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An Overview of Machine Learning in Biomedical Imaging

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Abstract. This literature review examines the role of Machine Learning (ML) in biomedical imaging, focusing on recent advancements from 2020 onwards. Biomedical imaging, including MRI, CT and so on, has become a cornerstone of clinical diagnosis and treatment. Recent developments in ML have significantly contributed to this field. By synthesizing findings from fourteen primary research articles that develop specific ML models, the review identifies three main applications of ML models in biomedical imaging: enhancing image quality, automating analysis, and developing predictive models. This paper will examine the strategies each model uses and the improvements it realizes specifically, such as its accuracy rate. Despite these advances, challenges such as data privacy concerns and the risk of diagnostic errors persist. The review also addresses the future directions, including the need for privacy-preserving techniques and the integration of ML education in medical training. This paper highlights the transformative potential of ML in biomedical imaging, emphasizing its role in improving patient outcomes and advancing healthcare.

Keywords: Machine Learning, Biomedical Imaging, Medical Diagnostics.

1. Introduction

As an important technique for clinical analysis and subsequent medical intervention, Biomedical Imaging reveals the interior structure and tissue in the human brain and body, which couldn't be seen simply using the eyes. Over the past hundred years of rapid technological development, especially with continuous advancements in optics, Biomedical Imaging has evolved from the initially extremely expensive X-rays to the now ubiquitous magnetic resonance imaging (MRI), positron emission tomography (PET), computed tomography (CT) and so on that could be found in almost every hospital. It has become an indispensable part of the process of clinical identification, treatment, and prognosis. In recent decades, noticeably, in the era of computer science, these biomedical imaging technologies can reflect tissues more accurately with the help of certain algorithms, which allows more accurate disease identification.

From initial optics to the assistance of computer science, humans always tried to solve problems using simpler ways. Machine Learning (ML) was invented for this purpose. It is a scientific investigation of the statistical models and algorithms used by computer systems to perform certain functions without the need for explicit programming, including supervised learning, unsupervised learning, reinforcement learning, and so on. With enough datasets available, it could execute tasks without guidance through data-driven learning and thus generalization to previously unknown data. As it becomes mature,

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Machine Learning is now starting to be used in the healthcare field, incorporating genetics, neuroimaging, radiography, and electronic health records.

Considering the promising prospect of ML in healthcare, this review will summarize the usage of ML in biomedical imaging through its three main functions currently, enhancing image quality, automated analysis, and predictive model. Besides, the challenges and future directions of ML will also be discussed.

2. Machine Learning in Biomedical Imaging

2.1. Enhancing Image Quality

In the past three years' studies, significant advancements have been made in the application of machine learning for enhancing image quality in biomedical imaging. Yang and associates presented a semi-supervised method utilizing a Deep Recursive Band Network (DRBN) for low-light picture enhancement in 2020. This approach unites both paired and unpaired data, bridging the gap between signal purity and perceived quality. It successfully reduces noise, brings back overall lighting, and maintains structural details [1].

Similarly, Munadi et al. concentrated on improving deep learning-based tuberculosis (TB) identification in chest X-ray pictures. Prior to feeding the photos into neural networks that have already been trained, they used image enhancement techniques including High-Frequency Emphasis Filtering (HEF) and Unsharp Masking (UM) to increase the quality of the images. Their research illustrated the significance of picture preprocessing in medical diagnostics by showing that improved images produced greater Area Under the Curve (AUC) scores and classification accuracy [2]. In 2023, Zamir et al. created MIRNet-v2, a multi-scale residual network intended for picture improvement and restoration. Contextual information is extracted from low-resolution representations and spatially exact high-resolution representations are maintained by this architecture. It does tasks like defocus deblurring, picture denoising, and low-light image improvement by combining characteristics from several scales [3].

2.2. Automated Analysis

Given the image, ML can also help with automated analysis, such as identifying pathologies and treatment choosing. This application could contribute to better health outcomes, lower healthcare expenses, along with further advancements in clinical research. By analyzing the image of interest, ML algorithms can detect anomalies that might be missed by the human eye, segment regions of medical images to highlight areas of concern and classify different types of diseases.

