**Multiclass Retinal Image Classification for Diabetic Retinopathy Stages Using Convolutional Neural Networks**

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**Abstract**

Diabetic Retinopathy (DR) is a leading cause of vision loss, requiring early detection for effective treatment. This study presents a deep learning-based approach for automated DR classification using convolutional neural networks (CNNs). A dataset of 2,750 retinal images, categorized into five classes, was processed with data augmentation and split into training, validation, and testing sets. ResNet152V2 and VGG19 were trained and evaluated using accuracy, precision, recall, F1-score, and AUC-ROC metrics. Grad-CAM was employed to enhance model interpretability by highlighting critical regions in retinal images. A user-friendly Streamlit-based web application was developed for real-time diagnosis. Experimental results demonstrate that ResNet152V2 outperforms VGG19, offering a reliable solution for DR detection.

**Keywords:** Diabetic Retinopathy, Deep Learning, Convolutional Neural Networks, ResNet152V2, VGG19, Grad-CAM, Medical Image Classification, Explainable AI, Streamlit, Retinal Image Analysis.

1. ***Introduction***

Diabetic Retinopathy (DR) is a progressive microvascular complication of diabetes mellitus that affects the retina, leading to vision impairment and potential blindness if left untreated [1]. It is one of the leading causes of preventable blindness worldwide, particularly among working-age adults. The condition arises due to prolonged hyperglycemia, which causes damage to the blood vessels of the retina, leading to leakage, hemorrhages, and neovascularization [2]. DR progresses through several stages, ranging from mild non-proliferative abnormalities to more severe proliferative forms characterized by abnormal blood vessel growth [3]. The early stages of DR are often asymptomatic, making early diagnosis and regular screening crucial for timely intervention. Clinical diagnosis typically involves fundus photography and fluorescein angiography, which allow ophthalmologists to detect microaneurysms, hemorrhages, and other pathological features of DR [4]. However, manual examination of retinal images is time-consuming and prone to variability among experts. With the increasing prevalence of diabetes worldwide, there is a growing demand for automated and accurate DR screening systems that can assist in early detection and classification of the disease [5]. Deep learning, particularly Convolutional Neural Networks (CNNs), has emerged as a powerful tool for medical image analysis, demonstrating high accuracy in detecting and classifying DR stages from retinal fundus images [6]. By leveraging large datasets and advanced neural architectures, CNN-based models can automatically extract relevant features and provide consistent predictions, reducing the burden on healthcare professionals [7]. This study focuses on the development of a CNN-based multiclass classification model using DenseNet121 to classify retinal images into different DR stages. By utilizing deep learning techniques, this approach aims to improve early diagnosis, facilitate large-scale screening, and ultimately contribute to better patient outcomes [8].

**Role of Deep Learning in Medical Image Classification**

Deep learning has revolutionized the field of medical image analysis by providing automated, highly accurate solutions for disease detection and classification. Traditional machine learning approaches rely on handcrafted feature extraction, which requires domain expertise and may fail to capture complex patterns in medical images. In contrast, deep learning, particularly Convolutional Neural Networks (CNNs), automatically learns hierarchical features from raw image data, enabling robust and scalable classification models [9].

CNNs have been widely applied in ophthalmology, demonstrating remarkable success in diagnosing retinal diseases, including Diabetic Retinopathy (DR), Age-related Macular Degeneration (AMD), and Glaucoma [10]. By utilizing large-scale labeled datasets and deep neural architectures, CNN-based models can identify pathological features such as microaneurysms, hemorrhages, and exudates with high precision [11]. These models have been trained on vast retinal image databases, such as the Kaggle DR dataset and the Messidor dataset, achieving expert-level performance in DR classification tasks [12]. One of the most significant advantages of deep learning in medical imaging is its ability to generalize across diverse datasets while maintaining high classification accuracy. Transfer learning, where pre-trained models like DenseNet121, ResNet, or VGG16 are fine-tuned on medical image datasets, has further improved model efficiency and reduced the need for extensive training data [13]. This approach allows researchers to leverage knowledge from large-scale natural image datasets (such as ImageNet) and adapt it for specific medical applications with minimal computational resources [14]. Beyond classification, deep learning models have also been integrated into clinical decision support systems, aiding ophthalmologists in diagnosing and monitoring DR progression. Saliency maps and Grad-CAM (Gradient-weighted Class Activation Mapping) techniques provide visual explanations of model predictions, increasing transparency and trust in AI-driven medical diagnosis [15]. The application of deep learning in DR screening has the potential to revolutionize early disease detection, especially in low-resource settings where access to trained specialists is limited [16]. This study focuses on the development of a DenseNet121-based deep learning model for the multiclass classification of retinal fundus images. By leveraging CNN-based feature extraction and transfer learning, this work aims to enhance the accuracy and efficiency of DR stage classification, ultimately contributing to improved patient care and large-scale screening efforts [17].

