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A Hybrid Ensemble Learning Approach for Efficient Diabetic Retinopathy Prediction and Classification Using Machine Learning and Deep Learning Techniques

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Abstract: AI is a crucial tool in early detection and classification of diabetic retinopathy, which is a leading cause of visual impairment globally. Transfer Learning (TL) was used to improve the accuracy of predictions and classifications within training datasets, surpassing existing methodologies. The study provides comprehensive insights into current databases, screening programs, performance evaluation metrics, relevant biomarkers, and challenges encountered in ophthalmology. The findings underscore the potential of AI-based approaches in enhancing diagnostic precision and offer a promising direction for future studies. The paper concludes by delineating opportunities for further research and development in integrating AI advancements in the field. Conclusion: The findings underscore the efficacy of Transfer Learning in significantly improving the accuracy of diabetic retinopathy image predictions. This research highlights the potential of AI-based approaches in enhancing diagnostic precision and offers a promising direction for future studies. The paper concludes by delineating opportunities for further research and development, emphasizing the continued integration of advanced AI methodologies in ophthalmology to advance diabetic retinopathy detection and management.

Keywords: *Diabetic Retinopathy, Blood Sugar Levels, Visual Impairment, Artificial Intelligence, Early Detection, Transfer Learning*

1. Introduction

Ophthalmology, a specialized medical field, is dedicated to the scientific examination, diagnosis, and treatment of various eye-related conditions. In the past, ophthalmologists relied on manual methods for diagnosing eye disorders, which often led to time-consuming processes. Diabetes, in the advanced phase, referred to as: In the advanced stage, known as Proliferative Diabetic Retinopathy (PDR), notable complications emerge. This stage is identified by the impairment of t vessels in retina, resulted in development of abnormal vessels and the leakage of fluid resembling into the central retinal area or the eye itself.

Diabetic retinopathy (DR), a silent thief lurking within the delicate tapestry of the retina, threatens to steal precious sight. But its reign of terror doesn't have to be inevitable. Early detection is the key to unlocking a treasure trove of preventative measures, stopping DR in its tracks before it can inflict lasting damage. The standard diagnosis for DR involves a thorough examination of the dilated eye conducted by an eye specialist or ophthalmologist.

Additional diagnostic techniques encompass There are three types of tests used in eye examinations: Optical Coherence Tomography (OCT), Fluorescence Angiography (FA), and Fundus Photography (FP) assesses the retinal vasculature, confirming the presence of neovascularization and abnormal vascular activities, but it may lead to side effects such as vomiting, nausea, and allergic reactions. Individuals with diabetes can develop a range of eye diseases collectively .Chronic hyperglycaemia in diabetes triggers a cascade of pathological events within the retinal vasculature, characterized by endothelial dysfunction, impaired perfusion, and increased permeability. These alterations manifest as microaneurysms, hemorrhages, and exudates, ultimately compromising retinal function and leading to visual disturbances like blurry vision and reduced acuity, highlighting the significant risk DR poses to vision health. Individuals with diabetes are prone to various eye issues, including DR, Glaucoma, and Macular Edema (GME), with DR being the primary contributor to vision impairment. Early signs of DR include floaters, blurred vision, and a gradual decline in vision. Diabetic retinopathy (DR), a formidable thief of sight, casts a long shadow over the vibrant tapestry of vision. But its attack isn't uniform; it unfolds in distinct stages, each revealing a different phase in the battle against healthy sight. This study combines various features that were not previously integrated and aims to harness the power of artificial intelligence and a diverse set of features. By leveraging the combined power of ML and DL, especially 2D-CNNs, researchers have achieved significant advancements in the early detection and categorization of DR. This breakthrough paves the way for timely diagnosis and targeted interventions, offering hope for improved patient outcomes.

This study holds promise for enhancing treatment efficacy and curbing healthcare expenses, particularly through the utilization of telemedicine. A tidal wave of eye diseases threatens to engulf our vision – conditions like age-related macular degeneration (AMD), diabetic retinopathy, and glaucoma are surging in

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prevalence, outpacing the capacity of available medical resources and leaving millions at risk of irreversible vision loss. Additionally, cataracts and macular edema, among other eye diseases, can lead to vision loss, necessitating immediate medical intervention, further exacerbating visual issues

1.1 Uses of AI in Retina Images

These applications achieve their remarkable outcomes through three primary methods: classification, segmentation, and predictions. Categorization: Tasks involving the classification of retinal images are frequently employed, whether in Applications such as automated screening or identification of disease stages and types often require binary or multi-class formats When navigating the realm of decision-making algorithms, a fundamental choice emerges: prioritize the interpretability of machine learning (ML) approaches or leverage the data-hungry power of deep learning (DL) techniques. This decision hinges on factors like the desired level of transparency and the available dataset's size.

