Hybrid Deep Learning and YOLO-Based Lesion Detection for Diabetic Retinopathy

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Abstract: In order to increase diagnostic accuracy and usability, this study proposes an expanded lesion-centric diabetic retinopathy (DR) detection system that combines cutting-edge deep learning, machine learning, and real-time object identification algorithms. The upgrade includes the Xception model for improved feature extraction in addition to hybrid CNN-based classification utilizing ResNet and GoogleNet. Optimized machine learning classifiers and an ensemble voting technique are then used to increase robustness.

Multiple YOLO-based detection models (YOLOv5x6, YOLOv5s6, YOLOv8n, and YOLOv9n) are used to precisely localize retinal lesions such microaneurysms, hemorrhages, and exudates, allowing for quick and reliable anomaly identification. Additionally, to facilitate user interaction, testing, and result display, a Flask-based web interface with secure user authentication is created. The expanded system is appropriate for affordable diabetic retinopathy screening in embedded and resource-constrained healthcare settings because to its enhanced accuracy, real-time performance, and practical application.

Index terms *- — Diabetic Retinopathy, Lesion Detection, Hybrid Deep Learning, Xception Network, YOLO Object Detection, Feature Selection, Machine Learning, Ensemble Classification, Raspberry Pi 4, Flask Framework*

1. INTRODUCTION

Diabetic retinopathy (DR) is a progressive eye disease caused by prolonged diabetes and is one of the leading causes of vision impairment and blindness worldwide. Early detection and timely treatment are crucial to prevent irreversible vision loss. Traditional diagnostic methods rely on manual examination of retinal fundus images by ophthalmologists, which is time-consuming, subjective, and often inaccessible in rural or resource-constrained regions. With the increasing prevalence of diabetes, there is a growing need for automated, accurate, and scalable screening systems for diabetic retinopathy.

Recent advancements in deep learning have significantly improved the performance of automated DR detection systems. Convolutional Neural Networks (CNNs) have demonstrated strong capability in extracting hierarchical features from retinal images, enabling accurate classification of

disease stages. Various studies have explored hybrid approaches combining CNN architectures and machine learning classifiers to enhance detection accuracy and robustness. Additionally, transfer learning and ensemble methods have been widely adopted to address challenges such as limited annotated datasets and model generalization. However, many existing systems primarily focus on image-level classification and often lack precise lesion-level analysis, which is essential for clinical interpretation and decision-making.

To address these limitations, this paper proposes an extended lesion-centric diabetic retinopathy detection framework that integrates hybrid deep learning models, optimized feature selection, and real-time object detection techniques. The system combines ResNet, GoogleNet, and Xception architectures for effective feature extraction, along with Adaptive Particle Swarm Optimization (APSO) for selecting the most relevant features. Multiple machine learning classifiers and an ensemble voting mechanism are used to improve classification reliability. Furthermore, YOLO-based models are employed for accurate localization of retinal lesions such as microaneurysms, hemorrhages, and exudates. A Flask-based web interface with secure authentication is developed to enhance usability and accessibility.

In addition, the proposed system is optimized for deployment on Raspberry Pi 4, enabling real-time, low-cost, and portable screening. This makes the system particularly suitable for rural healthcare environments where access to specialized medical infrastructure is limited. By combining classification, lesion detection, and user-friendly deployment, the proposed approach aims to provide an efficient, scalable, and clinically relevant solution for early diabetic retinopathy diagnosis.

2. LITERATURE SURVEY

a) A Literature Review of Early-Stage Diabetic Retinopathy Detection Using Deep Learning and Evolutionary Computing Techniques:

The Indian economy is incredibly dependent on agricultural productivity. This is one of the reasons that plant disease detection plays a crucial role in the agricultural industry, as plant diseases are rather common. If proper care is not given in this area, flowers may suffer significant consequences, which will have an impact on the product's quality, volume, or productivity. Automated methods for detecting plant diseases are particularly beneficial because they minimize the enormous amount of labor that has to be done to monitor large agricultural farms. They can also identify the early signs and symptoms of plant diseases when they appear on the leaves of the plants. In addition to classifying plant leaf diseases, this work offers an algorithm for picture segmentation that can be utilized for computerized detection, as well as a review on special illness classification techniques that may be applied to the detection of plant leaf diseases. A genetic algorithm is used to carry out image segmentation, a crucial step in the identification of disorders in plant leaf disease.

