Diabetic Retinopathy Detection using Deep Learning: A Review

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Abstract: Diabetic Retinopathy is a diabetes-related complication that affects the blood vessels in the retina of the eye. It is a leading cause of vision impairment and blindness worldwide if not treated on time. Early detection of this disease is crucial for timely intervention and prevention of vision loss. The ophthalmologist manually examines the morphological changes in retinal veins and lesions in fundus images. This process is time-consuming, expensive, and complex. Thus procedure can be streamlined with the help of computer-aided diagnostic systems (CADs) used for identifying DR lesions. Artificial Intelligence and Deep learning algorithms offer a more efficient and objective approach to analyzing retinal images, enabling automated detection of distinctive features associated with diabetic retinopathy. As a review, this paper concentrates on applications of deep learning models and transfer learning in diabetic retinopathy detection. Many publications are explored and various methods for preprocessing, segmentation, class balancing, feature extraction, data augmentation and classification used in these publication are discussed. This paper also provides an overview of performance results achieved by these state-of-the-art methodologies in published papers. The review highlights benefits and challenges of current approaches, offering valuable insights for other researchers.

Keywords: diabetic retinopathy; deep learning; classification; diabetes

1 Introduction

Diabetes mellitus is a chronic metabolic disorder characterized by elevated blood glucose levels due to either insufficient insulin production or the ineffective utilization of insulin by the body [1]. It is classified into several types, with type 1 and type 2 being the most prevalent [2]. Type 1 diabetes results from the autoimmune destruction of insulin-producing beta cells in the pancreas. In contrast, type 2 diabetes typically involves insulin resistance and relative insulin deficiency. Diabetes affects more than 400 million people globally, with estimates suggesting that this figure could reach 700 million by 2045 (IDF Diabetes Atlas, 2019) [3]. One of the most common and serious complications of diabetes is Diabetic Retinopathy (DR), which impacts about one-third of diabetics worldwide (WHO, 2020) [4]. DR is a serious and widespread complication of diabetes mellitus, posing a major global health challenge [5]. This condition involves progressive damage to the retina and is a leading cause of vision impairment and blindness among working-age adults globally. Retina is the light-sensitive tissue at the back of the eye. With diabetes mellitus reaching epidemic levels, especially in low- and middle-income countries, the need for effective screening, diagnostic and management strategies for DR has become more pressing than ever [6].

Chronic hyperglycemia in diabetes leads to damage to the small blood vessels supplying the retina. This damage manifests in two primary forms: Non-Proliferative Diabetic Retinopathy (NPDR) and Proliferative Diabetic Retinopathy (PDR) [7]. In Non-Proliferative Diabetic Retinopathy (NPDR), the small blood vessels in the retina weaken and develop microaneurysms. These weakened vessels may leak fluid or blood into the retina causing retinal swelling (edema) and leading to vision problems. As NPDR progresses, more significant blockages of retinal blood vessels can occur, reducing the blood supply to areas of the retina and resulting in more severe vision impairment. Proliferative Diabetic Retinopathy (PDR) is an advanced stage of the disease. The retina may become deprived of oxygen due to blocked or damaged blood vessels. In response, new, abnormal blood vessels may grow on the retina's surface or into the vitreous gel, which fills the inside of the eye. This proliferation of blood vessels can lead to severe vision loss if not treated promptly. These new vessels are fragile and prone to bleeding, which can cause sudden vision loss.

In the early stages, diabetic retinopathy often does not present any noticeable symptoms [8]. However, as the disease advances, individuals may start to experience blurred or fluctuating vision, small spots or floaters in their field of vision, reduced central vision, difficulty seeing at night, and even sudden vision loss. Detecting diabetic retinopathy early is vital for preventing vision loss [9]. Regular eye exams, including retinal screenings, can identify the condition in its initial stages, when treatment is most effective. Prompt intervention can help prevent or slow the progression of diabetic retinopathy and reduce the risk of severe vision impairment.

Diabetic retinopathy progresses through several stages:

1. Mild Non-Proliferative Diabetic Retinopathy (NPDR): This stage is characterized by the presence of microaneurysms and small hemorrhages within the retina.
2. Moderate NPDR: This stage is marked by significant blockages of retinal blood vessels, leading to reduced blood supply to areas of the retina.
3. Severe NPDR: This stage causes extreme blockage of blood vessels which makes some areas of the retina deprived of blood supply.
4. Proliferative Diabetic Retinopathy (PDR): The most advanced stage, where new abnormal blood vessels (neovascularization) form on the retina or optic nerve head. These vessels are fragile and prone to bleeding.

