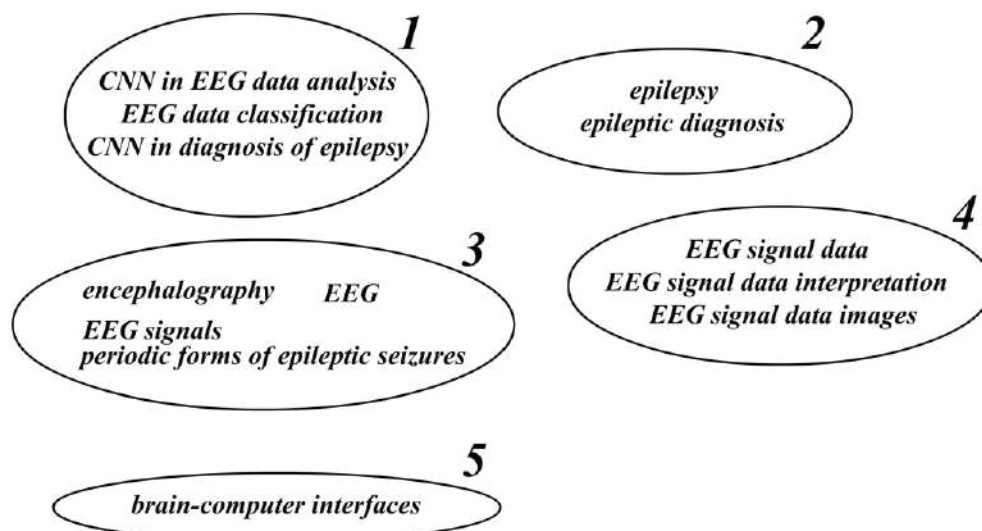


Fig. 2: Keywords are grouped in order to estimate the collections

The criteria for consideration of literatures are defined by the collection of keywords, the study of the research area needs a broad understanding from the non-automation to automation methods of applying learning in classification of EEG signal data and subsequently into diagnosis, they keywords are grouped as stated in the Fig. 2. The inclusion criteria expand into groups of keywords ensuring relevant collection of articles, conversely other documents in exclusion criteria. The collection of the articles are once again segregated into two periodic intervals of 2010 – 2014 and 2015- 2020. However, there exist so many publications and articles before these periods, are not measured for the systematic review, still their credits remain relevant. Following graphs project the collection of articles keyword-group wise and period-wise.

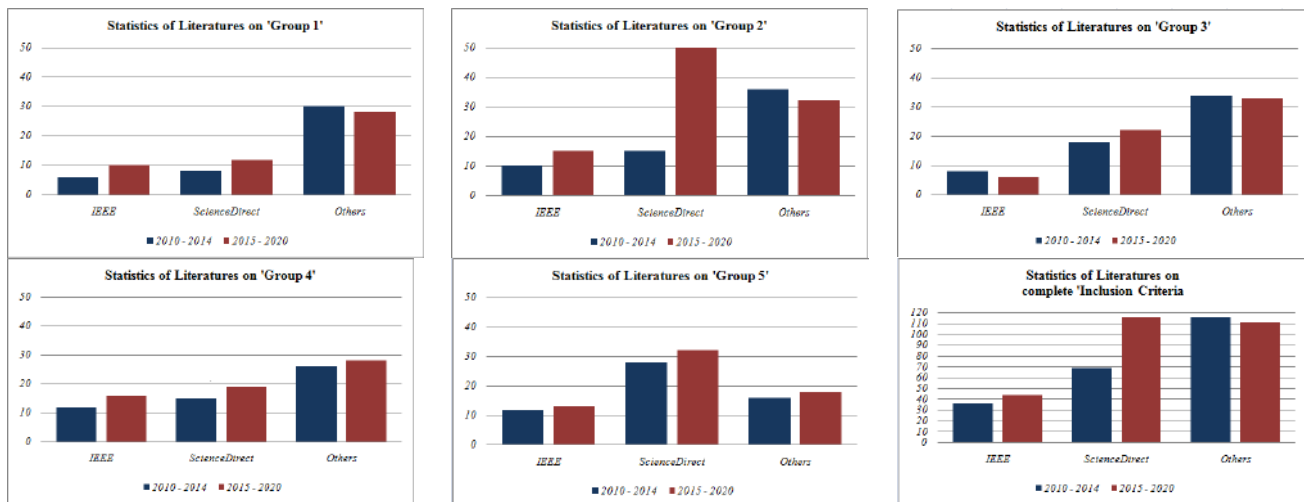


Fig. 3: Statistics of Literatures collected based on keyword-groups of inclusion criteria.

