APPLICATIONS OF NEUROIMAGING USING MACHINE LEARNING AND DEEP LEARNING TECHNIQUES

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Abstract

Neuroimaging allows us to study the brain in both health and disease, neuroimaging is essential to clinical care and research. The morphological structure, physiological architecture, and corresponding imaging features of the brain are intricately linked.

A person's brain changes in shape, function, and relationships between different parts as they develop, grow, get sick, and recover. Neuroimaging is one of the few fields that fully utilizes modern analysis tools to investigate the brain and its function from imaging data. ML has begun to play a role in the following areas recently tracking changes in imaging over time, quickly identifying acute disorders like stroke and anatomical measurements, detection, segmentation, and quantification of lesions and disease patterns. As our capacity to visualize and study the brain.

Keywords: ML, DL, SVM, CNN, MRI, fMRI, ANN, PET, EEG: Machine Learning, Deep Learning, Support Vector Machines, Convolutional Neural Networks, Magnetic Resonance Imaging, functional Magnetic Resonance Imaging, Artificial Neural Network, Positron Emission Tomography, Electroencephalography.

1. INTRODUCTION

Neuroimaging, the process of visualizing the structure and function of the brain, has greatly benefited from the integration of ML and DL techniques. These methodologies offer powerful tools to analyse complex patterns within neuroimaging data, facilitating both diagnosis and understanding of neurological disorders. ML algorithms, such as SVM and Random Forest, have been employed for tasks like classification [12] of brain images based on specific features or biomarkers. These methods excel at identifying subtle differences in brain structure or activity that might elude human observers, thus aiding in the early detection and differentiation of conditions like Alzheimer's disease or schizophrenia.

DL, a subset of ML that utilizes ANN with multiple layers, has revolutionized neuroimaging analysis. CNN, in particular, have shown remarkable success in tasks like image segmentation, where regions of interest within brain scans are delineated automatically. This capability is invaluable for neuroscientists and clinicians seeking to pinpoint areas of abnormality or track changes over time in conditions such as brain tumours or multiple sclerosis. Moreover, DL techniques enable the extraction of hierarchical representations from raw neuroimaging data, uncovering intricate patterns that may hold crucial insights into brain function and dysfunction.

The integration of ML and DL into neuroimaging workflows also extends to functional imaging modalities like fMRI and electroencephalography (EEG). These techniques capture brain activity in real-time, generating vast amounts of data that require sophisticated analysis. ML algorithms can decode complex neural signals, enabling tasks such as predicting cognitive states or characterizing brain connectivity networks. DL architectures[13], such as Recurrent Neural Networks (RNN) and Graph Neural Networks (GNN), are well-suited for modelling temporal dynamics and capturing complex interactions[14] between brain regions, advancing our understanding of brain networks and their role in cognition and disease.

Overall, the synergy between neuroimaging and ML/DL techniques holds tremendous promise for advancing our understanding of the brain and improving clinical outcomes for neurological and psychiatric disorders. By harnessing the power of artificial intelligence, researchers and clinicians can unlock new insights into brain structure, function, and pathology, ultimately leading to more accurate diagnoses, personalized treatments, and enhanced patient care.

2. LITERATURE REVIEW

- Karl-Heinz Nenning et al.[1] Because it allows us to study the brain in both health and disease, neuroimaging is essential to clinical care and research. The morphological structure, physiological architecture, and corresponding imaging features of the brain are intricately linked. A person's brain changes in shape, function, and relationships between different parts as they grow, age, get sick, and recover. Neuroimaging is one of the few fields that fully utilizes modern analysis tools to investigate the brain and its function from imaging data. ML has begun to play a role in the following areas recently: (a) tracking changes in imaging over time; (b) quickly identifying acute disorders like stroke; and (c) anatomical measurements, detection, segmentation, and quantification of lesions and disease patterns. Our knowledge of the complex relationships inside the brain and how they affect therapeutic decision-making is expanding along with our capacity to visualize and analyse the brain
- Mahsa Dadar et al.[2] In this research, we present a comprehensive overview of ML methods used to extract clinical classifiers from structural MRI data. To help researchers better apply these methodologies in future works, we carefully address practical issues that are frequently seen in the literature. Furthermore, in order to present a thorough picture of the state of the art in several domains, we examine how these algorithms are used to treat a variety of illnesses and conditions (such as

Alzheimer's disease (AD), Parkinson's disease (PD), autism, multiple sclerosis, traumatic brain injury, etc.).

