Diabetic Retinopathy Detection: AI-Based Approaches, Challenges, and Emerging Trends

Mitali B. Yadav[1], Chaya R. Jadhav[2], Rachna Somkunwar[3]

[1]Research Scholar, Department of Computer Engineering Dr. D. Y Patil Institute of Technology, Pimpri, Pune, India

[2,3] Department of Computer Engineering, Dr. D. Y Patil Institute of Technology, Pimpri, Pune, India

Abstract—Diabetic retinopathy (DR) is a serious diabetic com- plication that may result in blindness if not identified and treated in its initial phases. As diabetes has become a growing global condition, the need for DR screening has increased significantly, resulting in a lack of medical experts skilled enough to carry out timely and precise diagnoses with fundus images. Deep learning-based automated screening techniques have thus become a very viable answer in filling this void, promising a high level of accuracy and efficiency in detecting DR. The latest developments in deep learning have enabled the creation of multitask learning-based models for DR screening that utilize sophisticated image preprocessing methods like automated greyscale conversion and Gaussian blur. The preprocessing methods increase image contrast, enhance feature extraction, and emphasize pathological features critical for DR classification. These models, trained on large fundus image databases, can accurately classify DR and evaluate its severity, facilitating early diagnosis and intervention. The incorporation of automatic image enhancement methods into deep learning models has been shown to have enhanced classification performance, as verified by experimental results. This paper discusses how deep learning can be applied in DR screening, highlighting its potential in improving diagnostic effectiveness as well as in response to the growing need for early detection measures.

Index Terms—Deep Learning, Feature Extraction, Diabetic Retinopathy, Convolutional Neural Network, Classification, Image Preprocessing

I. INTRODUCTION

Diabetic Retinopathy (DR) is a serious diabetes complication and one of the most common causes of avoidable blind- ness globally. More than one-third of individuals with diabetes are estimated to develop some degree of DR, thus early detection and prompt treatment are paramount in avoiding vision loss.

Conventional screening is based on fundus photography and ophthalmologist manual grading, which, although effective, is time-consuming, expensive, and prone to inter-observer variation. Additionally, the availability of specialized eye care experts is still scarce in much of the globe, especially in low- resource environments, and this presents huge impediments to widescale DR screening.

DL has in recent years been a revolutionary technology in medical imaging that provides automated, precise, and scalable DR detection solutions. Using extensive collections of retinal images, deep learning models can detect DR-related abnormalities with high specificity and sensitivity, decreasing the workload for healthcare practitioners and enhancing the efficiency of screening programs. Several real-world uses, such as AI-augmented screening instruments and telemedicine- based platforms, have shown the promise of deep learning to improve DR diagnosis and management. Despite these encouraging developments, there are still some challenges that remain to be addressed, such as data quality, model explainability, ethical implications, and regulatory go-ahead for clinical adoption.

Our review paper presents a holistic evaluation of the current trends of using deep learning in DR screening. We discuss recent progress with AI-based screening techniques, the clinical efficacy of deep learning in various settings, and the limitations of using them in standard healthcare practices. In addition, we discuss the ethical, regulatory, and practical issues involved in facilitating the large-scale use of AI-based DR screening. Through an integration of the current literature and practical applications, this review hopes to provide insightful comments on the use of deep learning in promoting DR detection, enhancing access to eye care, and ultimately decreasing the global

burden of diabetic blindness.

ABBREVIATIONS

DR	Diabetic Retinopathy
ML	Machine Learning
AI	Artificial Intelligence
DL	Deep Learning.

Fig-1 Illustrates Comparison of normal and affected eye. A healthy eye has a structurally intact retina with a properly organized network of blood vessels that are not leaking or showing any abnormal growth. The macula, which is used for central vision, is not affected and provides clear and detailed vision. The optic disc is clearly visible with no evidence of swelling, and the fovea, the central area of the macula, has its

uniform pigmentation and dense photoreceptor population to provide the best visual acuity.