In the experimentation of EEG data analysis, shallow machine learning models like support vector machines; principal component analysis and linear discriminant analysis are combined with the convolutional neural networks [53]. End-to-end automated emotional recognition with automatic learning enhances the learning efficiencies and substantial improvisations in accuracy using convolutional neural networks [3][4][6][26][38]. The consensus in literature reviews comprises of publications pertaining to ‘epileptic electroencephalography’, online from various reputed organizations like Elsevier, IEEE Xplore, ScienceDirect, which support the technologies and state of the art models in CNN to augment EEG signal data analysis. Selection of EEG channels [14], feature selection, seizure detection [57], conversion and interpretation of EEG signal data, EEG signal data to EEG images and convolutional methods [53] in neural networks for EEG image data classification were the objectives in the preliminary studies of the literatures. Epileptic seizure detection [52][54][55][56] and analyses on EEG image data, entropy analysis [21] on EEG data with non-linear features [5], labeling [12] and keyword-based search are at the next level of studies of the literatures. Research tools like Mendeley, ScienceDirect were employed on the empirical analyses of the journal publications.

Many methods for automatic detection of seizures are proposed in the recent research. Amongst the erstwhile analog methods, the time-frequency domain [13] [20] methods play a predominant role along with non-linear methods of machine learning [15][31][41][43] in EEG single data analysis and are prudent in reliability, accuracy and efficiency[5]. Methods of machine learning and deep learning [40][45] tender quick mechanisms to extract features and classes from the EEG signal data when compared to generic signal processing procedures.

A study protocol on children hospital at Boston has been followed [65], where two groups are identified, first group is treated for ictal forms of encephalography signals and second group is treated for electrographic onset of a seizure using a computer. The database collected yielded with most sublime factors which pave solutions for analyzing EEG features. The goal and objective of the article is to work on design and evaluation of “clinical test on seizure onset detection algorithm”.

A framework using bi-clustering and extreme learning methods (ELM) [71] has been proposed by Qin. et al., which directs towards classification of seizures and non-seizure in EEG signal data. Many analog methods are used in [72] a novel idea is projected about time-frequency using local mean decomposition and support vector machines for the classification of EEG signal data including features. The complete recordings of EEG signal data are analyzed empirically and decomposition is also accomplished in [73] by Bhattacharya et. al. They have also utilized support of wavelet transform with least squares blended work with focal and non-focal classes using support vector machines. The affect of epilepsy has a spectrum, inclines in the form of disorder when the seizure experiences in the aided milieu and encephalogram is the mechanism which aids in this study [34]. Automation of

classification in the EEG signals is accomplished with CNN deep learning models, almost a central idea for all the research accomplishments in the recent times. The model presented in [34] not enough though to accomplish the expected accuracies but efficient and can be improvised. In the works of Yimin Hou et. al [74] a concept of EEG source imaging (ESI) is introduced which will generate the equivalent images for the EEG signals in coordination with the iterations of the CNN to process the four-class motor imagery which uses weighted norm estimation. Physionet is tested on the database of brain-electric signals, a work towards developing a global classifier. The experiment has achieved mean success of 93.30%, but has improvisation and better performance [30] with physio-scouts. A comprehensive attempt on the study of electro encephalography has been undertaken by W-L Mao et. al.in [49], with a simple variant of CNN architecture. Without overlaps a time-window based voltage frequencies of the EEG signals converted to image forms of normal printing resolution are used in EEG segmentation [9], Chainer v 1.2.4 of Python is used in the programming [27]. In Ciaran Cooney et. al. [36], brain-computer interfaces use transfer learning [27] [28] [36] towards solving the problems of classification of EEG signal data, though not exaggerative, methods of transfer learning generate accurate results on successive reinforcements. Finding the state of mind during the Resting state with closed eyes (REC) and Resting state with open eyes (EO) and detecting the electrical signals as brainwave patterns for the personal identification [24] [37] [61] helps in biometric signature in biometric system [37]. Almost 88% of accuracy has report in the article for a minimum 10-class classification of subject's brain wave patterns. Hence, the achievements prove the methods of deep learning [40] [45] with convolutional neural networks depose intensely in the diagnosis and analysis of EEG signal data for epilepsy disorder and seizures.

