A RESEARCH PAPER ON AI-POWERED RETINAL DISEASE CLASSIFIER USING FUNDUS IMAGES

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Abstract

Retinal diseases such as diabetic retinopathy, cataract, and glaucoma are among the most common causes of preventable blindness across the world. Early diagnosis is crucial, yet access to expert ophthalmologists is still limited, particularly in low-resource and rural regions. This study presents an AI-based retinal disease classification system that automatically detects and classifies fundus images into four categories: Cataract, Diabetic Retinopathy, Glaucoma, and Normal. The proposed system applies transfer learning using an optimized pre-trained ResNet-18 model designed for multi-class image classification. To enhance model generalization, the manually collected dataset was processed using augmentation, normalization, and image resizing techniques. A stratified data-splitting approach was adopted to ensure balanced distribution across training (70%), validation (15%), and testing (15%) sets. The model was trained for three epochs using the Adam optimizer along with cross-entropy loss, achieving an overall accuracy of 90%. Evaluation results showed excellent performance for diabetic retinopathy (F1-score: 0.97) and cataract (F1-score: 0.91). However, glaucoma classification remained comparatively challenging, with an F1-score of 0.84. Confusion matrix analysis indicated that most errors occurred between glaucoma and normal images, suggesting higher variability in the dataset and the need for more advanced feature extraction. For practical implementation, the trained model was deployed as a Flask-based web application, enabling real-time predictions through a user-friendly interface accessible even to non-specialists. The proposed approach holds significant potential for large-scale retinal screening, especially in telemedicine and rural healthcare settings. Although the initial outcomes are promising, improvements are required in glaucoma detection, dataset diversity, and model explainability. This work contributes toward the development of affordable AI-driven ophthalmology solutions aimed at reducing the global burden of avoidable blindness.

Keywords: *CNN, Fundus Imaging, Retinal Disease Classification, Diabetic Retinopathy, Cataract, Glaucoma, ResNet-18, Transfer Learning, Medical Image Analysis, Telemedicine, Flask Web Application*

Introduction

Vision is one of the most important human senses, significantly contributing to quality of life and enabling interaction with the outside world, while any form of visual impairment can cause serious functional limitations, social isolation, and reduced productivity. According to the World Health Organization (WHO), nearly half of the 2.2 billion people worldwide affected by blindness or visual impairment could have been prevented or treated through early diagnosis and timely intervention. In 2020, over 103 million individuals globally were living with diabetic retinopathy, and this number is expected to rise rapidly due to the increasing prevalence of diabetes, making it a leading cause of blindness among working-age adults. Fundus imaging is routinely used for screening and diagnosis because it captures detailed views of key retinal structures such as the optic disc, macula, fovea, and retinal blood vessels. Over the last decade, artificial intelligence (AI), particularly machine learning (ML) and deep learning (DL), has advanced considerably in solving complex pattern recognition tasks and is especially suitable for analyzing high-dimensional data like fundus images, as these methods can automatically learn discriminative features directly from raw images without manual feature engineering. To effectively detect multiple retinal conditions, there is a need for multi-class and multi-label classification models capable of identifying different diseases simultaneously; however, publicly available multi-disease fundus image datasets remain limited. By utilizing deep learning techniques along with preprocessing and augmentation strategies to address class imbalance, such systems can automatically extract meaningful features and achieve high accuracy and strong generalization performance across diverse datasets.

1.Literature Survey

1.AI-Powered Deep Learning for Retinal Image Analysis in Diabetic Retinopathy Detection:

Diabetic Retinopathy (DR) is an eye complication caused by diabetes and is recognized as one of the major causes of avoidable blindness globally, highlighting the importance of early and precise diagnosis. With the rapid progress in artificial intelligence, especially in deep learning, automated medical image analysis has become increasingly effective. This study proposes an AI-based deep learning framework for analyzing retinal fundus images to identify diabetic retinopathy in its early stages. Convolutional Neural Networks (CNNs) are utilized to automatically extract meaningful and discriminative features from retinal images, allowing accurate classification of different stages of DR with minimal human involvement. The developed system is designed to enhance screening efficiency, minimize reliance on manual examination, and assist ophthalmologists in making timely clinical decisions, ultimately strengthening large-scale diabetic retinopathy screening initiatives.

2.A low-cost AI-Powered System for Early Detection of Diabetic Retinopathy and Ocular Diseases in Resource-Limited Settings:

Diabetic Retinopathy and other eye disorders are significant contributors to vision loss, especially in low-resource regions where access to specialized medical care and advanced diagnostic facilities is limited. This research introduces an affordable AI-based system designed for the early identification of diabetic retinopathy and other common ocular diseases through retinal fundus image analysis. The proposed method utilizes deep learning algorithms to automatically examine retinal images and detect disease-specific patterns with high accuracy while ensuring cost-effectiveness and simple implementation. By reducing dependence on costly equipment and expert evaluation, the system supports large-scale, community-based screening and early diagnosis. Such an approach can help lower the burden of preventable blindness by enabling timely referrals and appropriate treatment in underserved healthcare settings.