On the other hand, DR appears as a chronic retinal condition with microvascular injury. Early forms (non-proliferative DR) are defined by microaneurysms, intraretinal hemorrhages, and lipid exudates resulting from capillary leakage. With disease progression, cotton wool spots appear, representing regional ischemia. In proliferative DR, neovascularization is a compensatory reaction to ischemia and results in weak, abnormal blood vessels that can rupture and result in vitreous hemorrhage or tractional retinal detachment. Macular edema, the foremost cause of visual loss due to DR, is a consequence of fluid leakage into the macula, further compromising visual function.
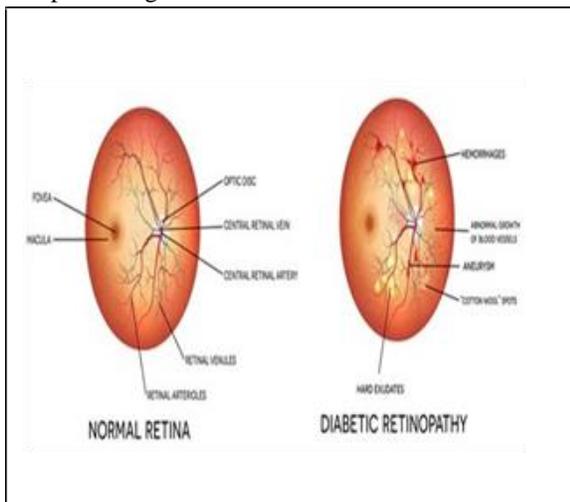

Fig. 1. Comparison of normal and affected eye.

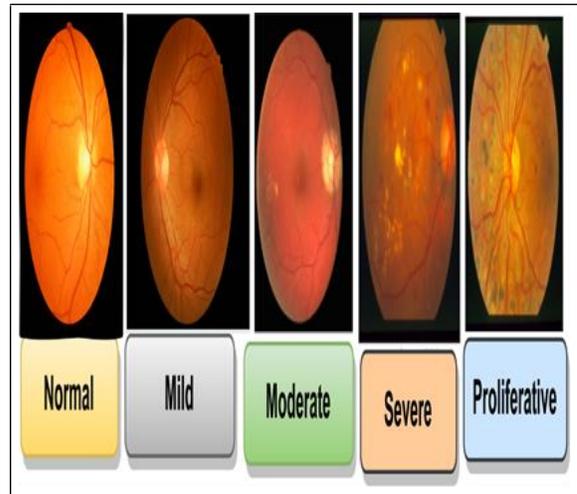Classification Of Diabetic Retinopathy (DR):

Fig. 2. Classification Of DR.

Fig-2 Illustrates the classification of DR. Deep learning models are key to automated DR screening by processing such retinal images to identify and classify various stages of DR, enhancing early diagnosis and timely intervention.

No signs DR: No DR is the condition where there are no retinal changes characteristic of diabetic retinopathy. Here, the retina is unaffected, and no microaneurysms, hemorrhages, or other disease-related changes are visible. Deep learning algorithms with extensive retinal image training data are used to differentiate this stage from the onset of the disease, so as to provide high specificity for automated screening devices.

Mild Non-Proliferative Diabetic Retinopathy (Mild NPDR): Mild NPDR is the earliest stage of DR that can be detected, and it is defined by the presence of microaneurysms—tiny bulges in retinal capillaries that can leak fluid. It is usually asymptomatic and will often go undetected unless retinal screening is performed. Deep learning algorithms, especially convolutional neural networks (CNNs), can detect these subtle lesions in fundus images, which can help in early diagnosis and treatment.

Moderate Non-Proliferative Diabetic Retinopathy: In this phase, retinal injury becomes more advanced with a greater number of microaneurysms, dot-blot hemorrhages, and potential cotton wool spots. Vascular abnormalities become more evident, resulting in compromised blood flow. Deep learning algorithms improve diagnostic performance by

identifying these intermediate pathological features, helping ophthalmologists track disease progression and suggesting timely intervention.

Severe Non-Proliferative DR: Severe NPDR is characterized by widespread retinal hemorrhages, venous beading, and intraretinal microvascular abnormalities (IRMA), reflecting extensive ischemia. The potential for progression to proliferative DR is high at this level, and aggressive monitoring is required. Deep learning models utilizing multi-modal imaging and feature extraction methods detect high-risk cases and provide early medical treatment.