b) An active deep learning method for diabetic retinopathy detection in segmented fundus images using artificial bee colony algorithm:

Diabetic retinopathy (DR) scans often utilize retinal fundus image analysis (RFIA) to assess a patient's risk of blindness. Various RFIA programs help ophthalmologists deal with the identification of visual

impairments. This study presents active deep learning (ADL) for automated DR stage detection utilizing a novel multi-layer architecture. The artificial bee colony (ABC) technique is used to segment the picture and calculate a threshold value based on the image histogram data in order to ease the identification of retinal lesions in the ADL system preparation. Additionally, segmented retinal characteristics may be automatically extracted using ADL-CNN, a tag-efficient convolutional neural network (CNN) architecture. There are two steps in this model's approach. In the first, utilizing basic accuracy labels in the training examples, pictures are chosen to learn either simple or complicated retinal properties. Second, helpful masks that segment regions of interest in the retinal picture and include important lesion traits are supplied. The most sophisticated techniques are compared using the same dataset in order to assess the performance of the suggested ADL-CNN model. Statistical measures including classification accuracy (ACC), sensitivity (SE), specificity (SP), and F-measure are used to quantify the system's efficiency. The ADL-CNN model applied to the EyePacs dataset containing 35,122 retinal images yielded 99.66% ACC, 93.76% SE, 96.71% SP, and 94.58% F-measure. In this regard, it can be said that the suggested approach performs well in identifying DR lesions from different fundus pictures and assessing their degree of severity.

c) Diabetic retinopathy detection using principal component analysis multi-label feature extraction and classification:

Millions of individuals worldwide suffer from diabetic retinopathy (DR), the most prevalent cause of vision loss. While there are established screening methods for identifying the illness, including as optical coherence tomography and fluorescein angiography, most patients are not aware of this and do not undergo these tests at the appropriate time. In order to prevent eyesight loss, which happens when Diabetes Mellitus (DM) is not treated for a long period of time, early diagnosis is essential. For disease prediction and classification, a number of Machine Learning (ML) and Deep Learning (DL) algorithms have been applied to DR datasets; however, most of them have overlooked the aspects of data pre-processing and dimensionality reduction, which are recognized as a significant gap leading to biased results. The color Fundus Photographs (CFPs) were subjected to data preprocessing in the first line of this study. We then used Principal Component Analysis (PCA) to extract features. A pre-trained Convolutional Neural Network (CNN) architecture served as the foundation for a Deep Learning Multi-Label Feature Extraction and Classification (ML-FEC) model. Then, transfer learning was applied to train a subset of the images using three state-of-the-art CNN architectures, namely, ResNet50, ResNet152, and SqueezeNet1 with parameter-tuning to identify and classify the lesions. The experimental findings revealed an accuracy of 93.67% with a hamming loss of 0.0603 for ResNet 50, an accuracy of 91.94%, and Hamming Loss of 0.0805 for Squeezenet1 and an accuracy of 94.40% with Hamming loss of 0.0560 was achieved by ResNet 152 which demonstrates the suitability of the model for implementation in daily clinical practice and to support large scale DR screening programs.

d) Diabetic Retinopathy Detection Using Machine Learning:

If left untreated, diabetic retinopathy, a condition brought on by chronic diabetes, can cause complete blindness. Therefore, early recognition of diabetic retinopathy is crucial, as is medical intervention to avoid its negative consequences. During an examination, manual ophthalmologist detection is more time-consuming and causes significant discomfort. Recently, machine learning has emerged as one of the most well-liked methods for enhancing performance across many industries, including the analysis and categorization of medical images. Consequently, an automated method helps identify diabetic retinopathy early. This study provides machine learning for the extraction of exudates, hemorrhages, and micro-aneurysms using a mixture of neural networks.

e) Diabetic Retinopathy Detection from Fundus Images of the Eye Using Hybrid Deep Learning Features:

Patients with long-term diabetes may develop a medical disease called diabetic retinopathy (DR). Vision impairment may result from delayed diagnosis. The primary cause of DR in diabetic people is elevated blood sugar. The retina's blood vessels are impacted by this. Because DR can cause structural changes to the retina, including microaneurysms (MAs), exudates (EXs), hemorrhages (HMs), and additional blood vessel development, manual diagnosis of DR is challenging. This study proposes a hybrid method for identifying and categorizing diabetic retinopathy in fundus pictures of the eye. Convolutional Neural Network (CNN) models that have already been trained are subjected to transfer learning (TL) in order to extract features that are then merged to create a hybrid feature vector. For both binary and multiclass fundus image classification, this feature vector is fed into several classifiers. Several indicators are used to assess system performance, and the outcomes are contrasted with more contemporary methods for DR detection. The suggested approach significantly improves fundus image DR detection performance. The suggested modified approach obtained the best accuracy of 97.8% for binary classification and 89.29% for multiclass classification.

