Machine Learning Approaches for Efficient Analysis of Neuroimaging Techniques

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Abstract: Machine Learning has a significant role in each person's daily life and plays a vital role in making life easier by contributing to various models where the machines learn and do the tasks better. Much research and development around machine learning algorithms and their applications are happening for classifying and clustering multiple types of data in several domains. Health care research also impacts machine learning in analysing different data for patients. Different types of image and Neuroimaging data analysis are the areas where a significant amount of research is happening with healthcare and machine learning. Neuroimaging data obtained from the imaging techniques like MRI, CT, fMRI, PET, and other techniques help doctors identify various disorders. Commonly studied diseases with the help of neuroimaging data include the disorders like Alzheimer's, MCI, Parkinson's Disease, and Autism. Machine learning algorithms are developed for the straightforward interpretation of neuroimaging data and identifying neurological disorders. Interpreting neuroimaging takes a lot of assumptions and risks by doctors; commonly used and developed Machine Learning models are CNN, SVM, ANN, and Deep CNN. The use of proper machine learning models can help doctors to validate their assumptions in critical conditions. The paper focuses on a survey of various approaches by researchers to bring out neuroimaging analysis models and identify effective models. The research also covers the multiple diseases and the best models available for detecting the disorders. This research aims to identify the challenges various researchers face while creating the models and the limitations of their models, and how machine learning algorithms could effectively analyse neuroimages.

1. Introduction

Machine learning is the process of helping machines to learn and perform tasks that humans cannot do precisely. The machines can perform these tasks with precision and high efficiency. There is a wide range of machine learning algorithms that work on various approaches to machine learning. Identifying the appropriate model for the task and making the machines learn these tasks to machines with a high range of precision. Machine learning algorithms can process text, images, or signals from various devices to measure multiple factors. One of the main domains is machine learning application research is carried out extensively in healthcare. The researchers try to create models that the medical practitioners can use to ease their work in analysing various data obtained for the disease diagnosis. There are multiple applications where machine learning algorithms can significantly contribute to analysing the data obtained from multiple neuroimaging devices.

Neuroimaging techniques play a crucial role in identifying various neurological disorders. These images help in the early diagnosis of the diseases, which will help the patients take care of themselves before the conditions related to the diseases become worse. Researchers focus on studying various neuroimaging techniques and applying machine learning algorithms to predict or classify diseases. The researchers take multiple approaches to solve the problems; the common problem they work with is categorising the disorders or detecting the same. Researchers also focus on using various inputs rather than using the information from the neuroimaging techniques to make the predictions more accurate. Most researchers are applying deep learning models for multiple problems.

Neurological disorders are medical disorders that affect the brain and the nervous system. These usually include structural, biochemical, or electrical abnormalities. Various neurological disorders are identified with the help of neuroimaging techniques. The neurological disorders include Alzheimer's, MCI, Parkinson's Disease, Schizophrenia, and Autism [1]. Researchers try to work with various neuroimaging data to identify neurological disorders with the help of various neuroimaging data. Identifying the disorders is done with the help of extensive feature extraction and selection process. The researchers also study the extraction of multiple features for processing. At the same time, some algorithms work on the imaging data and preprocess the images with different techniques to classify and categories the images according to the classes.

The commonly used methods for brain imaging include the following: Functional Magnetic Resonance Imaging (fMRI), Computerised tomography (CT), Positron Emission tomography (PET), Electroencephalography (EEG), and Magnetoencephalography (MEG). These techniques generate the data used by the machine learning algorithms to analyse neurological disorders. Identifying the efficient machine learning algorithm for the prognosis of neurological disorders is a challenging task. The main reason for this problem is the nature of outputs generated by the imaging techniques. Apart from the difference in data, the patient's lifestyle also plays a significant part in the disease. So many researchers try to study from this angle, connecting various external factors into the study; such studies stay incomplete as most of the elements may not play a significant role in the disease. However, these techniques can capture neurological images to analyse various disorders.