3.Advancing AMD screening with an offline, AI-powered smartphone-based fundus camera: A prospective, real-world clinical validation:

Age-related Macular Degeneration (AMD) is one of the primary causes of permanent vision loss in older adults, emphasizing the importance of accessible and efficient screening methods. This study enhances AMD detection by introducing an offline, AI-driven smartphone-based fundus camera developed for practical clinical application. The system combines a portable and cost-effective fundus imaging device with a deep learning model that can analyze retinal images without requiring internet access. A prospective clinical evaluation was performed to measure its effectiveness in real-world conditions, showing dependable AMD detection while preserving usability and affordability. This solution facilitates early screening in remote and underserved regions, assists healthcare professionals in making quick decisions, and encourages broader implementation of retinal screening beyond conventional hospital settings.

4.Innovative Approach for Diabetic Retinopathy Severity Classification: An AI-Powered Tool using CNN-Transformer Fusion:

Diabetic Retinopathy (DR) is a progressive eye disease that demands precise severity grading to ensure timely intervention and prevent vision loss. This study introduces a novel AI-based method for classifying DR severity using a hybrid CNN–Transformer framework. The proposed model merges the powerful local feature extraction ability of Convolutional Neural Networks with the global contextual learning strength of Transformer architectures to effectively interpret retinal fundus images. By capturing both detailed spatial information and long-range relationships within the images, the system improves classification performance across different stages of DR. The objective of this approach is to assist ophthalmologists with dependable automated evaluation, minimize diagnostic inconsistencies, and enhance large-scale screening as well as clinical decision-making in diabetic eye care.

2.Methodologies

1.Dataset Preparation and Splitting: - The dataset preparation was carried out using a Python-based pipeline to systematically arrange raw fundus images of four retinal categories—Cataract, Diabetic Retinopathy, Glaucoma, and Normal—into a structured format suitable for AI model training. To build a fair and unbiased system, the images were randomly shuffled to remove any sequencing bias and then divided into three stratified groups: 70% allocated for training and feature extraction, 15% for validation and hyperparameter adjustment, and 15% for final evaluation. This automated process ensured balanced class distribution across all folders while preserving original file metadata through the shutil.copy2() function. Such comprehensive preprocessing minimizes the risk of data leakage and enables the deep learning framework to deliver an unbiased and reliable assessment of diagnostic performance in practical applications.

Class	Training Images	Validation Images	Testing Images
Cataract	726	155	157
Diabetic Retinopathy	768	164	166
Glaucoma	704	151	152
Normal	751	161	162

TABLE 1: DISTRIBUTION OF IMAGES AFTER DATASET SPLITTING.

2.Data Preprocessing and Augmentation: - To maintain consistency and ensure compatibility with the model architecture, retinal images were processed using a standardized preprocessing workflow. Each image was resized to 224 × 224 pixels to align with the input requirements of ResNet-18 and to lower computational complexity. Pixel values were normalized using the ImageNet mean and standard deviation, facilitating effective transfer learning and promoting faster model convergence. To enhance model robustness and minimize overfitting, data augmentation techniques such as random horizontal flipping and slight rotations ranging from –10° to +10° were applied to the training set, mimicking real-world clinical variability. In contrast, validation and test images were limited to resizing and normalization only, without augmentation, ensuring preservation of original features and enabling an unbiased assessment of the model's performance on unseen data.

3.Data Loading: - Efficient data loading plays a crucial role in deep learning model training. In this study, PyTorch's Data Loader was utilized to retrieve images from organized dataset folders with support for batching, shuffling, and parallel processing to enhance efficiency and model generalization. A batch size of 32 was selected to maintain a balance between optimal GPU usage and stable gradient updates, ensuring diverse samples within each batch for reliable learning. The training dataset was shuffled at every epoch to reduce overfitting, whereas shuffling was disabled for validation and testing datasets to maintain consistent and fair evaluation. This systematic strategy ensured smooth gradient convergence, effective resource management, and dependable performance evaluation of the retinal disease classification system.

4.Model Architecture and Modification: - The proposed system utilizes the ResNet-18 architecture, which overcomes issues such as vanishing gradients through the concept of residual learning. Since it is pretrained on ImageNet, the model has already learned rich and complex visual representations, making it highly effective for transfer learning in medical image analysis. For the task of retinal disease classification, the original fully connected layer was modified to output predictions for the four specific classes, while the pretrained layers were preserved and fine-tuned. This approach allows for quicker training, improved accuracy, and optimal utilization of limited medical data, ultimately delivering a dependable solution for automated eye disease detection.

5.Model Training: - The model was trained using the Adam optimizer, which is well-suited for multi-class classification problems involving four categories. A learning rate of 0.001 was selected, and the Cross-Entropy Loss function was applied to measure classification error. The training was conducted for three epochs, utilizing a GPU for faster computation when available, and defaulting to a CPU otherwise. During each epoch, training loss and accuracy were computed to evaluate learning progress on the training dataset. At the same time, validation accuracy was tracked to examine the model's generalization capability and to identify any signs of overfitting.