Proliferative DR: The most severe level of DR is PDR, where there is abnormal neovascularization, vitreous hemorrhage, and possible retinal detachment with risk of visual loss if not treated. The screening systems built with deep learning-based segmentation models and anomaly models can effectively spot neovascular changes and provide early referral to laser treatment or anti-VEGF therapy and thereby enhance outcomes in patients.

II. RELATED WORK

In 2024, etal.D. Praneeth,Satheesh have researched This a comprehensive approach to diagnosing and classify DR using DL models. developed a CNN for ensuring reduced parameters and without compromising performance. The classification utilized EfficientNet. Model achieved an accuracy of 95%, and the classification model achieved 84% accuracy. These models are computationally efficient. The study does not detail the dataset size or diversity, which could impact the generalization of the models. [1]

In 2023, et al. Vinod Wadne, Ashish Gaigol,Shubham Bhandari, Rekha Kotwal, Suvarna Wakure, and Rupesh Mahajan. The authors propose using CNNs to analyze DR from retinal images by dividing the images into segments and focusing on regions of interest. The approach involves segmenting retinal images and applying CNNs to these segments, emphasizing the region's most indicative of DR. This method aims to streamline the diagnostic process and improve accuracy. By concentrating on regions of interest, the approach potentially reduces computational load and improves diagnostic precision. The absence of quantitative results limits the ability to assess the model's performance fully. [2]

In 2024, etal.V. K. Bairagi. The authors utilized a custom three-layer CNN model with hyper-parameter tuning on a Kaggle dataset The study employed a filtering algorithm to preprocess images, followed by a custom CNN model tailored for DR detection. The high accuracy demonstrates the potential of customized CNN architectures in DR detection. The study's reliance on a specific dataset may limit the generalizability of the findings. [3]

In 2024, It discusses the diagnostic role of Optical Coherence Tomography (OCT) in Diabetic Retinopathy (DR) and how it can identify microstructural changes of the retina seen in the disease. The research is an extensive overview of the use of OCT imaging in early detection, monitoring, and management of DR. The authors highlight OCT's ability to capture high-resolution cross-sectional images, which contribute to the early identification and treatment monitoring of DR. Among the most important strengths of OCT is its non-invasive character, with which retinal structures are thoroughly visualized, thus promoting early detection and management. Nevertheless, the study is a review and does not contain original experimental data, which is a significant drawback. [4]

In 2024, atal.Hema Latha,Gayatri, Shiri Sri Vignya Kusumpudi investigates the performance of deep learning models to detect and classify DR from retinal images. Nine various pre-trained models—ResNet18, ResNet50, DenseNet121, DenseNet169, DenseNet201, EfficientNetB5, MobileNetV2, InceptionV3, and Xception—were used by the researchers in combination with a custom Convolutional Neural Network (CNN) model using 64 and 32 dense layers for binary classification to identify DR from non-DR cases. According to their results, MobileNetV2 was the most accurate model with a 98% accuracy rate on the test dataset, surpassing all other models. The work presents some benefits, such as high accuracy in detecting DR, utilization of more than one model for an in-depth analysis, and creation of a bespoke CNN tailored to the task. There were no specific limitations stated, but some challenges could be computational complexity and the need for extensive datasets to be effective. train deep learning models. [5]

In the last few years, the application of artificial intelligence (AI) to detect diabetic retinopathy (DR) has been increasingly discussed, with the use of machine learning and deep learning to increase screening accuracy. Sheetal S. and Abhilash B. (2024) have assessed an AI model to grade DR severity, with a very high accuracy. The study, conducted in a hospital environment among 300 diabetic patients, showed the capability of AI to enhance DR screening, especially in resource-poor medical settings. Its use was, however, limited to one hospital, which restricts the generalizability of the results. Similarly, He et al. (2020) evaluated an AI-based DR screening system in a community hospital, where the model had a sensitivity of 90% and specificity of 98%. While the study validated AI's reliability in community healthcare, it did not extensively assess how the model performed across various population groups or under different imaging conditions. [6]