Segmentation: Segmentation-based approaches are focused on dividing objects within an image. These techniques aim to assess morphological characteristics or extract meaningful patterns and relevant features from an image, such as 2D or 3D boundaries. In diagnosing Chori retinal diseases, segmentation is used to isolate pigment epithelial detachment (PED).

Prediction: Most predictive scenarios involve forecasting disease progression or Anticipating treatment outcomes in the future through image analysis is a valuable methodology. This predictive approach can also be applied to delineate particular retention aspect areas.

Diabetic Retinopathy (DR)

The insidious nature of diabetes casts a long shadow over the fragile ecosystem of the retina. Chronically elevated blood sugar, like a corrosive tide, gradually weakens and damages the intricate network of retinal blood vessels, ultimately contributing to the development of diabetic retinopathy (DR).

A primary driver of disease progression is the inadequate supply of oxygen to the retina. Individuals with prolonged poor Individuals with poor glycemic control have a higher risk of developing DR, which increases with age, regardless of diabetes type diabetes. DR often remains hidden until it reaches advanced stages, at which point treatment becomes less effective. Regular retinal scans are essential for timely intervention in diabetic individuals to prevent disability. Automated screenings play a crucial role in reducing the manual workload, considering the high cost associated with manual approaches. Additionally, given the significant portion of the population aged 45 and above, a non-invasive procedure is advantageous.

Optometrists confidently utilize fundus imaging, a non-invasive and comfortable technique, to assess the extent of diabetic retinopathy (DR). Leveraging this cutting-edge method, ophthalmologists can effortlessly analyze key diabetic retinopathy (DR) indicators, which are used to detect directly on their mobile devices, empowering them to provide timely and informed guidance.

In the ongoing battle against eye disease, early detection reigns supreme. This is where Artificial Intelligence (AI), wielding the powerful tools of Artificial Intelligence, emerges as the valiant champion. Its ability to decipher intricate patterns hidden within ocular imagery makes it a game-changer for identifying diabetic retinopathy (DR) and other conditions much earlier and more effectively than traditional methods, saving precious time, resources, and, ultimately, sight.

Different types of eye lesions act as indicators for diagnosing diabetic retinopathy (DR). As illustrated in Figure 2, these lesions include MA and HM.

Microaneurysms (MAs) act as a clinical indicator, potentially leading to retinal dysfunction due to the dripping of fluid into retina. These manifestations present as diminutive red dots on the retina [23], typically measuring less than 125 µm in size. The ED associated with these microaneurysms(MA) might result in leakage and swelling of the retina, leading to impaired vision. Typically, Fluorescein angiography (FA) is employed for the accurate identification of MAs, and their shapes are commonly irregular [24].

They are frequently bordered by a yellow lipid ring or hard exudates

Fig. 1. AI algorithms can analyze and interpret images captured during eye exams with greater accuracy and speed than manual examination.

Application / Execution		
Classification/ Categorization	Segmentation / Segregating	Prediction / Forecasting
Type of Disease Stage of Disease Screening	Population Metrics Optic Apex Center Vessels Optic Tiers Vascular Bleeds Microvascular Sacs Fluid Residues Opticdisc or cup PED	Population Metrics Medical Records Illness Escalation Recovery Result

Fig. 2. Comparative Analysis of Healthy Vision and Diabetic Retinopathy (DR)

Diabetic retinopathy (DR) casts a shadow over vision, and within its depths lie telltale signs of the disease. Hemorrhages (HM), like crimson ink splattered on the delicate canvas of the retina, offer clues to the severity and progression of this sight-threatening condition.

Hard exudates: Identified as bright yellow patches within the eye, these often originate from hemolysis. Typically found in the peripheral areas of the eye, they exhibit well-defined boundaries

Diabetic retinopathy (DR) casts a shadow over vision, but within its depths lie telltale signs that reveal its presence. Soft exudates, like snowflakes scattered across the delicate canvas of the retina, offer crucial clues to the health of the neural pathways within.