Epoch	Loss	Accuracy	Validation Accuracy
1	0.5677	0.7989	0.8082
2	0.3427	0.8739	0.8716
3	0.3088	0.8949	0.8685

TABLE 2: MODEL TRAINING AND VALIDATION PERFORMANCE PER EPOCH.

6.Model Evaluation: After the training phase, the most effective model parameters were saved in a file named **retinal_model.pth**, making it possible to deploy the system directly and reproduce results without repeating the training process. The trained model was then assessed using a separate test dataset to ensure unbiased evaluation. Performance was analyzed through a classification report that included precision, recall (sensitivity), and F1-score for each retinal disease category. In addition, a confusion matrix and its corresponding heatmap were produced to visually represent the results, where diagonal elements indicated correct predictions and off-diagonal values revealed patterns of misclassification among the different classes.

7.Web Application Design and Deployment: - The application was designed as a web-based platform that combines an intuitive user interface with a deep learning model for predicting retinal diseases from fundus images. The backend was developed using Flask and incorporates a fine-tuned ResNet-18 convolutional neural network pretrained on ImageNet. Its original fully connected layer was replaced to output four classes—cataract, diabetic retinopathy, glaucoma, and normal—and the trained parameters were stored in a file named **retinal_model.pth**, which is loaded when the application starts. When a user uploads an image, it is processed through a PyTorch transformation pipeline that includes resizing to 224 × 224 pixels, conversion to a tensor, and normalization based on ImageNet mean and standard deviation values. During prediction, the model operates in evaluation mode, and torch.max() is applied to determine the class with the highest probability score. The frontend, created using HTML and CSS, features a modern glassmorphism-style upload interface with a gradient background, while JavaScript provides real-time image preview before submission. Once the image is submitted, Flask manages preprocessing and model inference, and the predicted result is displayed dynamically on the same webpage. This integrated framework supports real-time analysis, making the system practical for efficient and accurate retinal disease classification in both clinical and academic environments.

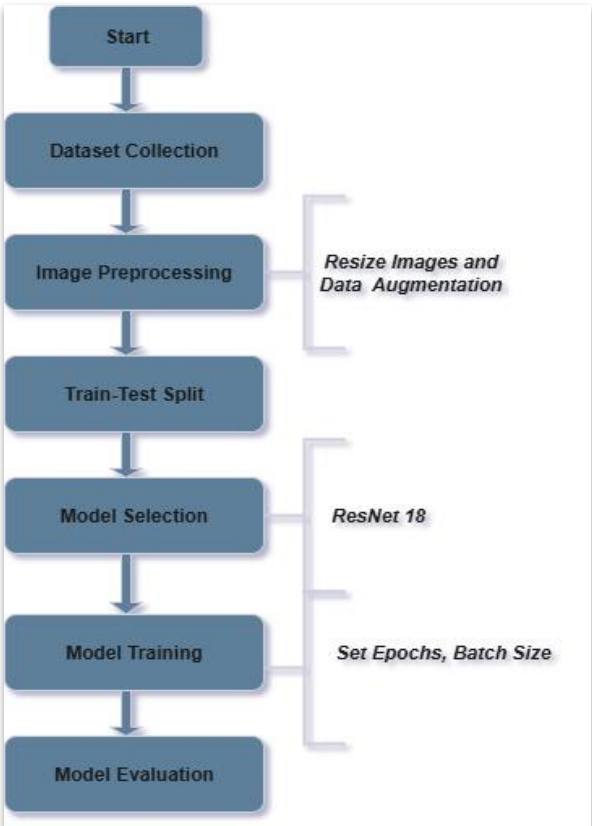

FIGURE 1: FLOWCHART OF THE AI-POWERED RETINAL DISEASE CLASSIFIER USING FUNDUS IMAGES.

3.Conclusion

This study demonstrates the significant role artificial intelligence can play in ophthalmology through the creation of a ResNet-18–based retinal disease classification system that achieves 90% accuracy in distinguishing among normal fundus images, diabetic retinopathy, cataract, and glaucoma. Beyond strong technical results, the real value of the project lies in its deployment as a Flask-based web application, which connects advanced deep learning models with practical clinical use, especially in rural and resource-constrained areas where access to trained ophthalmologists is limited. The model shows strong performance in identifying cataract and diabetic retinopathy—particularly important for preventing vision loss through early treatment—while glaucoma detection remains more challenging due to reliance on a single imaging modality, as glaucoma often requires additional structural assessments such as OCT or intraocular pressure measurements. Nevertheless, the research emphasizes careful data preprocessing and efficient system design, enabling scalability and operation even on low-end hardware to support broader healthcare accessibility. For further clinical advancement, future improvements should include multimodal data integration, enhanced interpretability using visualization methods such as Grad-CAM, and expansion of datasets to represent more diverse populations. Overall, this work represents an important step toward building a global, AI-enabled screening framework capable of delivering affordable and real-time diagnostic assistance to reduce preventable blindness worldwide.

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