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Machine Learning based Knowledge Extraction from MRI Scans: A Comprehensive Survey

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Abstract: With the recent advancement in the medical field, Magnetic Resonance Imaging (MRI) is evolving as a diagnostic tool for critical assessment of the health. It generates the 3D representations of the human body soft tissues for detection of the various abnormalities related to the brain. Traditionally the radiologists can interpret the MRI based on the quantitative data manually based on their expertise which is more time consuming and leading to erroneous prediction. With recent advancement in the technology, machine learning (ML) and diagnosis mechanism with the help of computer have enables the automated information extraction from the MRI images. It supports the faster diagnosis of the disease. This review paper presents a comprehensive study of the existing ML approaches used for MRI analysis inside medical image analysis. It focuses on the review of various mechanism used for feature extraction, classification, anomaly detection and segmentation of MRI images. It also highlights the various challenges identified through the detail literature including noise reduction, interpretability of ML systems, data imbalance. This review paper identifies the potential scope in MRI based knowledge extraction towards design the system of robust and accurate diagnosis of the diseases.

Index Terms **- Magnetic Resonance Imaging (MRI), Knowledge Discovery, Machine Learning, Medical Image Analysis, Image Segmentation, Brain Tumor Detection, Computer-Aided Diagnosis (CAD), Deep Learning, Feature Extraction, Anomaly Detection.**

I. INTRODUCTION

The clinical diagnosis and treatment have been drastically changes with the help of medical imaging. Medical imaging by providing detail internal presentation of the human body tissues. MRI proves a most standard technique for providing 3D structures of the internal tissues. It vastly used for detection of the brain abnormalities of the patient including Tumor and neuro disorders. Traditionally the radiologists analyse the brain MRI manually based on the visual representation which may lead towards incorrect diagnosis of the diseases. Such methods are highly error prone and heavily based on the human expertise.

As the volume of the MRI increases daily and with technology evolution, there is a pressing need of the intelligent automated system which can able to extract the meaningful information from these large images. Machine learning (ML) is one of the most used technologies for identifying the patterns form the images with the help of trained data. The ML can be used for preprocessing of images, extraction of features, segmentation, classification, and detection of anomaly. These mechanism shows the high accuracy and reducing diagnosis variability. However, the extraction of the knowledge from MRI images faces several challenges including hardware limitations, motion of patient, intent non-homogeneity. Also, non -availability of the annotated dataset is a major challenge. Despite these challenges various deep learning models, hybrid models and transfer learning models shows the further direction in the MRI knowledge extraction.

This paper reviews various ML based techniques for MRI based knowledge extraction. It discusses various mechanisms along with detail reviews for making the intelligent and robust medical imaging system. Section II shows the in-depth review of the various researchers' mechanism using ML for MRI knowledge extraction. Section III presents the challenges in-front of the MRI based ML mechanism towards developing intelligent ML based MRI knowledge extraction system.

II. LITERATURE REVIEW

Different researchers have worked in the field of the medical imaging for extracting the detail knowledge from MRI images. They find the various technique including segmentation, heterogeneous data processing, and image classification as follows –

Nayak, M.M., Kengeri Anjanappa, S.D. [1] proposes the hybrid naïve-bayes (NB) classifier for brain MRI images. This mechanism classifies the various MRI images into normal and abnormal categories for detecting the disorders and injuries. Th proposed approaches uses the pre-processing, feature extraction and reduction using NB. This approach effectively reduces the noise including skull and scalp. The proposed approach tested on the dataset and also compared with other models including RF, FF-ANN etc. This gives the better accuracy. This can be extended with the deep learning techniques. Saladi, Saritha, Yepuganti Karuna, et al. [2] proposes the more accurate detection of the brain tumor by processing the MRI. In the first part the preprocessing

has been performed with the help of the various approaches including HE, CLAHE, BPDFHE etc. After this the segmentation has been performed with the ARKFCM mechanism. The performance has been compared with the other approaches. In future it can be extend ed with the feature extraction mechanism. V. V. Chamundeeswari, V. S. Divya Sundar, et al. [3] focuses on the Alzheimer disease diagnosis with automated framework using CNN based classifiers. This model has been trained using the MIRIAD and ADNI datasets. The ResNet-50 architecture has been tested with the RF, SVM and SoftMax. The results shows that the ResSoft50-Softmax provides better results than the others. The deep learning approaches can be tested for further improvement in the accuracy.