- Daniel Ranti et al.[3] Understanding the vast amount of intricate electronic data that hospital systems have accumulated over the years could transform modern medicine, but it also poses many difficulties. DL is particularly well-suited to tackle these problems, and the field of medical ML is set for revolutionary expansion because to recent developments in methods and hardware. Because neurologic diseases often manifest with mild symptoms, the clinical neurosciences stand to gain most from these developments. Here, we review the various domains where deep learning algorithms have already sparked change: medical image segmentation for the quantitative assessment of neuroanatomy and vasculature; connectome mapping for the diagnosis of Alzheimer's, autism spectrum disorder, and attention deficit hyperactivity disorder; mining of microscopic EEG signals and granular genetic signatures; and medical image analysis for the improved diagnosis of Alzheimer's disease and the early detection of acute neurologic events. We also address the obstacles to addressing the current problems and highlight significant obstacles in the incorporation of DL techniques in the therapeutic setting.
- Ritu Gautam et al.[4] This study conducts a comprehensive analysis of DL techniques for prognosticating eight neuropsychiatric and neurological disorders—stroke, Alzheimer's, Parkinson's, epilepsy, autism, migraine, cerebral palsy, and multiple sclerosis. These disorders pose significant health risks and can lead to further complications. Utilizing insights from 136 relevant publications, the research explores the methodologies and frameworks employed by various DL algorithms in diagnosing these conditions. It examines morbidity and mortality rates, analyzes the performance and publication trends of deep learning methods, and scrutinizes key performance metrics. The study underscores the need for further investigation into DL models for diagnosing stroke, cerebral palsy, and migraine, while also identifying opportunities to leverage Deep Boltzmann Machine, Restricted Boltzmann Machine, and Deep Belief Network for diagnosing neurological and neuropsychiatric disorders.
- Bin Jiang et al.[5] Numerous DL based clinical applications related to radiology have been proposed and investigated. These applications include risk assessment, segmentation tasks, diagnosis, prognosis, and even therapeutic response prediction. Other cutting-edge uses of AI in medical imaging include the removal of image

artifacts, normalization and harmonisation of images, enhancement of image quality, reduction of radiation and contrast dose, and abbreviation of imaging study duration. These applications are specifically focused on the technical aspects of medical imaging and are particularly relevant to image acquisition. This paper will discuss this subject and aim to give a general overview of DL methods used in neuroimaging.

- Peter A. Bandettini et al.[6] Neuroscience research has changed as a result of the quick development of neuroimaging techniques and their expanding accessibility. The quality of the data we are able to gather regarding the locations, dynamics, fluctuations, magnitudes, and types of brain activity and structural changes will determine the answers to many of the questions we have about how the brain is structured. An attempt is made to capture the state-of-the-art in a small portion of the quickly developing field of neuroimaging in this review. A brief background is given for each topic discussed, along with an overview of some of the most recent advancements and problems. The next section describes a few notable articles that were published within the last year or two, giving an idea of the paths that each field is heading in. Among the topics discussed are PET, EEG, magnetoencephalography (MEG), diffusion tensor imaging (DTI), voxel-based morphometry (VBM), optical imaging, and fMRI.
- Soonmee Cha et al.[7] The field of neuroimaging brain tumors has changed over time, moving from being primarily focused on morphology to also including function, physiology, and anatomy. In addition to summarizing the most recent developments in physiology-based imaging techniques that support established brain tumor imaging procedures, this review describes the current imaging standard for patients with brain tumors. A summary of various modern imaging techniques, such as diffusion-weighted MRI, perfusion MRI, and proton magnetic resonance spectroscopic (MRS) imaging, is included along with an emphasis on the advantages and disadvantages of the current imaging standards. Each imaging technique's fundamental physical concepts are briefly explained, followed by a more thorough examination of its therapeutic applications and its drawbacks.
- Manan Binth Taj Noor et al.[8]Over the past few decades, neuroimaging—more specifically, MRI—has been more crucial in our understanding of brain functioning and illnesses. Innovative ML approaches and high-performance computing tools have made it possible to identify neurological illnesses with previously unheard-of

precision thanks to these state-of-the-art MRI scans. However, it is exceedingly challenging to reliably identify such illnesses from the acquired neuroimaging data due to similarities in disease characteristics. In order to identify neurological disorders—with a particular focus on Parkinson's disease, schizophrenia, and Alzheimer's disease—this article critically evaluates and contrasts the capabilities of the current DL - based techniques using MRI data obtained using various modalities, such as functional and structural MRI

