IJARCCE ISSN (O) 2278-1021, ISSN (P) 2319-5940

International Journal of Advanced Research in Computer and Communication Engineering

Impact Factor 8.471 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 14, Issue 11, November 2025

DOI: 10.17148/IJARCCE.2025.1411123

RetinoAI: Deep Learning Powered Detection of Diabetic Retinopathy

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Abstract: Diabetic Retinopathy (DR) is a progressive ocular disorder resulting from prolonged diabetes, in which damage to the retinal blood vessels can eventually cause permanent vision impairment. Early diagnosis is crucial, yet access to routine screening remains inadequate, especially in rural and resource-constrained communities. RetinoAI is an automated deep-learning framework designed to detect DR and classify its severity using retinal fundus photographs. The system uses Convolutional Neural Networks (CNNs) enhanced through transfer learning, accompanied by an optimized preprocessing pipeline incorporating image resizing, normalization, and augmentation to improve visual quality and model robustness. The DR classification module identifies disease grades ranging from No DR to Proliferative DR and generates corresponding confidence levels. To improve interpretability, RetinoAI employs Grad-CAM-based visual explanations that highlight important retinal regions contributing to the model's decision, supporting clinicians with clearer insight into AI-assisted diagnoses.

Keywords: Deep Learning, Diabetic Retinopathy, Convolutional Neural Networks, Fundus Image Analysis, Grad-CAM, Medical Imaging.

I. INTRODUCTION

Diabetic Retinopathy (DR) is a major visual impairment disorder associated with long-term diabetes, characterized by progressive deterioration of the retinal blood vessels. Without timely diagnosis and treatment, the condition can advance to severe and irreversible blindness. Conventional DR screening relies heavily on specialist interpretation of retinal fundus photographs, which can be subjective, labor-intensive, and difficult to access—particularly in remote and resource-constrained regions. As the worldwide prevalence of diabetes continues to escalate, there is a growing demand for reliable, scalable, and automated diagnostic solutions capable of supporting large-scale screening programs while reducing dependency on manual evaluations.

To address this need, RetinoAI is proposed as a deep-learning-driven framework that employs Convolutional Neural Networks (CNNs) to automatically detect DR features such as microaneurysms, hemorrhages, and abnormal neovascularization from fundus images. The system classifies DR severity based on clinically recognized stages and enhances diagnostic transparency through Grad-CAM visualization, which highlights the retinal regions contributing to the model's decision. By offering rapid, consistent, and interpretable predictions, RetinoAI provides an effective tool for both clinical centers and tele-ophthalmology environments, enabling earlier detection and improving patient care outcomes.

II. RELATED WORK

In [2] Early research in Diabetic Retinopathy (DR) detection depended primarily on handcrafted feature extraction techniques. Methods such as Local Binary Patterns (LBP), texture descriptors, vessel structure analysis, and wavelet-based features combined with classifiers like Support Vector Machines (SVM) and Random Forests demonstrated reasonable performance for identifying fundamental retinal lesions; however, these approaches were restricted by the need for manual feature engineering and limited generalization capability 1–4. Subsequent studies introduced hybrid frameworks that integrated handcrafted descriptors with deep-learning features to enhance recognition of microaneurysms, exudates, hemorrhages, and other red-lesion characteristics. These models also incorporated lesion count and area-based metrics to improve severity grading and clinical relevance 5–8. Research advancements in

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preprocessing and segmentation have focused on improving image quality using illumination normalization, contrast enhancement, noise suppression, and vessel segmentation. Techniques such as Local Ternary Patterns (LTP) and LESH have shown improved visibility of subtle early-stage lesions 9–10. With the evolution of deep learning, Convolutional Neural Networks (CNNs) demonstrated superior performance compared to earlier handcrafted approaches. Multi-layer CNNs, ensemble CNN architectures, and computationally efficient lightweight networks enabled more accurate multi-stage DR classification and robust feature representation 11–13. More recent investigations highlight the development of scalable, real-world DR screening solutions using end-to-end deep learning pipelines. These systems support automated detection, clinical interpretability, and integration into healthcare workflows, enabling cost-effective deployment for population-wide screening 14–16.

III. PROPOSED ALGORITHM

A. *Description of the Proposed Algorithm:*
The proposed system for deep learning powered Diabetic Retinopathy detection in four major stages: **Image Upload, Image preprocessing, Severity classification and Heatmap Generation.**

Step 1: Input Acquisation:

- Collect retinal fundus images from the user/clinician through the interface.
- Validate file format and resolution.