**Problem Statement**

Diabetic Retinopathy (DR) is a major public health concern, with its incidence increasing due to the global rise in diabetes cases. If left undiagnosed or untreated, DR can lead to irreversible vision loss. Traditional diagnostic methods rely on ophthalmologists manually analyzing retinal fundus images, which is time-consuming, prone to subjective bias, and not scalable for large populations . Additionally, limited access to specialized eye care in remote or underdeveloped regions exacerbates the issue, delaying early detection and treatment While deep learning has shown promise in medical image analysis, existing DR classification models often lack interpretability, making them less reliable for clinical adoption. Furthermore, many models focus on binary classification (DR vs. No DR) rather than multi-stage classification, which is crucial for effective disease monitoring and treatment planning . The need for an accurate, automated, and explainable DR classification system is evident, particularly one that can differentiate between multiple DR severity levels and provide visual explanations for its predictions.This research addresses these challenges by developing a deep learning-based approach using for multiclass DR classification. The integration of Grad-CAM ensures model interpretability, while a Streamlit-based web interface enables easy deployment for real-time analysis. This system aims to improve DR screening efficiency, reduce dependence on manual diagnosis, and enhance accessibility to automated DR detection tools.

1. ***Literature Review***

**Literature Survey**

Deep learning has significantly advanced the field of medical image analysis, particularly in the classification of retinal diseases such as Diabetic Retinopathy (DR). Several studies have explored the use of convolutional neural networks (CNNs) for DR detection and classification, demonstrating promising results in automated diagnosis. This section reviews key contributions in the field, highlighting their methodologies, findings, and limitations.

Early efforts in DR classification relied on traditional machine learning techniques such as support vector machines (SVMs) and random forests, which required handcrafted feature extraction from retinal fundus images [18]. While these approaches achieved moderate accuracy, their performance was constrained by the quality of extracted features and the need for domain-specific expertise. The emergence of CNN-based architectures revolutionized DR detection by enabling automatic feature extraction directly from images, leading to substantial improvements in classification performance [19].

A significant milestone was achieved by Gulshan et al. [20], who developed a deep learning system for DR detection using a large dataset of retinal fundus images. Their model, based on Inception-v3, achieved sensitivity and specificity comparable to ophthalmologists. Similarly, Pratt et al. [21] proposed a CNN-based framework using deep residual networks (ResNets), demonstrating high accuracy in distinguishing between different DR stages. These studies established the viability of deep learning for automated DR screening, paving the way for further advancements in the field.

More recent studies have focused on optimizing CNN architectures to improve DR classification accuracy and computational efficiency. Dos Santos et al. [22] investigated the performance of VGG16 and ResNet50 for DR classification, highlighting the benefits of transfer learning in leveraging pre-trained models. Their findings indicated that deep models trained on large-scale image datasets such as ImageNet could be fine-tuned for DR detection with high accuracy, reducing the need for extensive medical image datasets.

DenseNet-based architectures have also been explored for DR classification due to their efficient feature propagation and reduced parameter complexity. Yan et al. [23] utilized DenseNet121 to classify DR stages, demonstrating improved performance compared to traditional CNNs. Their model leveraged densely connected layers to enhance feature reuse, resulting in higher classification accuracy and robustness to variations in retinal images. The effectiveness of DenseNet121 in DR classification has motivated its adoption in this study, as it provides a balance between accuracy and computational efficiency.

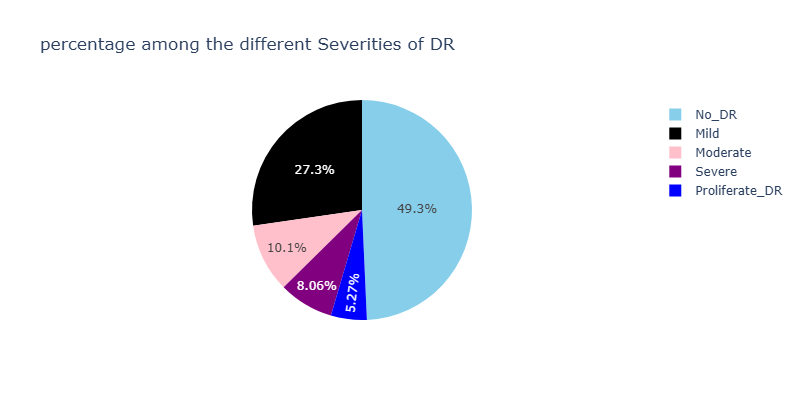
Despite these advancements, challenges remain in achieving robust and generalizable DR classification models. One major issue is dataset imbalance, where certain DR stages have significantly fewer samples than others, leading to biased predictions [24]. To address this, researchers have explored data augmentation techniques such as image rotation, flipping, and contrast adjustments to artificially expand training datasets [25]. Additionally, ensemble learning approaches, which combine multiple CNN architectures, have been investigated to enhance model robustness and reduce misclassification rates [26].