- Grega Repovš et al.[9] The assumption of linearity in neural processes by classic statistical methods limits their applicability to the analysis of neuroimaging data, as this work explores. It presents DL as a viable strategy to get beyond these restrictions, outlining its fundamental ideas and typical uses in neuroimaging research, such as data collection, segmentation, internal representation interpretation, and outcome prediction. The study discusses and suggests possible solutions for deep learning's problems with multidimensionality, multimodality, overfitting, and computing expense. The current application of DL in neuroimaging analysis is assessed, with a focus on the potential benefits of multimodality, raw data processing, and sophisticated visualization techniques. Research gaps and avenues for future investigation are noted, including the use of RDoC, transfer learning, and synthetic data generation frameworks.
- Li Zhang et al.[10] Recently, DL has been applied to the analysis of neuroimages, including PET, structural MRI, and fMRI. Compared to traditional ML, DL has significantly improved performance in computer-aided diagnosis of brain disorders. The uses of DL techniques for the analysis of brain disorders based on neuroimaging are reviewed in this work. By introducing several kinds of deep neural networks and recent advancements, we first give a thorough overview of DL techniques and widely used network structures. Next, we examine DL techniques for computer-assisted examination of four common brain disorders: schizophrenia, Parkinson's disease, Alzheimer's disease, and autism spectrum disorder. The latter two disorders are psychiatric and neurodevelopmental, respectively, and the first two are neurodegenerative.
- Jyoti Islam et al.[11] Alzheimer's disease is a degenerative neurological brain ailment that is incurable. Prompt detection of Alzheimer's disease can aid in appropriate management and avert harm to brain tissue. Researchers have used a number of

statistical and ML models to diagnose Alzheimer's disease. The exacting nature of Alzheimer's Disease detection stems from the similarities between standard healthy older people's MRI data and MRI data associated with Alzheimer's Disease. Modern DL methods have recently shown themselves to be as effective as humans in a variety of domains, including the processing of medical images. We suggest utilizing brain MRI data analysis to diagnose Alzheimer's disease using a deep CNN. We have performed extensive tests to show that, on the Open Access Series of Imaging Studies (OASIS) dataset, our suggested model performs better than comparing baselines.

3. RESULTS AND DISCUSSIONS

In this paper on neuroimaging using ML and DL techniques, several key findings and discussions emerge. Firstly, the integration of ML and DL methodologies into neuroimaging has significantly advanced the field, enabling more accurate diagnosis, prognosis, and understanding of neurological disorders. ML algorithms such as support vector machines and random forests have demonstrated efficacy in classifying brain images and identifying biomarkers for conditions like Alzheimer's disease and epilepsy. DL techniques, particularly CNN, have shown remarkable success in tasks like image segmentation and feature extraction, providing insights into brain structure and function. The results highlight the importance of these techniques in handling complex multivariate patterns in neuroimaging data. Additionally, discussions focus on the challenges faced, including data preprocessing, model interpretability, and generalization to new datasets.

Despite these challenges, the survey underscores the immense potential of ML and DL in advancing neuroimaging research and clinical applications. Further research directions are proposed, emphasizing the need for standardization, robust validation methods, and interdisciplinary collaborations to maximize the impact of ML and DL in neuroimaging. Overall, the survey provides a comprehensive overview of the current state, challenges, and future prospects of neuroimaging using ML and DL techniques, offering valuable insights for researchers and practitioners in the field.

4. CONCLUSION

In summary, the integration of ML and DL techniques into neuroimaging has revolutionized our understanding and diagnosis of neurological disorders. ML algorithms, such as SVM and random forests, excel in classifying brain images for early detection and differentiation of conditions like Alzheimer's disease and epilepsy, while DL methods, notably CNN, offer unparalleled accuracy in tasks like image segmentation, enabling precise delineation of brain regions. Despite challenges like data multidimensionality and overfitting, innovative solutions like transfer learning and synthetic data generation hold promise. Standardized methodologies for architecture and hyperparameter selection are crucial moving forward. With these advancements, neuroimaging promises to unveil new insights into brain function and pathology, leading to enhanced diagnostics, personalized treatments, and improved patient outcomes.

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