Traditionally, detecting and diagnosing diabetic retinopathy has depended on direct ophthalmoscopy, fundus photography, or optical coherence tomography (OCT), combined with clinical evaluation by trained ophthalmologists [10]. While these methods are effective, they are also time-consuming, resource-intensive, and prone to inconsistencies between different evaluators, especially in areas with limited access to specialized healthcare professionals

Artificial intelligence (AI), particularly deep learning has revolutionized the field of medical image analysis, including retinal scanning for diabetic retinopathy detection [11]. AI algorithms can analyze digital retinal images with speed and accuracy, potentially augmenting or even replacing traditional methods of manual evaluation by human experts. The integration of deep learning and AI into retinal scanning and diabetic retinopathy detection represents a paradigm shift in ophthalmic healthcare [12]. By leveraging the power of artificial intelligence, we can enhance early detection rates, improve patient outcomes, and ultimately reduce the global burden of diabetic retinopathy-related vision loss.

Deep learning uses neural networks with multiple layers to automatically learn and extract features from data [13]. Unlike traditional machine learning approaches that rely on manually engineered features, deep learning algorithms can automatically learn hierarchical representations of data. This makes them particularly effective for tasks such as image classification and segmentation. In the context of diabetic retinopathy, deep learning algorithms, especially convolutional neural networks (CNNs), have been successfully applied to automatically analyze retinal images and detect signs of DR [14]. These algorithms can identify microaneurysms, hemorrhages, exudates, and other diabetic retinopathy lesions with high sensitivity and specificity, enabling early diagnosis and timely intervention [15].

This paper investigates the complexities of diabetic retinopathy beginning with an exploration of its underlying mechanisms, stages, and symptoms. It outlines the global impact of DR and the urgency for improved detection and management strategies. The goal is to offer a comprehensive analysis of recent advances, methodologies, challenges, and future directions in this dynamic field. The Literature Review section will critically analyze a selection of recent studies highlighting their methodologies, datasets, results, future directions and contributions in detecting DR using Deep Learning (DL). This comprehensive examination will underscore the advancements made in understanding and managing DR, particularly through the use of innovative technologies like artificial intelligence. By critically assessing existing research and highlighting significant findings, this research aims to show the potential of deep learning in enhancing DR screening and classification.

2 Literature Review

Many researchers have dedicated their efforts to experimenting with a wide range of techniques, algorithms, and methods aimed at achieving the goals of detecting and classifying diabetic retinopathy. Their dedication has led to significant advancements and great enhancements in the detection and understanding of this disease.

In study [16], authors have utilized a Convolutional Neural Network (CNN) architecture to classify retinal images into two classes: 'no diabetic retinopathy' and 'with diabetic retinopathy'. They employed the APTOS-2019 Blindness Detection dataset from Kaggle for model training which consists of 3600 high-resolution retinal images. Pre-processing steps were applied to enhance image quality, including cropping, resizing, and converting images to grayscale. Further enhancements involved Gaussian-blur filtering and Contrast Limited Adaptive Histogram Equalization (CLAHE) to remove noise and improve contrast. A web-based interface was developed as the frontend, enabling user interaction by accepting high-resolution retinal images. Upon input, these images undergo preprocessing and enhancement before being fed into the trained CNN model for prediction. The results, indicating whether diabetic retinopathy is present or absent, are displayed alongside the input image on the web page. This study is significant due to its potential to enhance early detection and treatment of diabetic retinopathy through accurate and efficient image classification. The model achieved impressive accuracy metrics, with a training accuracy of 99% and validation accuracy of 93%. During testing, the model maintained a high accuracy of 91%, alongside an f1-score of 91% and precision of 96%.

The researchers of [17] aimed to develop diagnostic technology for automated grading of diabetic retinopathy severity using ultra-wide field fluorescein angiography (UWFA) and Early Treatment Diabetic Retinopathy Study (ETDRS) 7-standard field (7-SF). This cross-sectional study utilized UWFA data from 280 diabetic patients and 119 normal patients to train and test an artificial intelligence model. The model differentiated proliferative diabetic retinopathy (PDR) and non-proliferative diabetic retinopathy (NPDR) based on ischemic and leakage indexes, validated by ground truth annotations from retinal specialists. Results indicated 88.50% accuracy in original UWFA images and 73.68% accuracy in simulated 7-SF images for DR classification. Linear regression analysis confirmed significant relationships between these indexes and DR severity, enabling accurate grading with 76.8% accuracy. Integration of CycleGAN and convolutional neural network (CNN) models optimized DR grading with UWFA and simulated 7-SF, underscoring the model's efficacy in automated severity assessment immediately after examination.