Step 2: Image Preprocessing:

- Resize the input image to the required CNN input dimensions (e.g., 224×224).
- Normalize pixel values to stabilize model performance.
- Apply image enhancement techniques such as:
  - Histogram equalization.
  - Contrast adjustment.
  - Noise reduction.
- Output: Clean, standardized image ready for feature extraction.

Step 3: Feature Extraction Using CNN:

- Feed the preprocessed image into the trained Convolutional Neural Network.
- CNN automatically extracts hierarchical retinal features:
  - Blood vessel patterns.
  - Microaneurysms.
  - Hemorrhages.
  - Exudates.

Step 4: Classification:

- The CNN classifier predicts the DR stage:
  - 0 — No DR
  - 1 — Mild
  - 2 — Moderate
  - 3 — Severe
  - 4 — Proliferative DR
- Output: Predicted class label and probability score.

Step 5: Explainability Using Grad-CAM:

- Apply Grad-CAM on the final convolutional layer.
- Generate heatmaps that highlight the most influential regions.
- Overlay heatmaps on the fundus image for clinician interpretation.

Step 6: Result Display:

- Display:
  - Predicted DR stage.

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- Confidence level.
- Grad-CAM visual explanation.

- Provide classification summary for clinical review.

Step 7: Model Deployment:

- Integrate system into:
- Hospital screening tools.
- Telemedicine platforms.
- Mobile/desktop applications.

IV. PSEUDO CODE

```
BEGIN RetinoAI_System
   // Step 1: Input Acquisition
   INPUT fundus_image
   IF fundus_image is invalid THEN
      DISPLAY "Invalid image input"
      TERMINATE
   ENDIF

   // Step 2: Preprocessing
   resized_image = RESIZE(fundus_image, 224, 224)
   normalized_image = NORMALIZE(resized_image)
   enhanced_image = ENHANCE_IMAGE(normalized_image)
   // Step 3: Feature Extraction using CNN
   features = CNN_FEATURE_EXTRACTION(enhanced_image)

   // Step 4: Classification
   prediction, confidence = CNN_CLASSIFY(features)

   // Step 5: Explainability using Grad-CAM

   heatmap = GENERATE_GRADCAM(enhanced_image, prediction)

   // Step 6: Display Results
   DISPLAY "Predicted DR Stage: ", prediction
   DISPLAY "Confidence Level: ", confidence
   DISPLAY_HEATMAP(heatmap)
   // Step 7: Save/Upload Results
   SAVE_RESULTS(prediction, confidence, heatmap)

END RetinoAI_System
```

V. SIMULATION RESULTS

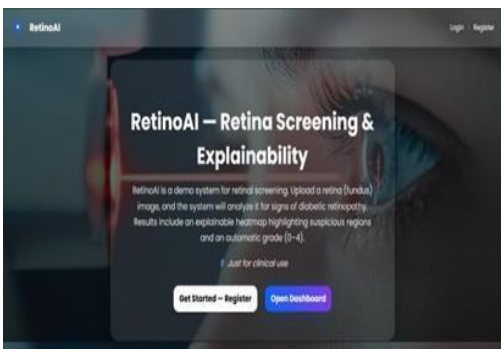

Fig.1. Home Page of RetinoAI

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The homepage presents RetinoAI as an AI-driven platform for screening retinal images and detecting Diabetic Retinopathy. It introduces users to the purpose and functionality of the system.

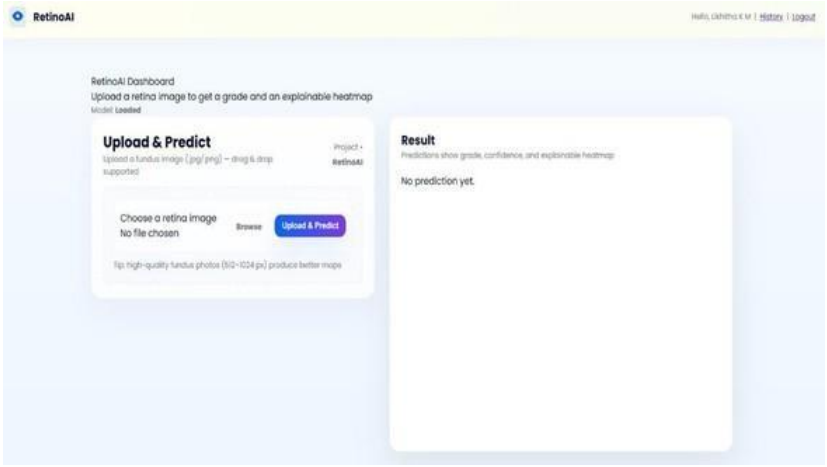

Fig.2. Dashboard of RetinoAI

The dashboard offers an intuitive workspace where users can upload retinal fundus images for automated DR analysis. It supports both browse and drag-and-drop options and displays the prediction results, including DR grade, confidence score, and explainable heatmaps.