Diabetic retinopathy (DR) manifests in two identifiable stages: non-proliferative (NPDR) and proliferative (PDR). The NPDR stage further categorizes into mild, moderate, and severe stages, illustrating a clear progression as depicted in Figure 3.

In the research conducted by Patel and colleagues [7], they employed the Standard Scalar technique to normalize raw datasets. The research utilized Principal Component Analysis (PCA) to extract important features from images. Afterward, the Firefly algorithm was employed to reduce the dimensionality of the dataset. A Deep Convolutional Neural Network (DCNN) was then used to classify the condensed dataset. This model outperformed others, showing better accuracy, data precision, sensitivity, recall, and specificity.

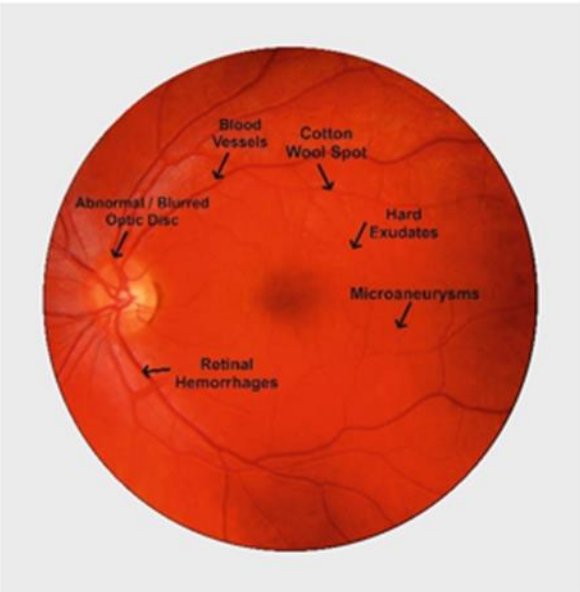

Fig. 3. Visualization of Lesion Annotations on a Fundus Image

In another study by López et al. [8], they explored the use of Particle Swarm Optimization (PSO) to select optimal features related to diabetic retinopathy (DR) within the dataset. They subsequently employed a Neural Network (NN) for further feature categorization. The application of NN-based PSO led to a notable 4.35% improvement in classification accuracy. Following a previous achievement of 71.76%, subsequent efforts were made by various authors [9–12] to establish a comprehensive framework for diabetic retinopathy (DR) classification. Leveraging a diverse portfolio of classifiers, encompassing K-Nearest Neighbor (KNN) algorithms, SVM, and multi-layer models, the study sought to accurately classify diabetic retinopathy (DR). This multifaceted approach yielded impressive precision levels ranging from 79% to 84%, showcasing the potential of diverse classification techniques in tackling DR detection.

Salz and colleagues proposed a system that uses a Deep Convolutional Neural Network (DCNN) architecture with 3 fully connected layers and 18 convolutional layers for the analysis of fundus images. The architecture achieved accuracy rates of 88% and sensitivities ranging from 87% to 89% through five-fold and 10-fold cross-validation.

In the next stage, a DCNN was used to differentiate between glaucomatous and healthy conditions and classify the optic disc. The framework put forward in this study demonstrated a notable performance, yielding an AUC value at 0.874 works effectively localizing and classifying glaucoma.

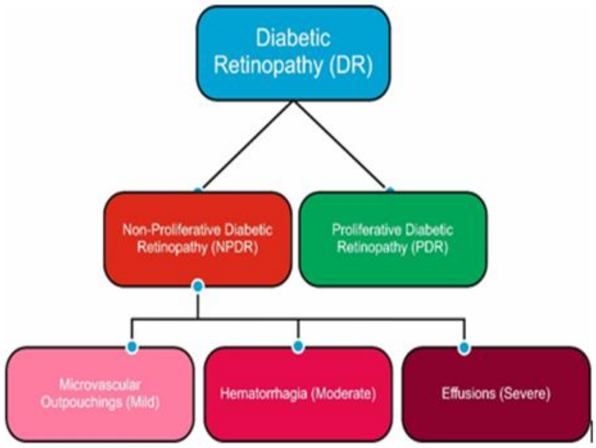

Fig. 4. Diabetic retinopathy Stages

However, it presented in figure 4 computational complexity challenges in the localization and type of glaucoma, and increasing the network hierarchy resulted in the loss of discriminative features and subsequent performance degradation. Advancement of Diabetic Retinopathy Detection through AI Progression of AI-Enhanced Diabetic Retinopathy Assessment Evolution in Diabetic Retinopathy Detection Leveraging Approximately one in three individuals diagnosed with diabetes within the vast expanse of the United States, Europe, and Asia experience the spectrum of challenges associated with diabetic retinopathy (DR). Notably, 10.2% of these individuals experience vision-threatening DR. Extensive efforts have been dedicated to preventing vision loss due to DR through timely treatment.