Another critical aspect of DR classification is interpretability. While deep learning models achieve high accuracy, their "black-box" nature limits clinical adoption. Recent studies have introduced explainability methods such as Grad-CAM and attention mechanisms to visualize model predictions and highlight pathological features in retinal images [27]. These techniques improve trust in AI-based systems and facilitate integration into clinical workflows.

1. ***Methodology***

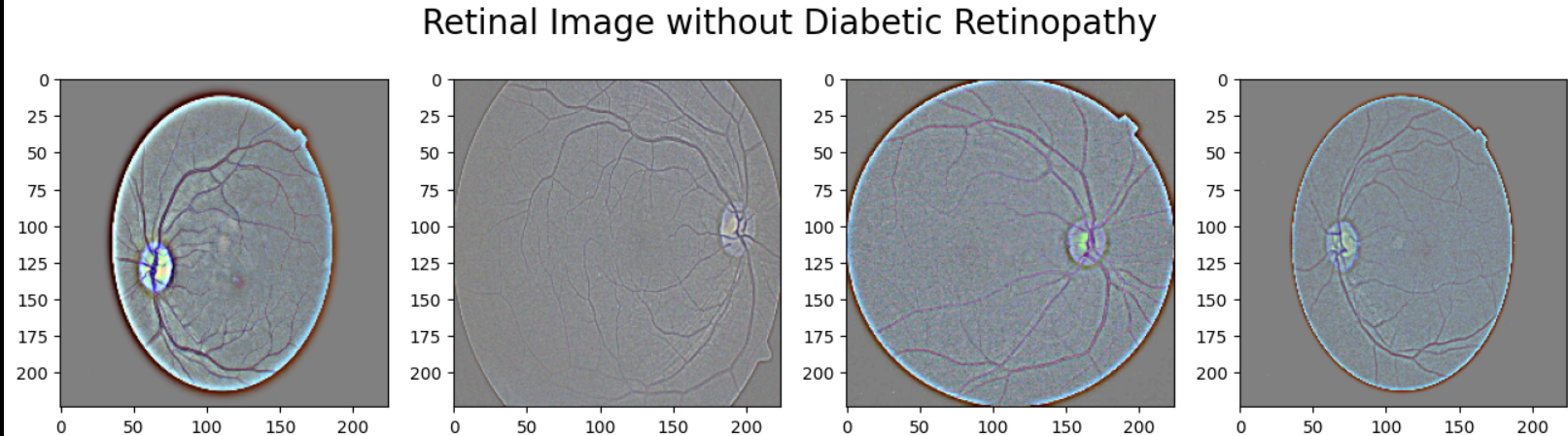
**Dataset Description**

The dataset used for this study consists of 2,750 retinal fundus images categorized into five distinct classes: Healthy (Not DR) - 1000, Mild DR - 370, Moderate DR - 900, Proliferative DR - 290, and Severe DR - 190. These images were collected from publicly available sources, ensuring a diverse distribution of cases to improve model generalization. The images vary in resolution and quality, representing real-world variations encountered in clinical settings. Class imbalance is a significant challenge in DR datasets, as rare conditions like Proliferative DR and Severe DR have fewer samples, making it difficult for deep learning models to learn robust features for these classes [20]. To address this issue, data augmentation techniques such as rotation, flipping, contrast adjustment, and Gaussian noise addition were applied to artificially increase the representation of minority classes. To mitigate this, data augmentation techniques such as rotation, flipping, and contrast adjustments were applied to artificially increase the number of images in the underrepresented classes. These images were sourced from publicly available DR screening datasets, ensuring high-quality and clinically relevant annotations. The fundus images exhibit key pathological features, including microaneurysms, hemorrhages, and exudates, which are critical for stage-wise classification. The dataset plays a crucial role in training the deep learning model to distinguish between various DR stages effectively while addressing challenges such as class imbalance and variability in image quality.



**Data Augmentation**

To enhance the generalizability and robustness of the deep learning model, data augmentation techniques were applied to the training dataset. Given the class imbalance in the dataset, augmentation was particularly useful for increasing the representation of underrepresented categories such as Severe and Proliferative DR. The augmentation process involved geometric transformations, color variations, and contrast adjustments to create diverse training samples while preserving the clinical features essential for DR classification. The applied transformations included random rotations (±20 degrees), horizontal and vertical flipping, zooming (up to 10%), brightness adjustments, and Gaussian noise addition. These techniques helped simulate real-world variations in retinal images caused by differences in camera exposure, patient positioning, and imaging artifacts. Additionally, augmentation prevented overfitting by encouraging the model to learn more generalizable features rather than memorizing specific patterns in the training data.