McKinney and associates, for instance, used a machine learning system to identify cancers in mammograms. According to their research, this method performed 11.5% better in early breast cancer identification than seasoned radiologists. This will enhance patient outcomes and medical efficiency by enabling the early detection and location of malignancies [4]. In a more recent study, a hybrid CNN model was created by Dihman and associates for tumor detection in medical imaging, which combines convolutional neural networks with machine learning techniques to enhance the detection accuracy of tumors in CT and MRI scans. It leverages image enhancement and classification capabilities and achieves significant improvements in precision and recall metrics [5]. Similarly, Dohmen and colleagues introduced the ikarus machine learning pipeline to distinguish tumor cells from normal cells at the single-cell level, which contributes to tumor detection at a micro level. By leveraging logistic regression and network-based propagation, ikarus demonstrated high sensitivity by achieving a balanced accuracy of 0.98 across validation datasets [6]. Considering ML's role in treatment choosing, a study demonstrated the use of ML in psychiatry, where algorithms predicted treatment outcomes by analyzing patient data including imaging clinical records. For example, it could predict certain patient's responses to antidepressant medications, achieving an accuracy rate of 85% [7]. This capability helps clinicians choose the best treatment options by simulating the possible outcomes.

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2.3. Predictive Model

As for a more well-known usage, machine learning models are used to predict disease progression and perform risk assessments using medical images. By studying previous longitude data, these models can provide valuable insights into the likely course of a disease and enable early intervention. For instance, a 2020 research by Banerjee and Das used a variety of machine learning (ML) techniques, including the use of support vector machines and neural networks with artificial intelligence, to identify lung cancer at an early stage. Specifically, logistic regression was employed to predict patient survival rates based on features extracted from CT images, demonstrating high accuracy with an AUC score of 0.92 [8].

Additionally, with convolutional neural networks (CNNs), Ahammed and colleagues built a machine-learning model for the categorization and early identification of skin disorders, including melanoma. The model could track changes over time by analyzing dermoscopic images to distinguish between different types of melanoma and other skin lesions. It achieved an accuracy rate of 88.83%, which demonstrated potential for aiding in clinical [9]. Furthermore, in 2020, Elaziz and his team introduced an innovative machine-learning approach for diagnosing COVID-19 based on chest X-ray images. This approach effectively extracted both coarse and fine details from X-ray images through the use of Fractional Multichannel Exponent Moments (FrMEMs). Importantly, the method was tested against two separate COVID-19 X-ray datasets, which demonstrated high accuracy rates of 96.09% and 98.09%, respectively [10]. ML models are also used to predict some heart diseases. Jindal and his team leveraged machine learning techniques, such as Logistic Regression and K-Nearest Neighbors (KNN), to assess the likelihood of heart disease by considering various patient medical characteristics, including age, gender, chest pain, and fasting blood sugar levels. The KNN model, in particular, demonstrated superior performance compared to previous classifiers, effectively identifying individuals at risk for heart disease with an accuracy rate of 88.52% [11]. Similar models to predict heart diseases were also developed by Shah [12] and Bhatt with the highest accuracy rate of 87.28% [13].

3. Challenges and Future Directions

Though given the benefits mentioned, it is acknowledged that integrating machine learning in biomedical imaging raises some challenges. Data privacy is a critical concern, with the use of patient data through training ML models raising issues related to confidentiality and security. To address this, Adherence to laws like the General Data Protection Regulation (GDPR) is indispensable. Also, some privacy-preserving (PP) computation techniques could be used for ML for secure data evaluation and processing [14]. It is also risky to rely solely on machines to judge health-related problems, which can lead to misdiagnosis or oversight of critical conditions. Therefore, it is crucial to ensure that ML models are supervised and validated by healthcare professionals to mitigate these risks.

To further enhance the integration of machine learning in biomedical imaging, it is crucial to incorporate ML education into the medical curriculum. This will improve the interaction and thus the ability of doctors to utilize ML tools effectively. Additionally, developing privacy-preserving computation techniques, such as federated learning, can ensure patient data confidentially while enabling the training process. Emphasizing collaborative efforts between healthcare professionals, regulatory bodies, and technology developers will foster ethical and transparent development, ultimately enhancing diagnostic accuracy and treatment outcomes.

4. Conclusion

ML has shown significant potential in enhancing biomedical imaging, aiding in diagnostic accuracy, and disease progression prediction. This paper reviews various ML techniques and their applications in medical imaging, highlighting both opportunities and challenges. Addressing the issues, the continued evolution of ML would promise to future transform medical diagnostics and offer more precise patient care.

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