A Systemic Review: An Early Detection of Diabetic Retinopathy Using Artificial Intelligence

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Abstract:
The global prevalence of diabetes is rapidly increasing, with over 463 million adults currently affected. This rise has led to a significant increase in diabetic-related eye conditions, particularly diabetic retinopathy (DR), which is now a leading cause of blindness among adults. DR results from damage to the blood vessels in the retina and often progresses without noticeable symptoms until vision is affected. Due to the growing diabetic population, effective screening for DR has become a major challenge, with millions of retinal images requiring analysis each year. Early detection is crucial, as most vision loss from DR is preventable. Traditional diagnostic methods like ophthalmoscopy are still in use, but emerging technologies such as artificial intelligence (AI), deep learning, and big data are proving to be valuable tools in enhancing early diagnosis and treatment planning.

Keywords: Diabetic retinopathy, population, ophthalmoscopy, Artificial Intelligence, diagnosis.

I. INTRODUCTION

Diabetic Retinopathy (DR) is a serious eye condition caused by diabetes, and if left untreated, it can lead to permanent blindness. Early diagnosis is crucial, but it's challenging due to the subtle changes in the retina during the early stages of the disease. To address this, the study proposes a deep learning-based approach using a custom Convolutional Neural Network (CNN) and compares it with several existing models. The study describes the implementation of AI-based systems like IDx-DR, which analyzes retinal images for signs of DR. The system was tested using a combination of proprietary and public datasets (such as Messidor-2) and showed promising results in clinical trials. IDx-DR not only evaluates image quality but also determines the presence of DR, offering an efficient, scalable, and cost-effective approach to eye care. This research aims to develop an automated deep learning system for early detection of eye diseases like glaucoma and diabetic retinopathy (DR), which often progress without early symptoms. The focus is on retinal blood vessel segmentation from fundus images using a modified version of the ColonSegNet model. The study integrates Explainable AI (XAI) and Grad-CAM techniques to visualize model decisions, helping clinicians understand why certain predictions were made. Future plans include developing a balanced dataset from diabetes-prone regions like Bangladesh and creating a platform for real-time DR diagnosis through image upload.

II. HANDLED METHODOLOGIES

The research uses a large set of high-resolution retinal images and applies various image preprocessing and augmentation techniques like flipping, rotation, resampling, and zooming to balance the dataset. The models evaluated include popular transfer learning models (DenseNet121, Xception, ResNet50, VGG16, VGG19, and InceptionV3), traditional machine learning (SVM), and neural network models like RNN. Both binary (DR vs. no DR) and multi-class (based on severity) classifications were performed. Among all models tested, the custom CNN showed the highest performance with 95.27% accuracy for multi-class classification and 100% accuracy for binary classification. Notably, the Xception model performed the best among the pre-trained networks, achieving 82% accuracy. The proposed CNN also performed well on external datasets like Messidor2 and IDRiD, showing strong generalization capabilities. To enhance segmentation, the study uses contrast enhancement (especially CLAHE on the green channel) and data augmentation to handle limited labeled images. Since default CLAHE settings can be suboptimal, the study proposes optimizing its parameters using Particle Swarm Optimization (PSO).

Additional pre-processing techniques include Top-Hat transformation and filtering to reduce noise and emphasize vessel structures. The model was trained and evaluated on standard datasets (DRIVE, CHASE_DB, STARE), achieving high accuracy, sensitivity, and specificity. A key limitation is the model's reduced ability to detect very thin vessels. Future work will focus on improving detection of these fine structures for better diagnostic accuracy.

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The Deep Learning System (DLS) uses eight CNN models based on the VGGNet design. These models help detect and classify eye problems like diabetic retinopathy (DR), glaucoma, and age-related macular degeneration (AMD). Two models are used for each condition, one checks image quality, and other filters out non-retinal or unclear images. Each eye photo is first cropped to show only the retina and resized to 512×512 pixels. These images are then passed through different layers of the CNN, where features are extracted. For DR, two models are used one takes the original image, and the other takes a version with better contrast. The results from both are combined to give a final score. If the score is 0.70 or more, the system marks it as needing attention. The same method is used for glaucoma and AMD. The networks are trained using many labelled eye images.They are also trained with slightly changed images (rotated, flipped, or resized) to learn better. If an image is of low quality or not a real retina image, it is rejected and marked for review. After analysis, a report is created.

III. TABLE

This study introduces an advanced deep learning pipeline for detecting diabetic retinopathy (DR) using large-scale fundus image data. Researchers developed a two-stage system: first, a convolutional neural network (CNN) extracted key image features; second, a gradient-boosting classifier made the final diagnosis. The model was trained on 75,137 fundus images from the EyePACS dataset, covering a diverse patient population and various imaging conditions. To address variability in the images (e.g., lighting, rotation, device differences), several preprocessing techniques were applied: image resizing, brightness and contrast adjustments, and data augmentation, particularly random rotations. These steps helped the model learn features invariant to orientation and imaging conditions. The CNN used a residual learning architecture composed of five blocks with increasing filter sizes. Each layer applied batch normalization and ReLU activation to maintain training stability and prevent overfitting.