Lakshmi, K., Amaran, et al. [4] presented the new mechanism called XAISS-BMLBT technique. It uses the explainable AI along with the segmentation and Bayesian. It uses the bilateral filter for the preprocessing of the images to reduce the noise. The ResNet50 has been used for extracting the image features. It also applies the optimization and hyper tuning of BRANN. Further this model can be further optimized in clinical environment along with advanced transfer learning model. Nahiduzzaman, M., Abdulrazak, L.F., Kibria, et al. [5] proposes the novel approach by integrating PDSCNN and RRELM for increasing the classification of the brain tumor into 4 various categories. The clarity and visualization have been increased using the CLAHE. The classification performance has been enhanced with the help of the proposed approach. The author has compared this approach with various state of art models for performance evaluation. This system can further be improved by consideration of the multi-model data and multi-layer transformer. Jiang, Y., Li, W., Li, J. et al. [6] studies ML based cross sectional MRI for progression in TLE. The 4 different types of the independent validations are used for showing the difference between the signation of neuroanatomical, progression of disease and epilepsy. These 5-year observation of the continuous result evaluation reveals that temporal surgery is beneficial for the patient. Further random test can be conducted for predictive label. Ramya, J., Uma Maheswari, B., Rajakumar, et al. [7] propose the framework for the classification of the AD suing MRI. 2D-ABF has been used for removal of noise which then enhanced using ECLAHE. The ROI is then segmented using the threshold and cluster technique. The GLCM features has been generated for computation of the pixel occurrence. The feature dimensions are reduced using the PCA. Classification has been performed using the LR mechanism. This system further extended with the help of various deep learning models.

Kumar, Anuj, Ashish Kumar Jha, et al. [8] uses the ML for determining the gliomas grade. The T2W MR sequence is used for the diagnosis and segmentation. Features are selected using the RF mechanism. The result also compared with the SVM, GB, NB and AdaBoost. The RF shows highest performance. This can be further tested on the large-scale imaging datasets. Song Jiang, Yuan Gu, Ela Kumar [9] use the 5 various ML techniques for classification of brain tumor. It includes the SVM, LR, KNN, SGD and DS. Performance has been measured using TSS based on confusion matrix. The results proves that KNN is mostly efficient mechanism. But it faces limited time and resources constraints. It shall be further extended with the consideration of the various types if the brain tumor. Vaidehi Satushe, Vibha Vyas, et al. [10] explores the various ML and DL algorithms for brain tumor diagnosis using MRI scans. CNN shows the success in classification and prediction. This review conducted through the articles from 2021 to 2025. Key part focused on the diverse dataset consideration and efficiency of the techniques. It can be extended with further direction related to the data diversity and interpretability.

Minhui Ouyang, Matthew T. Whitehead, et al. [11] focus on the childhood MRI scan for detection of the neurological and psychiatric disease. The multi-model MRI is very much used for comprehensive insights. The ML and DL techniques shows the promising future in this research. The scanning of early brain development has been done using MRI and which can be helpful for many reasons including prediction of various disorders. It further improved by consideration of the large-scale datasets having multimodal data. Hossein Sadr, Mojdeh Nazari, et al. [12] propose the deep learning-based model for automatic classification of the brain images with the help of MRI. These models are designed for both multiclass and binary brain tumors. It has been tested on various MRI datasets. Initially CNN with 26 layers has been applied for training. It finetuned with the Xception and VGG16. It uses the transfer learning effectively. There is a scope for inclusion of the clustering and data augmentation. K Gopikrishna, N R Niranjan, Siddharth Maurya [13] proposes the explainable ML based framework for MRI image classification. The RF has been used for feature extraction and training. This model gains the accuracy over the other models. This system further improved with the help of hybrid ML mechanism for training and LLM for the feature extraction.