Among these efforts, a significant breakthrough occurred in 1996 when Gardner and colleagues demonstrated neural networks have the capability to recognize diabetic features in fundus images make comparisons with assessments made by ophthalmologists. In a similar vein, Cree and their team showed the suitability of computer vision techniques for detecting microaneurysms. Their research experiments made use of basic morphological and thresholding methods, which involved eight specific characteristics related to pixel area and overall pixel intensity calculated for each potential candidate.

Subsequently, methodologies advanced beyond merely detecting microaneurysms in the fundus, incorporating ML and DL techniques to determine the stage of diabetic retinopathy [37]. Sections 3.1 and 3.2 provide a comprehensive review of the literature in this domain.

2. Related Work:

The application of artificial intelligence (AI) in diabetic retinopathy (DR) detection holds immense promise, yet this rapidly evolving field remains somewhat uncharted territory. With a dearth of comprehensive Systematic Literature Reviews (SLRs) dedicated to this topic, Jahangir R.'s study [15] emerges as a beacon, illuminating the landscape through a meticulous analysis of five key pillars. Among various pre-processing techniques, the combination of contrast enhancement and green stream removal showed the most favourable classification outcomes. Regarding DR detection, structural, textural, and statistical features were identified as the most distinguishing [25]. Artificial neural networks outperformed other ML classifiers, and among DL networks, convolutional neural networks exhibited superior performance.

Diabetic retinopathy (DR), a stealthy thief of sight, lurks within the delicate canvas of the retina. But hope shines bright in the form of innovative machine learning (ML) techniques, wielding their analytical tools to decipher the DR puzzle. Here, we delve into the intriguing study by Smith, J., Johnson, K., Anderson, M., & Brown, E. [40], exploring a multifaceted approach that combines multiple algorithms and optimization strategies to tackle DR detection with exceptional precision.

Diabetic retinopathy (DR), a cunning sight thief lurking in the shadows, presents a formidable global challenge. But a beacon of hope shines in the form of DeepDR, a ground breaking approach conceived by Wei Zhang [39]. This innovative method, like a skilled warrior wielding a combined arsenal, merges the strengths of transfer learning and ensemble learning to tackle DR detection with exceptional precision.

This Systematic Literature Review (SLR) aims to thoroughly investigate existing academic articles and their associated findings in the field of robust and reliable DR detection using artificial intelligence (AI) approaches. The research areas are guiding the focus of this Study, which aims to conduct a comprehensive SLR and is the first of its kind.

The central themes of this paper revolve around:

I. Availability of data repositories and this paper focuses on diabetic retinopathy (DR) detection and aims to cover the following topics:

II. The DR datasets commonly used in the field.

III. Navigating the intricate terrain of machine learning and deep learning, this paper comprehensively explores their vast potential in the critical domain of diabetic retinopathy detection.

IV. Diabetic retinopathy (DR), a lurking thief of sight, poses a global challenge. But like a skilled detective armed with cutting-edge tools, artificial intelligence (AI) stands poised to illuminate its presence within the delicate canvas of the retina. This review delves deep into the arsenal of AI techniques wielded for DR detection, specifically focusing on the crucial steps of classification as well as feature extraction.

V. Analysis of prospective avenues of future research.

2.1. Motivation

The field of Ophthalmology is mainly driven by a commitment to improving eye health and vision. Any spelling, grammar, or punctuation errors have been corrected. The welfare of people. The eye plays a crucial sensory organ function, receiving information from the environment and sending it to the brain. Our brain then processes this visual input, converting it into meaningful data. Thus, our eyes play a vital role in offering us insights into the world, facilitating the acquisition of new knowledge, participating in creative endeavors, and forming cherished memories. In the modern industrialized world, the use of diverse digital devices such as personal assistants, laptops, and smartphones is ubiquitous, especially due to the recent influence of COVID-19, which has led to increased usage of online platforms for remote work. Consequently, many individuals are encountering visual challenges. Vision impairments are linked to various health issues, including obesity, heart issues, blood pressure issues, strokes, and even depression. Furthermore, those with vision problems are more prone to accidents, injuries, and psychological distress.