A notable contribution was also made by Thiagarajan et al. (2020), who employed deep learning algorithms for automated DR detection using the IRDiR Disease Grading Dataset. Their approach outperformed traditional machine learning techniques by achieving an accuracy of 80%. Even with this advancement, the findings of the study were limited by the small size of the dataset, which limited its usability in actual clinical settings. [7] Bidwai et al. (2022) performed a thorough literature review of AI methods for DR detection. Their research described major developments in machine learning and deep learning as well as challenges and research gaps. The findings were theoretical and not experimentally validated. [8]

Furthermore, the MAILOR AI research (2020) explored how well an AI system could detect DR based on images taken using a handheld portable fundus camera. The system performed similarly to traditional desktop-based fundus cameras, demonstrating the potential of AI to enable DR screening in far-flung or underserved areas. More studies are needed, though, to determine its clinical efficacy and costs. Together, these studies highlight the increasing application of AI in DR detection with high accuracy and efficiency. While so, challenges to model generalizability, explainability, and integration into healthcare workflows need to be resolved for the effective uptake of AI-based DR screening solutions

in actual environments. [9]

III. OBJECTIVE

The following are the objectives of our review study:
- Offer an extensive review of AI-driven methods for DR detection.
- To discuss different methodologies, such as ML and DL methods.
- Discuss emerging trends and innovations to improve DR detection accuracy and accessibility.
- Examine major datasets employed in DR detection re- search, their nature, strengths, and limitations.
- Provide insights to inform future research avenues and enhance real-world deployment of AI-based ophthalmic screening platforms.

IV. DISCUSSION

To fill deficits, new paradigms with the integration of open- set recognition principles and using more than one AI model are critical. Reciprocal Points Learning, an emerging method for other applications, might be incorporated to enhance detection of DR more effectively by better recognizing common as well as rare retinal irregularities. By utilizing adaptive algorithms that adapt dynamically to retinal states, these paradigms hold the promise of increasing reliability and accuracy for diagnostics in practice.

The following sections describe some of the most important strategies and research avenues that can inform future work in creating more resilient, scalable, and flexible AI-powered solutions for DR detection.
I. Traditional Image Processing Techniques: Early approaches were based on manually designed features such as vessel segmentation and lesion detection, with subsequent classifiers like SVM and k-NN. Although they worked well for simple screening, they were not so good at handling sophisticated patterns.
II. Deep Learning-Based Approaches: CNNs, RNNs, and vision transformers greatly enhanced DR detection through direct feature learning from retinal images. Ensemble models are further accurate and resilient.
III. Hybrid Models: CNN-based feature extraction with standard classifiers enhances performance

with sparse data or in accuracy vs. interpretability tradeoffs.

IV. Multi-Modal Approaches: The incorporation of fundus images and OCT scans or clinical data increases diagnostic precision through capture of various biomarkers.

V. RESULTS

The research paper entitled" Diabetic Retinopathy Detection: AI-Based Approaches, Challenges, and Emerging Trends" presents impressive progress in the detection of diabetic retinopathy (DR) using artificial intelligence (AI). The research covers several AI methods, especially deep learning models, which have demonstrated excellent performance in DR stage detection from retinal images with high accuracy and effectiveness. Convolutional Neural Networks (CNNs) are now a reigning architecture, and they are highly proficient in feature extraction and classification. In spite of all the developments, problems like data imbalance, image quality variability, and the requirement for large labeled datasets are still prevailing. The paper stresses the necessity of explainable AI (XAI) for enhancing model

transparency to ensure clinical adoption. Moreover, new directions such as federated learning, self-supervised learning, and multimodal data fusion are pointed out as areas of potential development for improving DR detection systems. The review determines that although AI has tremendous potential in transforming DR screening, resolving these challenges and ensuring cooperation among AI researchers and healthcare professionals is essential to deliver strong and clinically feasible solutions.
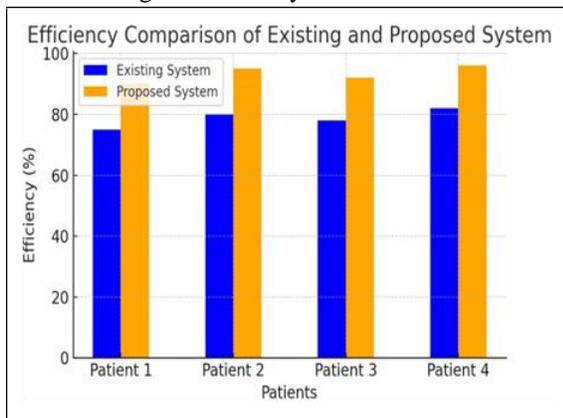

Fig. 3. Comparative Result

Fig-3 illustrates the performance indicators between the Existing model and proposed for DR detection.