3. METHODOLOGY

i) Proposed Work:

The proposed work presents an extended lesion-centric diabetic retinopathy detection system that integrates hybrid deep learning and machine learning techniques for accurate classification and analysis of retinal fundus images. The framework combines deep convolutional neural networks, including ResNet and GoogleNet, to extract high-level discriminative features, while the Xception model is incorporated to capture fine-grained lesion details. To improve feature quality and reduce redundancy, Adaptive Particle Swarm Optimization (APSO) is applied for effective feature selection. The optimized feature set is then classified using multiple machine learning algorithms such as Linear SVM, Random Forest, Decision Tree, Radial SVM, and Naive Bayes, along with an ensemble Voting Classifier to enhance robustness and reliability.

In addition to classification, the proposed system integrates multiple YOLO-based object detection models, including YOLOv5x6, YOLOv5s6, YOLOv8n, and YOLOv9n, to accurately detect and localize retinal lesions such as microaneurysms, hemorrhages, and exudates. A Flask-based web

interface with secure user authentication is developed to enable easy image upload, prediction, and visualization of results. The entire system is optimized for deployment on Raspberry Pi 4, ensuring real-time performance with low computational cost. This integrated approach improves diagnostic accuracy, interpretability, and accessibility, making it suitable for practical diabetic retinopathy screening, especially in resource-constrained healthcare environments.

ii) System Architecture:

The overall system architecture is designed as a structured pipeline that integrates image preprocessing, classification, and lesion detection modules for comprehensive diabetic retinopathy analysis. Initially, retinal fundus images are collected from standard datasets and passed through an image processing stage, where operations such as resizing, normalization, and enhancement are performed to improve image quality. Data augmentation techniques, including rotation and transformation, are applied to increase dataset diversity and improve model generalization. The processed images are then simultaneously fed into both classification and detection pipelines, enabling parallel analysis for efficient and accurate diagnosis.

In the classification pipeline, deep learning models such as ResNet, GoogleNet, and Xception are used for feature extraction. Adaptive Particle Swarm Optimization (APSO) is applied to select the most relevant features, which are then classified using multiple machine learning algorithms including Linear SVM, Random Forest, Decision Tree, Radial SVM, and Naive Bayes. An ensemble Voting Classifier further enhances classification reliability. In parallel, the detection pipeline employs YOLO-based models (YOLOv5x6, YOLOv5s6, YOLOv8n, and YOLOv9n) to identify and localize retinal lesions. The outputs from both pipelines are combined and presented through a Flask-based web interface with secure authentication, enabling real-time prediction and visualization. The architecture is optimized for deployment on Raspberry Pi 4, ensuring efficient performance in resource-constrained environments.

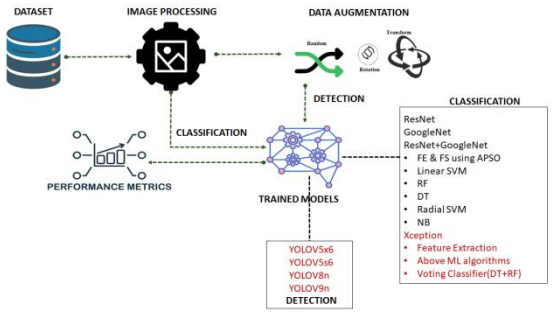

Fig1 proposed architecture

iii) Modules:

1. Dataset Module

This module is responsible for collecting and organizing retinal fundus images from standard diabetic retinopathy datasets. It ensures proper labeling and prepares the data for further processing and model training.

2. Image Processing Module

In this module, input images undergo preprocessing operations such as resizing, normalization, color conversion, and noise reduction. These steps improve image quality and make the data suitable for deep learning models.