Machine learning algorithms categorised under deep learning techniques play a significant role in analysing these data. Feed-Forward Neural Network (FFNN) under Artificial Neural Network, Auto-Encoders (AE), Deep Belief Networks (DBN), Deep Boltzmann Machine (DBM), Generative Adversarial Networks (GANs), Convolutional Neural Network (CNN), Graph Convolutional Networks (GCN), Recurrent Neural Network (RNN), and Long-Short-Term Memory (LSTM) are some of the algorithms that are commonly studied for the prognosis of neurological disorder and the analysis of various neuroimaging data [2].

2. Related work

Neuroimaging plays a significant role in diagnosing and treating various neurological disorders. Neuroimaging also have played a substantial role in drug discovery with the help of machine learning applications by giving precise information on the effect of drugs on the human body by classifying the various data points into different categories [3], making the study easy. Similarly, neurological disorders, which deal with the change in the biological organisation of the brain, can be studied with the help of machine learning algorithms and tools, especially with network-based models [4]. Different researchers across the globe study various neurological disorders; some of the major neurological diseases that those researchers work on include Alzheimer's disease [5], where the studies revolve around the multisource fusion data used for the prediction of the disease more effectively. The data can be collected from various heterogeneous data sources, where the data is commonly extracted from structural magnetic resonance imaging (MRI), cerebrospinal fluid (CSF), genetic, positron emission tomography (PET), and demographic data sources, where we could identify the importance of various neuroimaging techniques and their role in providing data for the disease classification.

Machine Learning algorithms play a massive role in classifying various data. That is a common approach that the researchers work with the neuroimaging data sources. The performance of the machine learning algorithms is always studied for evaluating performance of the machine learning algorithms. Many researchers have identified that the choice of machine learning algorithm significantly impacts prediction accuracy when working with neuroimaging data [6]. Many attributes play a critical role in neuroimage processing. One such factor that plays a significant role in the machine learning models is the sample size; the higher the sample size, the models perform better. Neural network machine learning models like Elastic Net, Random Forest, and Gaussian process regression are standard models that play a considerable role in comparing with other models with the change in sample sizes.

Many machine learning algorithms are designed to study neurological disorders like Parkinson's disease detection. Researchers perform comparative studies with these various models to identify their efficiency of the models. The classification approach has been followed by many researchers for handling Parkinson's disease [7]. However, the data used by the researchers are voice-based datasets, where they have benchmarked the standard machine learning algorithms like Multilayer Perceptron, K-Nearest Neighbor, and Support Vector Machine to compare and contrast the performance of the models. Studies could conclude that these algorithms can be used to develop models for the early detection of diseases from various data sources.

Alzheimer’s disease is another incurable neurological disease affecting the elderly population [8]. A lot of research revolves around developing efficient automated techniques required for the early diagnosis of the disease. ANN, SVM, and deep learning technique-based algorithms are the main algorithms used in the study to create efficient models for the prognosis of Alzheimer’s disease. Ensemble methods are also commonly made by researchers who focus on creating efficient models for disease detection. Artificial intelligence approaches, with machine learning and deep learning, and computer vision techniques, are used for the prognosis of neurodegenerative diseases and analysis. The data for this analysis is usually collected from neuroimaging techniques [9]. The commonly used imaging techniques for the different disease prognoses include Magnetic Resonance Imaging, Single Photon Emission Computed Tomography, Computed Tomography, and Positron Emission Tomography. These inputs are used better to identify neurodegenerative diseases like Alzheimer’s, Parkinson’s, and many others.

Machine learning and deep learning applications like Support Vector Machine, Random Forest, K Means, and Convolutional neural network are a few algorithms that are used and studied for various inputs from the neuroimaging techniques; sometimes, the information from the data sources is not compatible with the use of algorithms. The current developments in recent years support the use of new and powerful supervised machine learning and classification algorithms with the help of enhanced neural networks and learning models [13]. The researchers concentrated more on the detection and classification of dementia.