In [18], optical coherence tomographic angiography (OCTA), was explored for its micro level blood flow information in fundus vessels, particularly sensitive in diabetic retinopathy (DR). Existing models for fundus images often fail on OCTA due to its unique imaging mechanism, posing challenges in information extraction. The study proposed a deep learning framework integrating multilevel information from OCTA images. Initially, a U-Net-based model was used to segment large retinal vessels and the foveal avascular zone (FAZ) in OCTA images. Later, an isolated concatenated block (ICB) structure is introduced to fuse information from original OCTA images and segmentation outputs at different levels. Results from 301 OCTA images, including 244 normal and 57 DR-labeled by ophthalmologists, achieved 93.1% accuracy and 77.1% mean intersection over union (mIOU) using the proposed segmentation model. The deep learning framework, validated through 6-fold validation, significantly improves DR diagnosis accuracy with an achieved 88.1% accuracy and an area under the curve (AUC) of 0.92, outperforming state-of-the-art models like EfficientNet.

The authors of [19] proposed a novel approach to tackle imbalanced learning and data scarcity challenges in deep learning-based diabetic retinopathy (DR) detection. They highlighted issues with traditional supervised learning biased towards majority classes, which limits model performance. Their solution involves leveraging unlabeled retinal fundus images through self-supervised or semi-supervised learning. This entails pre-training a model on unlabeled data to extract retinal features, then applying them to a supervised DR detection task. Experimental results demonstrate a 4~5% accuracy improvement over baseline supervised learning models. Comparative analyses also show superior performance to state-of-the-art methods surpassing a customized CNN model by 9%. Binary classification and self-training semi-supervised learning are the limitations of the study. The study highlights that using smaller but balanced datasets can be effective. It also suggests that using unlabeled data can help overcome the difficulties of collecting large amounts of labeled data. Future research could improve semi-supervised learning methods and apply them to diagnose different stages of diabetic retinopathy.

In [20], researchers addressed the challenge of early detection and time-consuming diagnosis of diabetic retinopathy (DR) with a proposed deep learning-based computer-aided diagnosis method. Their approach utilizes a novel convolutional neural network (CNN) with a Siamese-like architecture. This CNN was trained using transfer learning to classify colored photos of the back of the eye into different stages of DR. Unlike older methods, their model uses images from both eyes to make more accurate predictions. They trained the model with 28,104 images and tested it with 7,024 images, achieving an accuracy score (AUC) of 0.951, which is better than older models by 0.011. They also tested a version of the model that can identify five different DR classes, achieving a kappa score of 0.829 on a validation set, showing better performance than models that don't use multiple sources of information. The model works by using the natural connections between both eyes, resulting in a sensitivity of 82.2% and a specificity of 70.7% in its best operating conditions. Future research will try to deal with challenges like working with different kinds of data and making sure the model can handle bigger sets of data.

In [21], researchers focused on detecting and classifying diabetic retinopathy (DR). They emphasized the need for reliable screening methods, particularly leveraging Big Data and Deep Learning (DL) solutions. Using the Indian Diabetic Retinopathy dataset (IDRID) from Kaggle, they preprocessed images by cropping, resizing, and converting them to grayscale before employing DL techniques on the Spark platform. Their study compares InceptionV3, Xception, and VGG19 models with Logistic Regression for binary DR classification. InceptionV3 achieves the highest accuracy at 95%, surpassing Xception (92.50%) and VGG19 (89.94%). Their contributions include exploring DL and Big Data tools for DR, evaluating various datasets, and integrating DL frameworks in PySpark for efficient classification. The study underscores the potential of their pipeline to enhance clinical management by reducing vision loss. Future research aims to expand datasets and optimize preprocessing steps for improved model performance with different classifiers.

Authors of [22] tackled the challenge of detecting diabetic retinopathy (DR) from retinal images, which requires specialized expertise. They used advanced deep learning models such as InceptionResNetV2, VGG16, VGG19, DenseNet121, MobileNetV2, and EfficientNet2L. These models were trained on a dataset taken from Kaggle. To improve the models' accuracy and prevent overfitting, the authors employed techniques like data augmentation and a two-step training process. Their research yielded impressive results, particularly with InceptionResNetV2 achieving a high accuracy of 96.61%. This study highlights how their approach enhances the precision of DR diagnosis, making it more clinically relevant. It also suggests avenues for future research to further refine these models and broaden their application across diverse datasets. By leveraging state-of-the-art deep learning techniques and a systematic training approach, the authors demonstrate significant advancements in the field of DR classification. Their work shows promise for practical use in medical settings, potentially improving how doctors detect and manage DR, ultimately benefiting patients worldwide. InceptionResnetV2 and DenseNet121 models used by the authors showed the best results of classifying and detecting diabetic retinal retinopathy achieving a test accuracy of 96.61% and 94.20%, respectively