DISCUSSIONS

Hinton et. al. [70] propounded Deep Learning analogous to human thinking. Many abstract comprehensions and levels of filtering combine lower level layers to higher level layers representing the attributes stated in the problems towards enunciating the distributed qualifiers in data. Deep Belief Networks [46] work as greedy layer-by-layer training algorithm with allied Deep Confidence Networks. Solutions for many optimization problems with crispy results are flexibly narrowed taking advantage of deep learning [40][45]. A complex model of data with iterative strides could be solved with proven accuracy for many big data based problems.

Researchers of deep learning has increased rapidly ever since 2000, exploring into new methods finding responsibly solutions in diverse fields. Natural Language Processing, Image Recognition, Speech Recognition and some other fields are interesting to get dynamic solutions for their complex built of models using deep learning, therefore it is not less to employ the deep learning methods to parse and analyze EEG signal data.

CNNs employ almost eight layers where five are convolutional and three are fully-connected layers for image classification [48][63], which is akin to the ImageNet. The factors that influence on the performance of the training and testing are due to nonlinearities that are saturating during the propagation in the layers, which is also referred ReLU. ReLU influences at the kernel level at each convolutional layer, the kernels of convolutional layers are connected to kernel maps of the previous layers in the sequential propagation.

The fundamental characteristic of the signal is single-channel [14], therefore EEG signals appeal as nonlinear and non-stationary, where iterative filtering is applied in decomposition of such non-stationary signals. Features are extracted from the non-stationary signals during decomposition. The features are given as input to a set of classifiers and their performances [30] are empirically compared with the respective frequencies developed from the brain electrical waves naturally, in order to study the structures of the recordings. Different sets of classifiers are participated and formulated as multi-class classification. The multi-class classification problem is evaluated for each class in the classification problem.

Table 1: Various CNN methods and frameworks employed on EEG Signal Image datasets

S.No.	Authors	CNN and Methods	Epileptical Status	Accuracy
1	Sebastian Stober et. al. [1]	A Deep Learning SVM based CNN with Sequential Application with stochastic gradient descent	Distinguishing the rhythm stimuli	97%
2	Panagiotis Tzirakis [4]	A multimodal system that operates on raw EEG signals	Affect Recognition based on raw EEG signals	88%
3	Poomipat Boonyakitanont et. al. [5]	A potional applicatoin of Machine Learning and Bayes Classifier	variance, energy extracted from raw EEG to distinguish seizure and normal EEG signals.	98%
4	Vikrant Doma et. al. [6]	neurophysiological mechanisms, SVM, Naïve Bayes, Decition Trees	Emotion Classification with raw EEG sgnals	98.01%
5	D. Gajic et.al. [8]	Time-Band Decomposition using standard CNN model	Energy entropy based EEG signal segmentation	90%
6	Siuly Siuly et. al. [10]	Random Sampling, k-NN, SVM with CNN and Optimum allocation	detection of multicategory brain dynamics quantification through EEGs	90%
7	Ali Shoeb et. al. [50]	Binary Classification and Feature Vector Detection	detect the onset of epileptic seizures	96%
8	Alex Krizhevsky et. al. [63]	ImageNet on 1000 different classes	Classification of EEG Signal Data	62.5% to 83%
9	Afshin Shoeibi et. al. [64]	DL techniques such as CNNs, RNNs, and Aes	fast detection of epileptic seizures	90%
10	Manish Sharma et. al. [69]	Time-Frequency Localised Bi-orthogonal Wavelet Filter with CNN	EEG Signal Data Classification	90%