Identifying efficient machine learning algorithms for a specific task is where heavy research needs to be carried out. This means that the machine learning algorithms sometimes work better when used alone with properly preprocessed data. The data collected from various sources sometimes requires preprocessing and transformations with the different models. This process sometimes will decrease the accuracy of the algorithms as well. Identifying the efficient model is often a challenging task. However, identifying the efficient model from the existing models is a difficult task, again due to the various models’ data and other parameters. The findings from the study are discussed below in the findings section, where the models identified are expressed in the form of a tabular structure for efficient understanding of various models used for the different use cases. A lot of research articles are studied and the findings are summarised below in the findings section, where we can see the best performing machine learning algorithms with the various neuroimaging data and commonly studied neurological disorders.

3. Findings

From the survey of various papers that are aligned for the creation of the study on the machine learning models for the analysis of neuroimaging data for the detection of neurological disorders, we could observe and find out the various dataset the researchers used for multiple investigations for the neurological disorders, The effective machine learning models that the researchers were trying to build for multiple diseases. And we reviewed a few neuroimaging techniques in detail to identify efficient machine learning algorithms for neuroimage analysis. From the survey as part of the study, the commonly used data by the researchers for the analysis of various neurological disorders are summarised in Table 1.

Table 1. Neurological disorders and the data used

Disease	Data Used
Dementia, MCI and Alzheimer’s	MRI, CN, PET, rfMRI, MCI, fMRI, CSF, EEG, EMCI, LMCI, Gene Sequence, AD data
Parkinson’s Disease	SPECT, PET, Data from a wearable device, MRI, SPECT images, EEG, Speech, Audio, CT-MRI, MRI-T1W1, Handwriting images, DTI, CT, Transcranial sonography,

Schizophrenia	rs-fMRI, sMRI, FC (multimodal), SC, MRI, EHR, MRI-T1WI
Autism Spectrum Disorder	rs-fMRI, Kinematic Data, FC, SC, Genes, Familial gene pathways, Eye movement, Audio
Epilepsy	FC, EEG and ECoG Signals, MRI-T1W1, CT, rs-fMRI
Multiple Sclerosis	Clinical, Survey, Gene Expression, DWI, Genetic, MRI, Lipid Markers, SNPs, Gait Data, Immune repertoire,
Brain tumour, lesion, and haemorrhage	MRI-T1W, MRI PET, MRI-T1WI, MRI, DTI, EHR

Many researchers have focused on creating machine learning models for various neuroimaging data processing. For the prognosis of neurological disorders, the commonly worked neurological disorders and the machine learning models are summarised in table 2.

Table 2. Neurological disorders and machine learning models

Disease	Existing Methods
Dementia, Alzheimer's Disease, and MCI	CNN, SAE, SAE, 3D_FTCNN, 3 D-CNN, Multi-Level CNN, Alex Nets, DBM, Stacked-denoising sparse auto-encoder, SVM, MDL
Parkinson's Disease	Fuzzy C Means, SVM, NN, KNN, Regression & Classification, RBFNN, Random Forest, PNN, ANN, Naive Bayes, Linear discriminant, vector quantisation
Down syndrome	KNN, SVM, SVM-RBF, SVM-Linear, Random Forest
Autism Spectrum Disorder	Logistic Regression, SVM, Naïve Bayes, KNN, ANN, CNN, AD Tree, Neural networks
Epilepsy	DLSTM, D-1DCNN, 3DCNN, DCNN, DNN, BLSTM, DBN, RNN, CNN
Multiple Sclerosis	Fuzzy logic based Sugeno model, DT, MLP, LVQ, RBF, NLP, ANN, SVM
Stroke	ANN, SVM, Adaptive boosting, SR-KDA, Deep CNN, M-SVM, Non-linear regression model

As part of the study, we studied the most worked neuroimaging techniques; we could identify that many studies revolved around the fMRI and EEG data. Various diseases have been studied; from that, we could identify a few models that work better with fMRI and EEG for various neurological disorders, The major neurological diseases, the problems the researchers worked on, the machine learning model, and the dataset they have used for fMRI and EEG are summarised in Table 3 and Table 4.