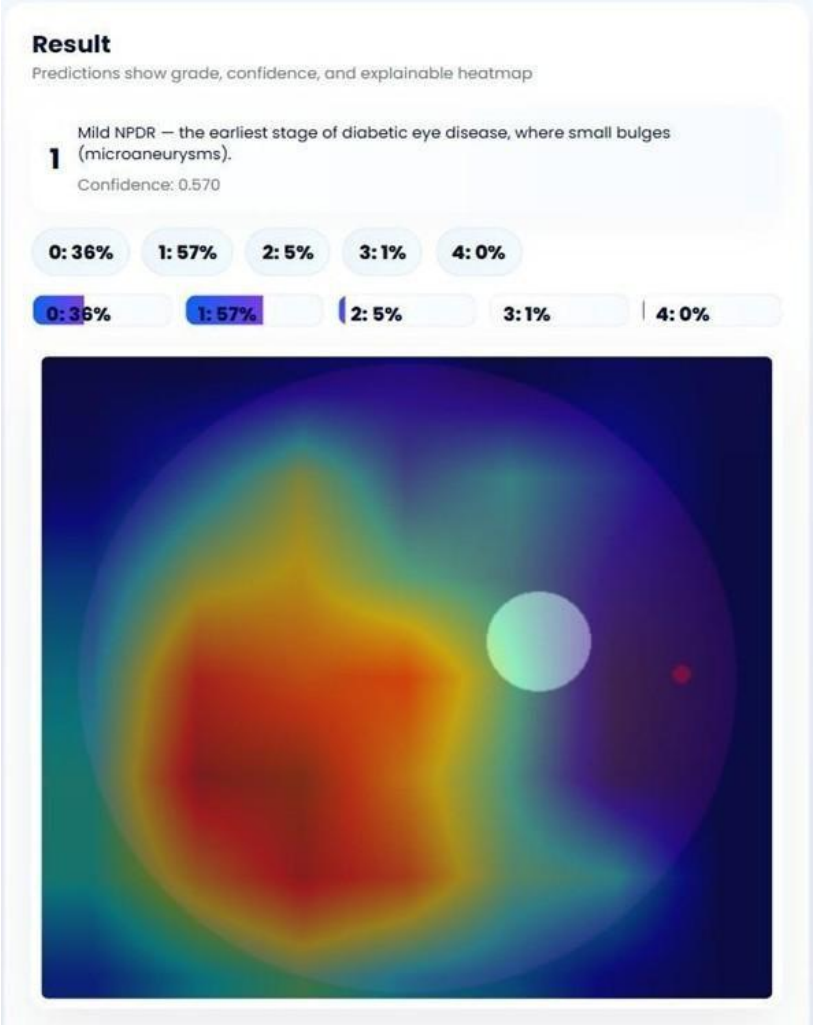

Fig.3. Result of RetinoAI

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The heatmap visualization highlights the retinal regions that contributed the most to the model's prediction. Warmer colors indicate higher influence, helping clinicians interpret the AI's diagnostic reasoning.

VI. CONCLUSION AND FUTURE WORK

RetinoAI offers a robust AI-driven approach for automating the detection and grading of Diabetic Retinopathy, effectively overcoming the constraints of traditional screening that rely heavily on specialist expertise and manual evaluation. By leveraging deep learning techniques, specifically CNN-based modeling, the system is capable of identifying subtle retinal changes with improved accuracy and reliability. The inclusion of Grad-CAM visualization enhances interpretability by clearly indicating the retinal regions that contribute to each prediction, thereby fostering greater clinical confidence in AI-assisted outcomes. The solution is scalable and adaptable for integration into telemedicine platforms and healthcare facilities, enabling widespread DR screening across both urban and underserved rural regions. Through early identification and timely clinical intervention, RetinoAI aims to reduce the risk of vision loss and improve patient care. Overall, this work demonstrates the potential of AI to significantly reduce screening workload and expand access to efficient and accessible eye-care services.

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