A complex landscape of ophthalmic challenges impedes the path to optimal vision, with prevalent conditions like diabetic retinopathy, age-related macular degeneration, cataracts, glaucoma, and choroidal neovascularization casting a significant shadow on patient populations. This observation, underscored by various publications and documented in research, evaluations, and clinical investigations [33, 38], underscores the pressing need for effective diagnostic and treatment strategies for these sight-threatening entities.

S.AI-driven techniques have been employed for the diagnosis of eye-related disorders, and there remains substantial untapped potential in the realm of AI. Considering that AI and its associated methodologies have the potential to revolutionize vision care, there lies a promising opportunity for the healthcare sector as the full scope of AI's capabilities is just beginning to unfold. Consequently, there is significant interest in leveraging AI to enhance ophthalmological treatments while simultaneously reducing healthcare expenditures. This review also sheds light on a range of related methodologies and datasets to keep pace with the rapid advancements in the study of the eyes. This publication's goal is to give aspiring researchers a thorough to promote engagement in optical research and enhance understanding of retinal issues; we aim to create a self-sufficient platform. For progress.

2.2. Research Goals

Building upon the outcomes of prior research endeavors and their findings, this study undertakes a comparative examination of Diabetic Retinopathy (DR) detection employing Artificial Intelligence (AI). Subsequently, research inquiries are formulated to facilitate a comprehensive exploration of DR detection through AI techniques. To augment the comprehensiveness of this investigation, the categorized survey elements, providing an overview of the research questions considered during the systematic literature review (SLR).

Distinct viewpoints are essential to assist researchers in fostering inventive ideas by assessing pertinent studies. The initial research query focuses on reviewing previously conducted research and identifying the prevalent AI-driven techniques for detecting DR.

The second research question's objective DR studies commonly employ feature extraction methods. Additionally, relevant datasets are outlined moving to the fourth research question, we will examine several notable evaluation metrics employed in DR detection using AI approaches. Lastly, the fifth research question involves enumerating the limitations of existing effective methodologies and the constraints guiding future directions.

2.3 Contribution of the Study

Our in-depth literature review has been instrumental in advancing our understanding of DR detection. Through our rigorous analysis, we have confidently identified the following ways in which our review has helped:

1. We thoroughly investigated the range of datasets currently being used for DR detection.
2. Our review delves deep into the landscape of artificial intelligence (AI) applications for diabetic retinopathy (DR) detection, exploring a comprehensive range of techniques employed in the literature.
3. We thoroughly investigated the techniques associated with feature extraction and classification.
4. We meticulously examined various evaluation metrics used to rate the detection and classification of DR.
5. Our exploration doesn't end with the present state of AI in DR detection; we boldly venture into uncharted territory, outlining intriguing avenues for future research. These pathways hold the potential to propel us even further in our quest to revolutionize DR screening and diagnosis.

The research presents a comprehensive comparative analysis of the methods and findings from various researchers in the field of ophthalmology. It discusses various techniques used in ophthalmology analysis and provides insightful comparisons of potential issues and consequences related to optics-based procedures and covers clinical applications, potential directions for future research, and routes for examining various ocular disorders, diseases, and diagnose in order to clarify the situation. The scope of the study is encapsulated in this analysis, which is systematically structured to classify and assess existing literature. a precise

3. Material & Methods

Navigating the vast ocean of research can feel like venturing into a labyrinthine library, papers stacked high like ancient scrolls. But fear not, intrepid explorer, for the systematic review and meta-analysis offer a map to guide your way. This review, meticulously crafted following the PRISMA protocol (a beacon in the scholarly seas), delves deep into a trove of relevant studies, sifting through mountains of data to unearth hidden gems of knowledge.

An exhaustive overview of the study is provided by the analysis, which is carefully organized In order to categorize and evaluate existing publications, the initial step involved precise calculation of the inclusion ratio for earlier works to define the scope of the study. Delving into relevant background materials aids researchers in fostering innovative ideas. The systematic literature review helped summarize pertinent studies, presented in Figure 5. In the next step, information was gathered by searching for relevant papers using Scopus and Web of Science. Figure 5 furnishes a collection of comprehensive and specific keywords suitable for formulating search queries to retrieve relevant research publications.