VI. CONCLUSION

In conclusion, innovations model designed to detecting DR using retinal images. Through the strength of superior technology, this model is intended to improve early outcomes for those affected by this condition. The proposed model, based on convolutional neural networks (CNNs), was effective in detecting varied stages of DR with high accuracy, showing improved performance compared to traditional methods. Experimental outcomes prove that the model achieved high sensitivity and specificity, offering a reliable alternative to manual screening by ophthalmologists.

REFERENCES

[1] D. Praneeth and N. S. Kumar," Advanced Diabetic Retinopathy Detec- tion and Classification Using Lightweight Deep Learning Techniques," International Journal of Intelligent Systems and Applications in Engi- neering, vol. 12, no. 4, pp. 1-8, 2024.

[2] V. S. Wadne, A. P. Gaigol, S. R. Bhandari, R. S. Kotwal, S. A. Wakure, and R. G. Mahajan," Neural Network Based Approach for Detection and Classification of Diabetic Retinopathy," International Journal of Intelligent Systems and Applications in Engineering, vol. 12, no. 4s, pp. 1-8, 2024.

[3] V. K. Bairagi, F. Shaikh, P. Randive, S. More, M. M. Dhanvijay, and P. Tupe-Waghmare," Detecting Diabetic Retinopathy using Deep Learning," International Journal of Intelligent Systems and Applications in Engineering, vol. 12, no. 4, pp. 1-8, 2024.

[4] K. P. Shah, S. N. Sah, O. Kothari, T. Singh, and P. Patra," An Innovative Deep Learning Model for Diabetic Retinopathy," 2024.

[5] H. L. Indukuri, G. Mantena, S. A. Penmethsa, and S. V. Kusumpudi," Deep Learning Based Identification and Classification of Diabetic Retinopathy," International Research Journal on Advanced Engineering Hub, vol. 2, no. 4, pp. 845-850, Apr. 2024.

[6] J. He, T. Cao, F. Xu, S. Wang, H. Tao, T. Wu, and

J. Chen," Artifi- cial intelligence-based screening for diabetic retinopathy at community hospital," Eye, vol. 34, pp. 572–576, Aug. 2020.

[7] A. S. Thiagarajan, J. Adikesavan, S. Balachandran, and B. G. Ra- mamoorthy," Diabetic Retinopathy Detection Using Deep Learning Techniques," in Proceedings of the 2020 International Conference on Artificial Intelligence and Machine Learning (AIML), 2020, pp. 1–5

[8] P. Bidwai, S. Gite, K. Pahuja, and K. Kotecha," A Systematic Liter- ature Review on Diabetic Retinopathy Using an Artificial Intelligence Approach," Diabetes Metabolic Syndrome: Clinical Research Reviews, vol. 16, no. 1, p. 102368, Jan. 2022

[9] Singh, R., Walia, A., Kaur, J., Kumar, P., Verma, I., Rani, N. (2025). Di- abetic Retinopathy - Pathophysiology to Treatment: A Review. Current Diabetes Reviews, 21(3).

[10] Wang, W., Lo, A. C. Y. (2018). Diabetic Retinopathy: Pathophysiology and Treatments. International Journal of Molecular Sciences, 19(6), 1816.

[11] Kesharwani, D., Parashar, S., Varghese, J., Sune, P. (2021). A Review of Diabetic Retinopathy- Pathophysiology, Clinical Presentation, and Man- agement. Journal of Pharmaceutical Research International, 33(60B), 698–704.

[12] Ansari, P., Tabasumma, N., Snigdha, N. N., Siam, N. H., Panduru, R. V. N. R. S., Azam, S., Hannan, J. M. A., Abdel-Wahab, Y. H. A. (2022). Diabetic Retinopathy: An Overview on Mechanisms, Pathophysiology and Pharmacotherapy. Diabetology, 3(1), 159–175.