Table 3. Machine Learning models for fMRI

Neurological disorder	Problem	ML model	Dataset
MCI	MCI Prediction	Graph convolutional networks (GCN)	Alzheimer's Disease Neuroimaging Initiative (ADNI)

ASD	ASD Diagnosis	stacked multiple sparse autoencoders (SSAE)	Autism Imaging Data Exchange (ABIDEa)
Schizophrenia	Schizophrenia diagnosis	Deep Belief Network (DBN)	Multi-site1

Table 4. Machine Learning models for EEG

Neurological disorder	Problem	ML model	Dataset
Alzheimer's	Diagnostic of Alzheimer's	SVM, DL	CUH
		DNN	GODC
Epilepsy	Diagnosis of Epilepsy	RNN	EEG signals
		SAE	
		RNN	
		CNN	
		SSDA and Convolutional Auto-encoder (SSDA, CAE)	Scalp EEG dataset

From the survey and the study conducted to identify the efficient machine learning approaches for neuroimaging data to identify the various neurological disorders, we could find that detecting the neurological disorders from the neuroimages is challenging with multiple types of neuroimages of different classification models. It is essential to develop a model that can accommodate various neuroimages to detect neurological disorders. It helps doctors use the standard model to screen neurological disorders quickly. Incorporating the multiple neuroimages helps the doctors to widen their search space initially and then narrow down their diagnosis domain to make more quick decisions, which will eventually speed up the treatment process.

Commonly followed methodology for the multimodal neuroimage analysis for the multimodal predictions and classifications for various diseases include the following steps; Data acquisition and feature extraction are one of the main steps, where the data is obtained from various sources, and then the required features are identified and extracted from the images. Identifying the best learning frameworks is the next important step in multimodal creation. Once the models are identified, training the models for effective models and predictions are being done. After identifying and training the models and then creating the multimodal step, various multimodal creation techniques; one commonly used technique is multimodal data fusion. Once the multimodal is created, the models are finetuned for better performance [28]. based on the various techniques. These multi models are then tested and benchmarked with various techniques and inputs. This approach works for one input and various machine learning algorithms for one disease. However, for the multimodal to work effectively, there is a significant gap in building such complex models to analyse multiple diseases and various data sources better.

Multiple neuroimages help use the same model for different approaches, allowing doctors to make decisions faster based on the model suggestions. Unique models for diseases make the diagnosis decision slower than having a multimodal model for the analysis of the neuroimaging data for classification or a prediction approach. Increased demand for standard methods and models to process various medical imaging techniques will classify and narrow down the search space for the disorders, facilitating doctors to take a second opinion based on their findings. A standard system that takes up any neuroimaging data and then analyses the same will help accurately identify the disorder, thereby helping faster treatment planning and delivery with the proper treatment and care.

4. Conclusion

Neuroimaging plays a significant role in the detection of neurological disorders. The neurological disorders, which can be identified with the change in neurological behaviour, can only be identified with the help of neuroimaging techniques. Much research is being carried out on the methods that support and work effectively to detect the disorders. Many researchers have focused on developing machine learning models that analyse neurological disorders. Most researchers focus on developing models that predict or classify the diseases based on the imaging data; some have included additional parameters to increase the accuracy of the results. Most of the research is working with single machine learning models, and there exists a gap where the researchers could focus on developing multimodal, where various models can be applied to a machine learning model, to improve the accuracy and the prediction results.

However, very minimal work is carried out in creating multimodal classification models for accommodating multiple neuroimages to predict diseases. The different models are created by researchers for other neurological disorders, complicating disease detection, and creating confusion in identifying a better model. Few researchers focused on working with multiple modalities rather than different images for disease detection. The models designed for the machine learning-based neuroimaging data require effective and accurate models to process the medical images and gain information. A small error will cause a complete mistake in predicting the disease and cause a human life. With the survey on various neurological disorders and the machine learning algorithms for detecting practical neuroimage processing machine learning algorithms, the researchers were trying to build are mainly specific to certain diseases. Thus, we could identify many limitations in handling various neuroimaging data to predict multiple neurological disorders. No exact or standard model is available to analyse more than three heterogeneous data types. So, the review will help the researcher know more about multi-model development for accommodating the different neuroimages.