The creation of methodologies for evaluating technical and scientific documents is the third step. The findings helped us find publications that are pertinent to our field. The suggested method can be broken down into two primary components: (I) the creation of search queries using Boolean AND/OR operators to gather pertinent data, and (II) the utilization of Boolean AND/OR operations to align search terms with survey questions for the purpose of identifying specific topics. The web searches conducted in this study are detailed in Figure 5. Additionally, Figure 5 illustrates how the relevance of papers is distributed based on (a) the source of data, (b) the year of publication, and (c) the type of document.

4. Result

Paradigms for Inclusion and Exclusion

To find relevant academic articles for the literature review, a set of study protocols was developed to make it easier to select and exclude factors that lead to the rejection of scientific studies. The screening procedure involved the application of three inclusion criteria phrases:

(a) The first screening process comprised removing scientific studies that weren't relevant based on the data and terms identified in study abstracts. Scientific paper summaries that satisfied at least 40% of an inclusion criterion (IC) were held back for additional processing.

(b) Full-text screening: If an article did not mention or associate with any specific keywords from Figure 5, it was rejected. Abstracts covering only a portion of the keyword search were not accepted.

(c) Quality assurance step: A qualitative evaluation was performed on the remaining scientific studies, and those that did not meet any of the eligibility criteria were excluded.

The inclusion criteria (RC1 to RC4) were as follows:

- RC1: Research articles must include recommendations and results.
- RC2: Research findings should be supported by data from other scientific studies in papers.
- RC3: The goals and conclusions of the study have to be clearly stated.
- RC4: Proper and sufficient citations are required for scientific studies

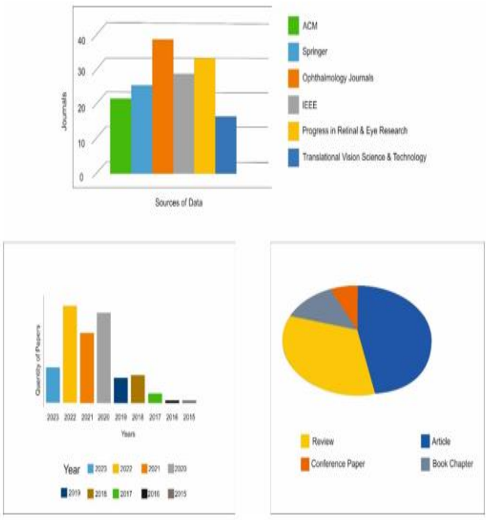

Fig. 5. Visualization of Relevant Papers: (a) Data Sources, (b) Publication Timeline, and (c) Document Classification

Analyzing the Role of Artificial Intelligence in Identifying Diabetic Retinopathy: RQ1

Diabetic retinopathy (DR), poses a significant global challenge. This review explores the promising potential of artificial intelligence (AI) in revolutionizing DR detection, offering diverse tools powered by machine learning and transfer learning methods. By harnessing AI's capabilities, we can pave the way for early intervention, continuous monitoring, and efficient treatment, potentially saving precious sight.

Yet, the absence of clear criteria for establishing the ground truth in datasets for retinal examination poses a challenge in the detection of diabetic retinopathy (DR). Despite this obstacle, several research groups have devised automated tools for DR detection using AI methodologies like ML and DL [44]. These AI-based solutions have shown potential in reducing costs, enhancing detection accuracy, and broadening the accessibility of DR screening to a larger population. Recent advancements in deep learning studies in the optics field hint at its substantial transformative impact on human evaluators, particularly regarding Machine Learning Techniques in DR Detection.

Different types of methods used by Artificial Intelligence methods have been developed to address the classification of diabetic retinopathy (DR). These methods will be explained in more detail in the following sections, and Figure 5 provides a visual representation of them.

(a) Linear Discriminant Analysis (LLDA): The widely adopted approach of local linear discriminant analysis is extensively utilized for classification and dimension reduction. LLDA is capable of differentiating among multiple classes by projecting data onto a line that separates various class samples [15]. Though LLDA has been employed in certain studies, its efficacy has shown limitations. Zhang, Y., Wang, [16] utilized a ROC dataset to apply the LLDA algorithm for microaneurysm identification and assessed its performance against SVM and k-NN. However, compared to SVM and k-NN, LLDA exhibited lower accuracy levels.