In [23], authors addressed the significant health challenge of diabetic retinopathy (DR). Their study focuses on leveraging advanced models trained on diverse image datasets to propose a CNN model for DR detection. They employed transfer learning models such as DenseNet121, Xception, ResNet50, VGG16, VGG19, and InceptionV3. They also utilized SVM and neural network models like RNN for binary and multi-class classification. Their approach, utilizing multi-label classification with softmax functions and categorical cross-entropy, achieved a good accuracy, precision, and recall values. Xception model set a benchmark with 82% accuracy, but their CNN model surpassed this, achieving 95.27% accuracy on APTOS 2019 dataset. The paper provides a comprehensive overview of these methods, discussing associated challenges and proposing potential enhancements. It integrates deep learning techniques, machine learning models, explainable artificial intelligence (XAI), and gradient-weighted class activation mapping (Grad-CAM). Insights into their accuracies and challenges aim to guide future research in disease detection through medical imaging. Furthermore, the model's performance was validated on additional datasets, demonstrating 93.86% accuracy on Messidor2 and 91.18% on IDRiD datasets, confirming its robustness across different data sources.

In [24], authors have developed a Convolutional Neural Network (CNN) model specifically designed to detect diabetic retinopathy (DR) across its various stages using image based data. Leveraging the Indian Diabetic Retinopathy Image Dataset (IDRID) from IEEE DataPort, their model achieved an impressive accuracy of up to 96%. The CNN architecture they implemented was tailored to categorize eye fundus images of patients, utilizing carefully pre-processed ground truth photos to ensure precise classification. The dataset was then divided, with 70% allocated for training purposes and the remaining 30% reserved for validation. The CNN model consistently demonstrated high accuracy, which either matched or surpassed previous methodologies, despite working with a smaller dataset. Their research not only highlights the effectiveness of their CNN model in automating and enhancing the screening process for DR but also shows the importance of accurate data preprocessing and rigorous model evaluation. By achieving such robust performance metrics, they contribute significantly to advancing the field of medical image analysis and DR diagnosis.

Researchers in [25] focused on early automated detection and prediction of diabetic retinopathy (DR). They proposed an innovative approach to improve classification accuracy using ensemble deep learning (DL) models. Their method involved training on a dataset that includes a specific class for poor-quality images and addressing a common limitation in existing datasets. Evaluation was done on the APTOS dataset and this study demonstrated superior performance of the ensemble models based on Xception and EfficientNetB4 architectures. By preprocessing data from both the DDR and APTOS databases using four distinct methods, the study created five different training input types. These inputs were used to train individual CNNs, whose outputs were aggregated using majority voting and average probability fusion techniques. The ensemble models consistently outperformed single DL architectures in terms of overall accuracy and Cohen's Kappa coefficient, with the EfficientNetB4 architecture delivering the best results. Their findings suggest that this approach not only enhances multiclass DR classification accuracy but also holds promise for improving treatment planning and risk assessment in clinical settings. By addressing the complexities of DR staging and classification, this research contributes significantly to the field of medical imaging and automated disease diagnosis.

Authors of [26] concentrated on detecting Diabetic Retinopathy (DR), a vision-threatening complication associated with poorly controlled blood sugar levels. They utilized the VGG19 pre-trained CNN model, which was fine-tuned to identify early-stage DR. Datasets were preprocessed using the CLAHE algorithm. Their model achieved a significant accuracy of 93.89% after 20 epochs, along with a robust 90% F1 score. This result demonstrates a strong performance of the model in classifying Mild Diabetic Retinopathy and No Diabetic Retinopathy cases. Transfer learning with the VGG19 architecture allowed them to adapt the model's predefined features through fine-tuning. The study employed RGB image datasets. Image preprocessing involved applying the CLAHE algorithm to fundus images from Kaggle and Messidor datasets, with training facilitated by NVIDIA GEFORCE GTX GPU for efficient computation. Dropout layers were utilized to mitigate overfitting, and a final dense layer with two neurons enabled binary classification. Comparative analysis against existing models highlighted the superior accuracy of their approach. Future research aims to expand the dataset with additional CLAHE-preprocessed images to enable multi-class classification across various severity stages of DR.