References

1. Kaur, H., Malhi, A.K. & Pannu, H.S. Machine learning ensemble for neurological disorders. *Neural Comput & Applic* **32,** 12697–12714 (2020). https://doi.org/10.1007/s00521-020-04720-1.

2. Zhang L, Wang M, Liu M and Zhang D (2020) A Survey on Deep Learning for Neuroimaging-Based Brain Disorder Analysis. Front. Neurosci. 14:779. DOI: 10.3389/fnins.2020.00779.

3. Doyle, O.M., Mehta, M.A. & Brammer, M.J. The role of machine learning in neuroimaging for drug discovery and development. Psychopharmacology 232, 4179–4189 (2015). https://doi.org/10.1007/s00213-015-3968-0

4. Stam, C. Modern network science of neurological disorders. Nat Rev Neurosci 15, 683–695 (2014). https://doi.org/10.1038/nrn3801.

5. Ye, Jieping, Teresa Wu, Jing Li, and Kewei Chen. "Machine learning approaches for the neuroimaging study of Alzheimer's disease." Computer 44, no. 4 (2011): 99-101.

6. Lee Jollans, Rory Boyle, Eric Artiges, Tobias Banaschewski, Sylvane Desrivières, Antoine Grigis, Jean-Luc Martinot, Tomáš Paus, Michael N. Smolka, Henrik Walter, Gunter Schumann, Hugh Garavan, Robert Whelan, "Quantifying performance of machine learning methods for neuroimaging data", NeuroImage, Volume 199, 2019, Pages 351-365, ISSN 1053-8119, https://doi.org/10.1016/j.neuroimage.2019.05.082.

7. Gunjan Pahuja & T. N. Nagabhushan (2021) A Comparative Study of Existing Machine Learning Approaches for Parkinson's Disease Detection, IETE Journal of Research, 67:1, 4-14, DOI: 10.1080/03772063.2018.1531730.

8. M. Tanveer, B. Richhariya, R. U. Khan, A. H. Rashid, P. Khanna, M. Prasad, and C. T. Lin. 2020. Machine Learning Techniques for the Diagnosis of Alzheimer's Disease: A Review. ACM Trans. Multimedia Comput. Commun. Appl. 16, 1s, Article 30 (January 2020), 35 pages. DOI: https://doi.org/10.1145/3344998.

9. Vij, R., Arora, S. (2022). Computer Vision with Deep Learning Techniques for Neurodegenerative Diseases Analysis Using Neuroimaging: A Survey. In: Khanna, A., Gupta, D., Bhattacharyya, S., Hassanien, A.E., Anand, S., Jaiswal, A. (eds) International Conference on Innovative Computing and Communications. Advances in Intelligent Systems and Computing, vol 1388. Springer, Singapore. https://doi.org/10.1007/978-981-16-2597-8_15.

10. Brody, Herb. "Medical imaging." Nature 502.7473 (2013): S81-S81.

11. Smith, Kerri. "fMRI 2.0: functional magnetic resonance imaging is growing from showy adolescence into a workhorse of brain imaging." Nature 484.7392 (2012): 24-27.

12. Sonka, Milan, Vaclav Hlavac, and Roger Boyle. Image processing, analysis, and machine vision. Cengage Learning, 2014.

13. Mirzaei, Golrokh, and Hojjat Adeli. "Machine learning techniques for the diagnosis of Alzheimer’s disease, mild cognitive disorder, and other types of dementia." Biomedical Signal Processing and Control 72 (2022): 103293.

14. Zhang, J. Mining imaging and clinical data with machine learning approaches for the diagnosis and early detection of Parkinson’s disease. npj Parkinsons Dis. 8, 13 (2022). https://doi.org/10.1038/s41531-021-00266-8.