Teng Z, Li L, Xin Z, Xiang D, Huang J, et al. [14] reviews the various approaches based on the AI for the segmentation. It highlights the advantages and limitations of the XAI and TAI over the traditional mechanisms. XAI offers the transparency and interpretability whereas TAI offers the reliability over the segmentation techniques. This TAI can be extended for reliability and safety inside the segmentation. Md. Faysal Ahamed, Md. Munawar Hossain, et al. [15] presents review of the various segmentation techniques. Author proposes the federated learning-based technique to enhance the performance of the segmentation. The author gives path for designing the optimal solution for solving this issue. This can be further tested over the clinical environment. Md. Naim Islam, Md. Shafiul Azam, et al. [16] uses the ML and DL techniques for brain tumor detection accurately. The 13 layers CNN and LSTM have been used for improving the performance of the classification. This model further combines with the ensemble or hybrid mechanism for improving accuracy along with region of interest detection.

Luis Sánchez-Moreno, A. Perez-Peña, et al. [17] explores various algorithm including Inception-ResNet-v2, VGG16 and DenseNet121 for brain tumor MRI classifications. The ensemble classifier enables the robustness with the help of the voting mechanism. The results shows that ensemble model gives mor performance than the CNN. This model further improved for the interpretability of the data. Usman Amjad, Asif Raza, et al. [18] presents the review of the various mechanisms for tumor segmentation, and modalities. The CNN and K-means performance had been assessed for prediction structure of genes. Further this model has been extended with the help of AI algorithms. The feedback mechanisms can be adapted with deep learning mechanism. Y.L. Jia, B.N. Yang, et al. [19] presents the detail review of the various mechanism for the ML based techniques used for PTSD based neuroimaging. It can able to find the disease at early stage. Th accuracy can be enhanced with the help of the various model of the ML. This work gives the pathways for detection of the {TSD with the ML in the actual clinical environment. Rahim Khan, Sher Taj, Zahid Ullah Khan, et al. [20] proposes the hybrid model based on DL which combines the ResGANet and CE-EEN-B0 for BT detection in the earlier step. Th regression model is also used. With Grad-CAM, it improves the interpretability by combining the regression and classification. Further, more focus to be given on dataset and automated system for diagnosis.

III. CHALLENGES

With analysis of the various techniques from the literature, following are the major challenges need to address for extraction of the knowledge from MRI images using ML –

1. Limited availability of medical image annotated dataset which can constraint inside model generalization process.
2. The heterogenous collection of the source data leads to poorly training of the data due to various protocol, vendors, structures, etc.
3. Need to resolve the problem of the class imbalance inside the dataset.
4. The various preprocessing challenges including intensity heterogeneity, motion of the patient, misclassification, inaccurate segmentation, and normalization.
5. Need to identify the ML mechanism for interpretability of the MRI for making the transparency.
6. The overfitting of the training data degrades the performance of the system with unseen noise patterns.
7. Challenges for processing 3D MRI analysis related to the computational resources.
8. Integration of the multi-model data becomes complex due to their differed structure and pattern.
9. Need to use the deep learning models and hybrid models for enhancing the accuracy.
10. Security and privacy of the patient data need to addressed.
11. The validation of the model results with real-world clinical environment and their working constraints.
12. Need of the lightweight, explainable model for 3D MRI processing inside the clinical setup.
13. Need for the generalized model which can be suitable for various types of the medical imaging.

IV. CONCLUSION

MRI has been used as a most powerful visual tool for getting the internal details of the human body. It helps for detecting the diseases at early stages mostly related to the brain. Over the past years with evolution of ML mechanism, it transforms the manual diagnosis mechanism to the automatic diagnosis process. Nowadays deep learning mechanism can be used for extraction of the knowledge from the MRI which is the helping tool for increasing the precision and accuracy in the MRI analysis. This review papers presents review of various ML based techniques used for the training of the dataset, preprocessing, segmentation and classification of the images. It gives the scope to use the federated learning, transfer learning and explainable AI for addressing the current challenges faced in the medical imaging. It also reviews the various hybrid and ensemble models which can be useful for the further development of the AI based intelligent MRI analysis system inside the clinical environment for early diagnosis and care.

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