Amongst the tasks of machine learning [31][41][43] and deep learning[40][45] the most challenging is classification, particularly when data sets are uncertain with more complex attributes. The needy area of classification is to identify the appropriate classes, where attributes have to be explored studying different characteristics. A binary classification [17] model on multichannel EEG has been proposed by Ali Shoeb et. al [50]. The challenging part of the algorithm is to track the brain electrical activity through EEG signals with particular montage points; an appropriate machine problem is shaped out of the study of the attribute and channels of the EEG signal data. In [66] Yang Li et. al. has described the way of unified temporal spectral squeeze and excitation network, which coordinates with a minimum efforts of maximum mean discrepancy and mitigating minimizing-discrepancy in overfitting problem.

According to survey in epileptic signal classification by J. Prasanna et. al. [75] epilepsy is due to electric signals transformed from brain which may be drawn into power spectrum density diagrams. A deep CNN may be employed to chart the power spectrum images and identify the period states of epilepsy as interictal, preictal, post-

preictal, seizure. Case studies from CHB-MIT epileptic EEG data were instrumental in the proofs of the experiments. Classification accuracy achieved is potentially to reduce the damage caused from seizure occurrences. The classification model has to be proven a good performantly comparative to other LSTM based DCNN algorithms. According to the model proposed by J.X.Chen et. al. [23] on the epileptic EEG signal data with disorders in the subject, an end-to-end learning of signals aids in detecting the periodic states of the epilepsy or for a normal brain electrical signal, which are attributed with spatial and temporal dimensions. A simple Bayesian network can worked on the binary classification and building of a shallow machine learning model would yield good results.

Rahib Abiyev et. al. [24] has propounded a novel ideal of CNN for epileptic EEG signal data classification. According to the consensus by the author, epilepsy is a neurological disorder which yields into different types of signal data, which may intensely require ensemble methods blended into CNN for efficient classification.

Dynamical Graph [53] Convolutional Neural Networks was proposed by Tengfei Song et. al. [3], which is one of the outstanding frameworks for classification. The theory of dynamic learning into intrinsic relationships pertaining to newly discovered features is introduced for EEG signal data classification. DREAMER, a data set which exclusively contain the EEG signal data set with all the feature specification is used in the algorithm, a better version of feature recognition on dependent and independent subjects is explored.

Cheng Lian Liu et. al. [25] propounded a multi-view convolutional neural network framework which works for the EEG signal data collected from different montage pints and comparison are made from each montage point. The signals produce unpredictable similarities with seizure challenges which meet in the experimentation with feature extraction [5] with respect to different frequency and time domain [13][20] aspects. A normal study of electroencephalogram needs to work attentively for understanding the features of epileptic states, which may temporally connect and disconnect at several montage points.

CONCLUSION

Emanating electrical signals of brain whether a healthy or ailed subject need to be precautionarily studied for predicting the future damages of the brain and other allied diseases. A physical electrical station in the brain affects all the subjects irrespective of gender, age and other cohort conditions. General, thought of the conditions of epilepsy is experiences that stamp in the subconscious region of the brain; thus, a neurological disorder causes frequently occur, even to a serious seizure which shall be rudimentary for the EEG signal data examination [27]. Though time taking and force waits cause cumbersomeness, the acquisition of EEG signal data is always worth inspecting, analyzing unconditionally. Feature extraction and categorization of EEG signal data for classification is the primary task that needs to be automated at every instance of EEG examination. Various deep learning [70] and machine learning methods have been studied in the surveys, which are automated, classifier based and attribute-oriented learning, are very have influence in developing a novel [24] [69] [72] idea to improve the speed and accuracy of determining the nature of the EEG signal data acquired for a subject. This survey gives a route map to work on the necessities of the development in deep learning using various forms of convolutional neural networks to bring out the most feasible solution to track the nature of electrical signals that emanate from the brain, through understanding the affects. Performances, as mentioned in [18] [30] of each method and algorithm both in deep learning and other statistical methods have been studied and drafted in this paper to enable researcher to drive towards developing most feasible composition of components in Convolution Neural Network.

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