3. Data Augmentation Module

This module generates additional training samples using transformations like rotation, flipping, and scaling. It helps increase dataset diversity and reduces overfitting, improving model generalization.

4. Feature Extraction Module

Deep learning models including ResNet, GoogleNet, and Xception are used to extract meaningful features from retinal images. These features capture important patterns related to diabetic retinopathy lesions.

5. Feature Selection Module (APSO)

Adaptive Particle Swarm Optimization (APSO) is applied to select the most relevant features from the extracted feature set. This reduces dimensionality and enhances classification efficiency.

6. Classification Module

Optimized features are classified using multiple machine learning algorithms such as Linear SVM, Random Forest, Decision Tree, Radial SVM, and Naive Bayes. A Voting Classifier (DT + RF) is used to improve accuracy and robustness.

7. Lesion Detection Module

YOLO-based models (YOLOv5x6, YOLOv5s6, YOLOv8n, YOLOv9n) are used to detect and localize retinal lesions such as microaneurysms, hemorrhages, and exudates in real time.

8. Performance Evaluation Module

This module evaluates the performance of classification and detection models using metrics like accuracy, precision, recall, sensitivity, specificity, and F1-score.

9. User Interface Module

A Flask-based web application provides user registration, login, image upload, and result visualization. It ensures secure and user-friendly interaction with the system.

10. Prediction and Output Module

The final results, including disease classification and detected lesion regions, are displayed to the user in both textual and visual formats for easy interpretation.

iv) Algorithms:

1. ResNet Algorithm

ResNet (Residual Network) is a deep convolutional neural network architecture designed to overcome the vanishing gradient problem by introducing residual or skip connections. These connections allow gradients to flow directly through the network, enabling effective training of very deep models. In the proposed system, ResNet is used to extract high-level discriminative features from retinal fundus images, capturing complex lesion-related patterns such as microaneurysms, hemorrhages, and texture variations. Its deep hierarchical learning capability significantly improves diabetic retinopathy classification accuracy.

2. GoogleNet Algorithm

GoogleNet, also known as Inception v1, employs inception modules that perform parallel convolutions with different kernel sizes within the same layer. This design enables multi-scale feature extraction, allowing the network to capture both fine and coarse retinal features simultaneously. In this project, GoogleNet contributes computational efficiency while maintaining strong feature representation. Its ability to extract diverse spatial features enhances the detection of varying lesion sizes in diabetic retinopathy images.

3. Hybrid GoogleNet + ResNet Algorithm

The proposed hybrid model integrates GoogleNet and ResNet to leverage the strengths of both architectures. GoogleNet provides efficient multi-scale feature extraction, while ResNet ensures deep feature learning with improved gradient flow. Features extracted from both networks are fused to form a richer representation of retinal abnormalities. This hybrid approach improves robustness, enhances classification accuracy, and provides better generalization across different diabetic retinopathy stages.

4. Xception Algorithm

Xception is a deep learning architecture based on depthwise separable convolutions, which significantly reduce computational complexity while maintaining high accuracy. In the proposed system, Xception is used as an additional feature extractor to capture fine-grained lesion details that may be missed by conventional CNNs. Its lightweight and efficient structure makes it suitable for deployment on embedded platforms such as Raspberry Pi 4. Xception enhances overall system performance by improving feature diversity.

5. Adaptive Particle Swarm Optimization (APSO)

APSO is an optimization algorithm inspired by the social behavior of bird flocks and fish schools. It is employed in this project for feature selection by adaptively adjusting particle velocities and positions to identify the most informative features. APSO reduces feature dimensionality, minimizes redundancy, and improves classifier efficiency. By selecting optimal lesion-related features, APSO enhances classification accuracy while reducing computational overhead.

6. Linear Support Vector Machine (SVM)

Linear SVM is a supervised learning algorithm that identifies an optimal hyperplane to separate different classes with maximum margin. In this system, Linear SVM is applied to classify optimized deep features extracted from retinal images. Its simplicity, speed, and effectiveness in high-dimensional spaces make it suitable for real-time diabetic retinopathy screening. Linear SVM contributes to stable and reliable classification results.

7. Radial Basis Function SVM (Radial SVM)

Radial SVM employs a radial basis function kernel to handle non-linear relationships between features. It maps input data into a higher-dimensional space where complex class boundaries can be identified. In diabetic retinopathy detection, Radial SVM effectively captures non-linear lesion patterns present in advanced disease stages. This improves classification performance where linear separation is insufficient.