The model used cross-entropy loss to differentiate between healthy and diseased images. A heatmap visualization layer was also included, helping to highlight diagnostically significant regions in the fundus images, such as hemorrhages and microaneurysms.

Feature vectors from the model included both the deep features (1024) and three metadata components (original image width, height, and field of view), making a 1027-length input for the final gradient-boosting classifier.

DATASET	COMPARISON	AUC	SENSITIVITY	SPECIFICITY
Internal validation	EyePACS (All DR levels)	0.97	94%	98%
External Validation	MESSIDOR 2 (No DR vs. Any DR)	0.94	0.95	87%
	MESSIDOR 2 (No DR vs. Mild DR)	0.83	74%	80%
	E-Ophtha (No DR vs. Mild DR)	0.95	90%	94%

Fig 1.1 comparison of validation

The research explores the integration of retinal imaging with clinical parameters to develop an advanced detection system capable of addressing this significant public health concern. DR represents a microvascular complication of diabetes mellitus characterized by progressive retinal damage due to prolonged hyperglycemia. As the predominant cause of preventable blindness among adults aged 20-74, its clinical spectrum ranges from mild non-proliferative changes to sight-threatening proliferative diabetic retinopathy (PDR) and diabetic macular edema (DME). Timely intervention remains critical for preserving visual function. Modern diagnostic paradigms leverage: - Machine learning algorithms for pattern recognition - Deep learning architectures for image interpretation - Computer vision techniques for feature extraction Convolutional Neural Networks (CNNs) have demonstrated particular efficacy in analyzing fundus photographs, offering:

- Enhanced diagnostic precision
- Reduced inter-observer variability
- Accelerated screening processes.

The investigation employs a prospective cohort design with: 1. Multimodal data acquisition: - High-resolution fundus photography - Glycemic parameters (fasting glucose, HbA1c) - Duration of diabetes 2. AI model development: - CNN architecture optimization -Multi parameter integration - Performance validation System performance assessed through: - Diagnostic accuracy - Sensitivity/specificity profiles - Receiver operating characteristic (ROC) analysis.

The integrated AI diagnostic platform demonstrated: Superior detection capability compared to conventional methods, enhanced predictive value through clinical data incorporation, Reliable performance across disease severity stages While the AI system shows transformative potential for DR screening, further refinements are necessary to: - Minimize diagnostic errors - Improve generalizability - Facilitate clinical implementation.

The use of Artificial Intelligence (AI), particularly Deep Learning (DL), to address these challenges. Deep learning algorithms, especially Convolutional Neural Networks (CNNs), have demonstrated high sensitivity and specificity in detecting referable DR and Diabetic Macular Edema (DME) from retinal photographs and OCT scans. The Google (Gulshan etc...) algorithm achieved >= 87% sensitivity, >= 90% specificity, and an AUC of >=0.99. FDA-approved AI system like ID×DR validate the clinical utility of DC in real world settings. Despite promising results, several challenges remain. DC models are often “black boxes”, making interpretability and clinical trust difficult. Trainings require large, diverse, and annotated datasets to ensure generalized. Additionally, issues around data privacy, ethical regulations, and seamless integration into healthcare workflows must be resolved before widespread deployment. Future research should focus on enhancing model explainability using visualization tools like heatmaps, expanding global datasets to reduce bias, conducting real-world validation, and establishing ethical frameworks for clinical AI. In conduction, DL has the potential to transform diabetic eye disease screening by improving accuracy, efficiency, and accessibility. However, successful clinical adaption depends on overcoming challenges in transparency, validation, and integration within existing healthcare systems.

The role of artificial intelligence (AI), particularly Deep Learning (DL) models such as convolutional neural networks (CNNs), in automating retinal image analysis with high diagnostic accuracy. AI system, including ID×DR and Eye Art, have demonstrated over 90% sensitivity and specificity for detecting referable DR and Diabetic Macular Edema (DME), enabling large scale deployments in the USA, Singapore, UK, India and Africa. AI screening offers cost-effective, scalable solutions that enhance access to Care in low- resource settings. However, Challenges remain in model interpretability, regulatory frame work, and the need for diverse, high-quality datasets. Future directions emphasize explainable AI, ethical integration into clinical workflows, and broader validation to ensure fairness and generalizability. With responsible implementation, AI can significantly reduce the global burden of DR- related vision loss.

VII. CONCLUSION

To provide interpretability, the framework incorporates Grad-CAM for visualizing the decision-making regions of the model. The proposed system was validated on three publicly available datasets- DiaRetDB1, APTOS 2019, and EyePACS-achieving high classification accuracy (up to 99.12%) and low false detection rates. Its ability to deliver quick predictions (0.8 seconds per image) and provide explainable insights makes it suitable for real-world diabetic retinopathy screening. The paper concludes that this hybrid framework offers a clinically viable and efficient solution for early DR detection with improved reliability and transparency.

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