Authors in [27] presented a novel methodology utilizing Convolutional Neural Networks (CNNs) for intelligent retinopathy prediction and automatic screening of diabetic retinopathy. Their approach involves training the CNN model on a dataset comprising images of eyes with and without retinopathy. The classification process is handled by fully connected layers, while pooling layers reduce inter-layer coherence to enhance feature extraction. A feature loss factor is introduced to augment pattern recognition through kernel-based matching, aimed at improving diagnostic accuracy. In Pre-processing, dataset was cleaned by removing the images that appeared entirely black and then the remaining images were scaled down to 256. Comparative evaluations against existing methods such as DREAM, KNN, GD-CNN, and SVM demonstrate superior performance of the proposed CNN model. The model achieved an overall accuracy of 98.45% for training set and 92.15% for testing set.

In study [28], the authors presented a methodology for diabetic retinopathy (DR) detection utilizing a hybrid CNN-SVD model. Their approach integrates preprocessing, data augmentation, feature extraction, and classification stages, achieving notable performance on the IDRiD dataset. Specifically, the model demonstrates 98.06% accuracy, 83.67% sensitivity, and 100% specificity for DR detection, surpassing existing techniques. For Pre-processing, authors converted the images to RGB first. Then they applied CLAHE (Contrast Limited Adaptive Histogram Equalization) on these images. Data Augmentation was also utilized in this study involving techniques like rotation, flipping, cropping and resizing. The study underscores the importance of optimizing preprocessing and feature extraction techniques to enhance model efficacy. Future research directions include extending the model's predictive capabilities beyond DR detection and exploring Generative Adversarial Networks (GANs) for synthetic data augmentation.

In [29], the authors presented a methodology for classifying diabetic retinopathy (DR) stages with minimal learnable parameters to expedite training and model convergence. They introduced the VGG-NiN model, which combines VGG16, spatial pyramid pooling (SPP) layers, and network-in-network (NiN) layers. The SPP layer allows the model to process DR images at any scale, while NiN layers enhance nonlinearity and classification performance. The model demonstrates superior accuracy and computational efficiency compared to state-of-the-art methods. The study addresses the major drawback of numerous learnable parameters in the ensemble model. By modifying the existing CNN architecture, the authors improved the efficiency and accuracy of DR stage classification in color fundus images. The proposed model is validated on imbalanced versions of the Kaggle dataset, showing better performance with lower computational demands than other ensemble and non-ensemble methods. Future research will focus on further architectural changes and preprocessing techniques to enhance early-stage DR classification.

The researchers presented an innovative IoT and cloud-based deep learning model for diabetic retinopathy (DR) diagnosis in [30]. The proposed system involves multiple processes: data collection, preprocessing, segmentation, feature extraction, and classification. Initially, IoT-based data collection captures retinal fundus images using a head-mounted camera, which are then sent to a cloud server. Preprocessing involved enhancing the image contrast using the Contrast Limited Adaptive Histogram Equalization (CLAHE) method. Then segmentation was performed using the Adaptive Spatial Kernel distance measure-based Fuzzy C-Means clustering (ASKFCM) model. The Inception v4 deep Convolutional Neural Network (CNN) served as a feature extractor, and the extracted feature vectors were classified using the Gaussian Naive Bayes (GNB) model. The proposed model was evaluated on the benchmark MESSIDOR dataset. It achieved a superior performance compared to other models. Specifically, the model attained a sensitivity of 98.47%, specificity of 99.59%, and accuracy of 99.37%.

3 Conclusion

DR is a serious and widespread complication of diabetes mellitus. It affects the blood vessels in the retina of the eye. It is a leading cause of vision impairment and blindness worldwide if not treated on time. With diabetes mellitus reaching epidemic levels, especially in low- and middle-income countries, the need for effective screening, diagnostic and management strategies for DR has become more pressing than ever. In this study, 15 publications have been analyzed that have used deep learning techniques to detect and classify diabetic retinopathy. Many DR Datasets such as APTOS 2019 Blindness Detection, MESSIDOR, Kaggle Dataset, IDRiD, and DDR are used by the researchers. Pre-processing techniques like CLAHE (Contrast Limited Adaptive Histogram Equalization), image conversion to RGB, image scaling, cropping, resizing, gray-scale conversion and dataset cleaning are discussed. Data Augmentation techniques discussed to increase the size of dataset are cropping, rotation, flipping and resizing. Hybrid models, Ensemble models, Deep CNN architectures and pre-trained models like Xception, EfficientNet, VGG, DenseNet, ResNet and many more were used by the researchers for grading diabetic retinopathy. Then Performance of these models is discussed through metrics like Accuracy, Sensitivity, Specificity, AUC, F1-score and Kappa score along with challenges, advantages and future directions of the publications.

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