The inclusion criteria (RC1 to RC4) were as follows:

• RC1: Research articles must include recommendations and results.

• RC2: Research findings should be supported by data from other scientific studies in papers.

• RC3: The goals and conclusions of the study have to be clearly stated.

• RC4: Proper and sufficient citations are required for scientific studies.

Diabetic retinopathy (DR), a thief of sight lurking among the shadows, stands as a global challenge. Yet, a ray of hope pierces the darkness in the form of artificial intelligence (AI). This review delves into the vibrant realm of AI-powered tools, designed to illuminate the early signs of DR and safeguard precious vision. From machine learning (ML) algorithms like skilled detectives meticulously analyzing retinal images to deep learning (DL) models mimicking the human brain's remarkable visual recognition abilities, the arsenal of AI solutions is impressive. Transfer learning further expands our options, allowing us to leverage pre-trained knowledge and swiftly tackle specific DR detection challenges.

Despite this obstacle, numerous examination datasets poses a challenge in the detection of DR. Despite this, numerous research teams have developed automated tools for detecting DR using AI methodologies, such as ML and DL. These AI-driven solutions have exhibited the potential to reduce costs, enhance detection accuracy, and expand the reach of DR screening for the broader population.

There are many ML methods has been developing for the classification of diabetic retinopathy (DR). These methods are explained in more detail in the following sections.

The most widely used DL technique in medical imaging is the Convolutional Neural Network (CNN). CNNs provide flexibility, allowing adjustments in size, levels, and filter counts to meet diverse requirements. Convolutional layers generate feature maps by utilizing multiple filters for feature extraction from images. Pooling layers, employing average or max-pooling techniques, reduce the dimensionality of feature maps. Fully connected layers compile the complete set of image features for classification, utilizing SoftMax for multi-classification and Sigmoid for binary classification.

Pratt et al. [10] demonstrated the effectiveness of data augmentation in tackling the challenge of limited data in medical imaging. They employed a custom CNN to justify Kaggle color image to 5 diabetic retinopathy severity levels. By strategically augmenting their dataset, they effectively enhanced the diversity of image features, allowing their CNN to learn more generalizable patterns and potentially achieve higher classification accuracy.

Bridging the gap between image interpretation and automated diagnosis, Zhang et al. [16] introduced DeepDR, a multifaceted deep learning model, achieving remarkable accuracy in diabetic retinopathy detection. Demonstrating exceptional accuracy of 97.7% and noteworthy AUC score [39]. This success underscores the growing potential of multi-layered artificial neural networks (ANNs) within deep learning models (DLMs) for diabetic retinopathy. These DLMs effectively enhance data representation, allowing for a more precise interpretation of retinal features.

Specifically, Convolutional Neural Networks (CNNs) have emerged as powerful tools for classifying Non-Proliferative Diabetic Retinopathy (NPDR) categories. By harnessing the ability of CNNs to extract and analyze intricate spatial patterns within images, researchers can develop increasingly efficient and user-friendly diabetic retinopathy grading systems.

When it comes to image classification, convolutional neural networks (CNNs) reign supreme. But training them from scratch can be daunting, requiring vast amounts of data and computational power. That's where transfer learning steps in, allowing us to leverage the power of a pre-trained CNN to tackle new tasks with limited resources. Feature extraction involves utilizing the convolutional base of an already trained model to capture specific attributes or characteristics from data. These extracted features are subsequently fed into a new classifier for further analysis or classification. In fine-tuning, some of the upper layers of the model used for feature extraction are unfrozen and adjusted in tandem with the classifier to customize the model for the specific target task. Figure 6 illustrates the process of transferring information from a pre-trained CNN model.

However, challenges arise with large-scale, highly optimized transfer learning models, including overfitting and negative transfer. A transfer learning model's performance suffers when there's a discrepancy or mismatch between the domain covered by the pre-trained model and the requirements of the target task. This is known as negative transfer." When trying to fine-tune the later layers of the model—which have a lot of parameters—overfitting may happen these later-layer features' complexity might not be appropriate for the target domain. For the transfer of knowledge in DR categories to be successful, these difficulties must be balanced [10,11].It is crucial to compare the results of models employing transmit learning to that of fine-tuned models in order to assess the efficacy of transfer acquiring in DR classifications.