15. J. Chandra, Madhavi Rangaswamy, Bonny Banerjee, Ambar Prajapati, Zahid Akhtar, Kenneth Sakauye, Alwin Joseph, “Applications of artificial intelligence to neurological disorders: current technologies and open problems”, Editor(s): Anitha S. Pillai, Bindu Menon, Augmenting Neurological Disorder Prediction and Rehabilitation Using Artificial Intelligence, Academic Press, 2022, Pages 243-272, ISBN 9780323900379, https://doi.org/10.1016/B978-0-323-90037-9.00005-9.

16. Rahul Sharma, Tripti Goel, M. Tanveer, R. Murugan, FDN-ADNet: Fuzzy LS-TWSVM based deep learning network for prognosis of Alzheimer’s disease using the sagittal plane of MRI scans, Applied Soft Computing, Volume 115, 2022, 108099, ISSN 1568-4946, https://doi.org/10.1016/j.asoc.2021.108099.

17. Sharma, Preeti and Devershi Pallavi Bhatt. "Importance of Deep Learning Models in the Medical Imaging Field." Approaches and Applications of Deep Learning in Virtual Medical Care, edited by Noor Zaman, et al., IGI Global, 2022, pp. 1-23. https://doi.org/10.4018/978-1-7998-8929-8.ch001.

18. Kernbach, J.M., Ort, J., Hakvoort, K., Clusmann, H., Neuloh, G., Delev, D. (2022). Introduction to Machine Learning in Neuroimaging. In: Staartjes, V.E., Regli, L., Serra, C. (eds) Machine Learning in Clinical Neuroscience. Acta Neurochirurgica Supplement, vol 134. Springer, Cham. https://doi.org/10.1007/978-3-030-85292-4_16.

19. Sharda, Megha, and Anya Chakraborty. "Predictive Modeling, Machine Learning, and Neuroscience." (2022).

20. Peide, Li, et al. "Coupled Support Tensor Machine Classification for Multimodal Neuroimaging Data." arXiv preprint arXiv:2201.07683 (2022).

21. Ansingkar, N. P., Rita Patil, and P. D. Deshmukh. "An efficient multi-class Alzheimer detection using hybrid equilibrium optimizer with capsule autoencoder." Multimedia Tools and Applications (2022): 1-32.

22. Kaul, Deeksha, Harika Raju, and B. K. Tripathy. "Deep Learning in Healthcare." Deep Learning in Data Analytics. Springer, Cham, 2022. 97-115.

23. Aslan, Zülfikar, and Mehmet Akin. "A deep learning approach in automated detection of schizophrenia using scalogram images of EEG signals." Physical and Engineering Sciences in Medicine 45.1 (2022): 83-96.

24. Kaka, Jhansi Rani, and K. Satya Prasad. "Differential Evolution and Multiclass Support Vector Machine for Alzheimer’s Classification." Security and Communication Networks 2022 (2022).

25. Sharma, Deepak Kumar, et al. "Deep learning applications for disease diagnosis." Deep Learning for Medical Applications with Unique Data. Academic Press, 2022. 31-51.

26. Mannil, Manoj, et al. "Foundations of Lesion Detection Using Machine Learning in Clinical Neuroimaging." Machine Learning in Clinical Neuroscience. Springer, Cham, 2022. 171-182.

27. Biessmann F, Plis S, Meinecke FC, Eichele T, Müller KR. Analysis of multimodal neuroimaging data. IEEE Rev Biomed Eng. 2011;4:26-58. doi: 10.1109/RBME.2011.2170675. PMID: 22273790.

28. S. Liu et al., "Multimodal Neuroimaging Feature Learning for Multiclass Diagnosis of Alzheimer's Disease," in IEEE Transactions on Biomedical Engineering, vol. 62, no. 4, pp. 1132-1140, April 2015, doi: 10.1109/TBME.2014.2372011.