8. Random Forest Algorithm

Random Forest is an ensemble learning method that constructs multiple decision trees and aggregates their predictions to improve accuracy. It reduces overfitting and enhances generalization by introducing randomness in feature selection and data sampling. In the proposed system, Random Forest efficiently handles complex feature interactions and improves robustness in diabetic retinopathy classification.

9. Decision Tree Algorithm

Decision Tree is a supervised learning algorithm that uses hierarchical decision rules based on feature values. It provides interpretable classification paths, allowing insight into the decision-making process. In this project, Decision Tree serves both as an individual classifier and as a base learner in the voting ensemble. Its simplicity and transparency support explainable diagnostic outcomes.

10. Naive Bayes Algorithm

Naive Bayes is a probabilistic classifier based on Bayes' theorem, assuming independence among features. Despite this assumption, it performs efficiently on large datasets and high-dimensional feature spaces. In the proposed system, Naive Bayes provides fast classification and serves as a lightweight alternative suitable for real-time applications on embedded hardware.

11. Voting Classifier (DT + RF)

The Voting Classifier combines predictions from Decision Tree and Random Forest classifiers to produce a final decision. By aggregating outputs from multiple classifiers, this ensemble approach improves robustness and reduces misclassification risk. The voting mechanism enhances stability and accuracy, particularly when individual classifiers show varied performance across different datasets.

12. YOLOv5x6 Algorithm

YOLOv5x6 is a high-capacity real-time object detection model designed for accurate localization and classification of objects within images. In this system, it is used to detect and localize retinal lesions by generating bounding boxes and confidence scores. Its high accuracy makes it suitable for detailed lesion-centric diabetic retinopathy analysis in clinical scenarios.

13. YOLOv5s6 Algorithm

YOLOv5s6 is a lightweight variant of YOLOv5 optimized for faster inference with reduced computational requirements. It enables real-time lesion detection while maintaining acceptable accuracy. This model is particularly suitable for embedded deployment on Raspberry Pi 4, ensuring quick diagnosis in resource-constrained environments.

14. YOLOv8n Algorithm

YOLOv8n introduces architectural improvements for better feature aggregation and detection efficiency. It balances speed and accuracy, making it effective for detecting subtle retinal abnormalities. In the proposed framework, YOLOv8n enhances detection reliability while supporting real-time performance.

15. YOLOv9n Algorithm

YOLOv9n represents an advanced generation of the YOLO family with improved precision and optimized inference speed. It enhances the detection of small and complex lesions in retinal images. By integrating YOLOv9n, the system achieves high detection

accuracy and efficient real-time performance, strengthening lesion-centric diabetic retinopathy diagnosis.

4. EXPERIMENTAL RESULTS

The experimental evaluation of the extended diabetic retinopathy detection system was conducted to validate the effectiveness of integrating the Xception model, multiple machine learning classifiers, and YOLO-based lesion detection. Retinal fundus image datasets were used for both training and testing phases. The Xception-based feature extraction combined with classical machine learning classifiers demonstrated improved classification stability and accuracy compared to standalone CNN models. The inclusion of the Voting Classifier (Decision Tree + Random Forest) further enhanced robustness by reducing classification variance across different diabetic retinopathy stages. The application of Adaptive Particle Swarm Optimization (APSO) contributed to improved performance by selecting the most relevant lesion-related features and reducing redundant information.

For lesion localization, the extended framework evaluated multiple YOLO variants, including YOLOv5x6, YOLOv5s6, YOLOv8n, and YOLOv9n, to analyze detection accuracy and inference efficiency. High-capacity YOLO models provided precise localization of retinal lesions, while lightweight versions achieved faster inference suitable for embedded deployment. The integration of a Flask-based user interface enabled seamless image upload, real-time prediction visualization, and secure user interaction. Real-time testing on Raspberry Pi 4 confirmed that the optimized detection and classification pipeline operates efficiently with acceptable latency. These results demonstrate that the extended system improves diagnostic accuracy, real-time performance, and usability, making it a practical and scalable solution for diabetic retinopathy screening in resource-constrained healthcare environments.

Accuracy: A test's accuracy is its capacity to distinguish healthy from ill cases. Find the percentage of instances with genuine positives and negatives to assess test accuracy.