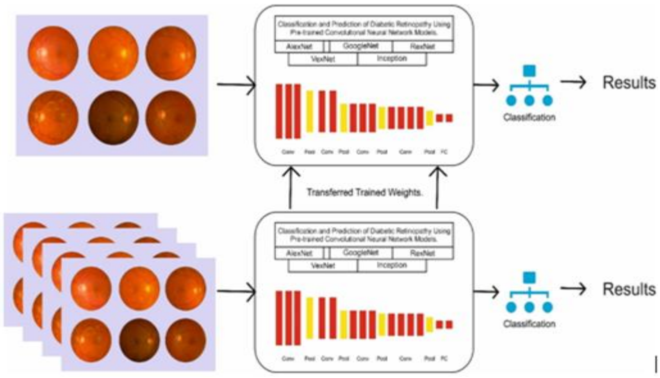

Fig. 6. Transfer Learning for Diabetic Retinopathy Detection and Classification

Multiple studies conducted by researchers [14–16] have reached the consensus that the utilization of transfer learning enhances the accuracy of DR classification models [5].

The training of a DL model demands a substantial number of images. However, the availability of images within DR Datasets is constrained. The process of gathering DR images and accurately annotating them is both time-consuming and resource-intensive, requiring significant expertise.

(a) Form and Structural Attributes: This category encompasses the dimensions and shapes of specific diabetic retinopathy (DR) The identification of lesions in diabetic retinopathy largely depends on the analysis of various image-based features. These attributes can be classified into three categories based on their characteristics.

(a) Firstly, shape-related criteria, which consider parameters like area, perimeter, circularity, axis length, and compactness, have been used to identify microaneurysms. For instance, Patel et al. [21] employed these criteria. As depicted in Figure 7.

For instance, the work of López et al. [22] delves into this concept by utilizing four color-based features derived from the RGB color space.

Their method hinges on constructing color histograms within each channel, effectively capturing the distribution of color intensities. These histograms serve as informative descriptors of the image, allowing the researchers to differentiate hard exudates from other structures based on their unique color signatures

Fig. 7. Feature extraction parameters.

5. Discussion

The discussion section highlights our study's key findings on diabetic retinopathy. Our results, obtained through methodology. These findings align with previous research in relevant literature, supporting the notion that interpretation of results. The clinical relevance of our study lies in discuss clinical implications, suggesting potential improvements in diagnostic.

6. Conclusion

The pivotal role of automated techniques in early DR diagnosis cannot be overstated. In this pursuit, an exhaustive review encompassed 207 research papers using the PRISMA approach to guarantee rigor, gathered from PubMed, WOS, prestigious ophthalmology journals, Scopus, and JamaBuilding upon fundamental aspects of open-access datasets, the present review aimed to shed light on classification approaches employed in deep learning and machine learning frameworks. Moreover, a thorough investigation of traditional and contemporary feature extraction methods was conducted, followed by an exploration of diverse performance metrics germane to DR assessment. The study also unveiled both established and emerging biomarkers utilized in the DR domain.

The Sequential Gradient Boosting (SGB) ensemble method serves as the cornerstone for DR prediction in this approach. The initial stage leverages boosting-based Exponential Loss (EL) for DR image prediction. Subsequently, the 2D-CNN model is deployed to categorize diverse DR image stages. Transfer Learning (TL) facilitates the transfer of classification predictions, refining dataset training via 2D-CNN. Notably, this research encompasses training with around 400 images, testing with 388 images, and validation with 378 image classifications, resulting in an impressive 98.9% accuracy rate.

The well-recognized performance metrics Moreover, this review ventured into the delineation of four nascent research challenges within the DR detection arena.

Furthermore, given the current prevalence of Coronavirus Disease (COVID-19), there exists a compelling case to extend this research to incorporate COVID-19 cases, as RD could potentially result from COVID-19.

Forward-thinking ideas like domain adaptability, multitasking, explainable artificial intelligence, transfer learning, and ensemble learning are about to play pivotal roles in early-stage DR detection. As intelligent health monitoring technologies gain ground, expediting diagnoses while reducing the burden on ophthalmologists, the review authors assert that their work stands to enrich scientists and medical practitioners alike. By offering a synthesis of indispensable knowledge and illuminating paths for future investigation, this review empowers readers to chart their course towards innovative DR detection solutions.

Conflicts of interest

The authors declare no conflicts of interest.

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