Accuracy = TP + TN /(TP + TN + FP + FN)

$$Accuracy = \frac{(TN + TP)}{T}$$

Precision: Classification accuracy or positive cases constitute precision. The formula for accuracy is:

Precision = True positives/ (True positives + False positives) = TP/(TP + FP)

$$\Pr e\,cision = \frac{TP}{(TP + FP)}$$

Recall: A model's recall measures its ability to recognize all appropriate machine learning class instances. The ratio of accurately predicted positive observations to total positives indicates a model's class instance detection skill.

$$Recall = \frac{TP}{(FN + TP)}$$

mAP: Mean Average Precision ranks quality. It considers the number and order of relevant ideas. Calculating MAP at K uses the arithmetic mean of each user or query's Average Precision (AP).

$$mAP = \frac{1}{n}\sum_{k=1}^{k=n} AP_k$$

$$AP_k = \text{the AP of class } k$$

$$n = \text{the number of classes}$$

F1-Score: A high F1 score suggests an accurate machine learning model. Integrating recall and precision improves model correctness. Accuracy measures how often a model predicts a dataset correctly.

$$F1 = 2 \cdot \frac{(Recall \cdot \Pr e\,cision)}{(Recall + \Pr e\,cision)}$$



Fig3 Home page

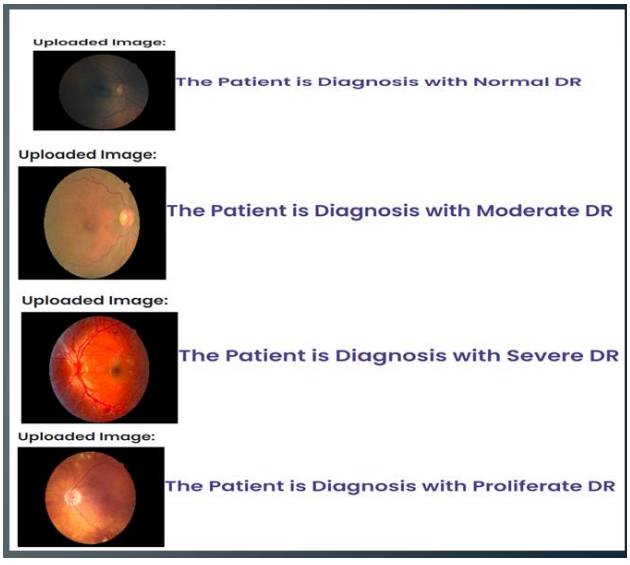

Fig4 Analysis results

5. CONCLUSION

This paper presented an extended lesion-centric diabetic retinopathy detection system that integrates hybrid deep learning, machine learning, and real-time object detection techniques for accurate and efficient diagnosis. The combination of ResNet, GoogleNet, and Xception models enabled effective feature extraction, while Adaptive Particle Swarm Optimization (APSO) improved feature selection and reduced computational complexity. The use of multiple machine learning classifiers along with a Voting Classifier enhanced classification robustness and reliability across different stages of diabetic retinopathy.

Furthermore, the integration of YOLO-based models allowed precise detection and localization of retinal lesions, improving interpretability and clinical relevance. The implementation of a Flask-based web interface ensured user-friendly interaction and secure access to the system. Deployment on Raspberry Pi 4 demonstrated the feasibility of real-time, low-cost, and portable screening. Overall, the proposed system provides a scalable and efficient solution for early diabetic retinopathy detection, making it suitable for practical use in resource-constrained and rural healthcare environments.

6. FUTURE SCOPE

The proposed system can be further enhanced by incorporating multimodal retinal imaging techniques, such as Optical Coherence Tomography (OCT), to improve early-stage detection and provide more comprehensive analysis of retinal structures. Future work may also explore advanced deep learning architectures, including attention mechanisms and

transformer-based models, to improve feature representation and detection accuracy.

Additionally, integrating Explainable AI (XAI) techniques can enhance model transparency by providing visual explanations for classification and lesion detection results, thereby increasing clinical trust. The system can be extended using federated learning approaches to enable collaborative model training across multiple healthcare institutions while preserving patient data privacy.

From a deployment perspective, further optimization using edge AI accelerators and newer hardware platforms can reduce inference time and improve efficiency. Expanding the Flask-based system into a mobile or cloud-integrated telemedicine platform would support large-scale remote screening, making the solution more accessible in rural and underserved regions..

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