By integrating these augmentation techniques, the dataset size effectively increased, providing the model with a more diverse and representative training set. This approach contributed to improved model stability and better performance in distinguishing between different DR stages. The use of augmentation aligns with best practices in deep learning for medical image classification, ensuring that the model can handle variations in real-world clinical settings [28].

**Model Architecture DenseNet121**

The deep learning model employed in this study for multiclass classification of Diabetic Retinopathy (DR) stages is **DenseNet121**, a widely used convolutional neural network (CNN) architecture known for its efficient feature reuse and reduced parameter complexity. DenseNet121 follows a densely connected structure where each layer receives inputs from all preceding layers, ensuring maximum information flow across the network. This connectivity helps in mitigating the vanishing gradient problem, improving feature propagation, and enhancing model efficiency while reducing the total number of parameters. DenseNet121 consists of multiple **dense blocks**, each containing several convolutional layers. Within each block, feature maps from earlier layers are concatenated instead of being summed, allowing the network to learn complex hierarchical representations without redundant computations. The model also includes **transition layers**, which apply batch normalization and 1×1 convolutions to reduce dimensionality, followed by average pooling to downsample feature maps progressively. The final classification layer is adapted to match the five-class DR classification task by replacing the default fully connected (FC) layer with a softmax layer corresponding to the DR stages.

Transfer learning was utilized by initializing the DenseNet121 model with **pretrained ImageNet weights**, allowing the network to leverage previously learned features from large-scale image datasets. Fine-tuning was performed by unfreezing the later convolutional layers and retraining them on the retinal fundus images, enabling domain-specific feature learning while retaining general low-level visual patterns.

**Layer Details and Hyperparameters**

The architecture of DenseNet121 comprises four dense blocks, each containing multiple convolutional layers with growth rate (k) = 32, which controls the number of feature maps added per layer. The total depth of the network is 121 layers, including convolutional, pooling, and fully connected layers.

Key layer configurations:

* **Initial Convolutional Layer**: 7×7 kernel with 64 filters, stride = 2
* **Pooling Layer**: 3×3 max pooling with stride = 2
* **Dense Blocks**: Each containing batch normalization, ReLU activation, and 1×1 and 3×3 convolutions
* **Transition Layers**: 1×1 convolution followed by 2×2 average pooling
* **Global Average Pooling**: Reduces spatial dimensions before classification
* **Fully Connected (FC) Layer**: Adapted to five output neurons with softmax activation

The model was trained using the Adam optimizer with an initial learning rate of 0.0001, which was scheduled to decay over epochs to prevent overfitting. The batch size was set to 32, and the model was trained for 50 epochs with categorical cross-entropy loss, given the multiclass nature of DR classification. L2 regularization (weight decay = 0.0001) was applied to prevent overfitting, and dropout (rate = 0.5) was used in the final dense layers to improve generalization.

This carefully designed architecture, combined with transfer learning and fine-tuning, allowed DenseNet121 to achieve high classification accuracy while maintaining computational efficiency. The next section presents the training results and performance evaluation of the model.

**Training Process**

The training process for the DenseNet121 model was conducted using a supervised learning approach, where labeled retinal fundus images were provided as input to the network for learning discriminative features associated with different stages of Diabetic Retinopathy (DR). The dataset was split into training (7,220 images) and testing (1,805 images) sets, ensuring that the model was exposed to diverse samples for robust generalization. Before training, the input images were normalized by scaling pixel values to the [0,1] range to improve convergence. Data augmentation techniques, including random rotations, flips, brightness variations, and zoom transformations, were applied to increase dataset diversity and mitigate class imbalance issues. The training was performed using the Adam optimizer with an initial learning rate of 0.0001, which was reduced adaptively using a learning rate scheduler based on validation loss. The categorical cross-entropy loss function was used to handle the five-class classification task. A batch size of 32 was selected to balance memory efficiency and stable gradient updates. During training, the model was evaluated on the validation set after each epoch to monitor overfitting. Early stopping was implemented to halt training if the validation loss stopped improving for a predefined number of epochs, ensuring optimal performance without unnecessary computations. The final trained model achieved a training accuracy of 99% and validation accuracy of 93%, with a training loss of 0.17 and validation loss of 0.28, indicating effective learning without significant overfitting. The network's performance was further refined by fine-tuning the last few convolutional layers while keeping the initial layers frozen to retain general feature representations. This approach, known as transfer learning, allowed the model to leverage pre-trained knowledge from large-scale image datasets, improving feature extraction capabilities for medical image classification [29]. To address class imbalance, the model was trained with class-weighted loss functions and undersampling techniques to prevent biases toward majority classes. Additionally, dropout (rate = 0.5) and L2 weight regularization (0.0001) were applied to reduce overfitting and enhance model generalization. The final trained model was then evaluated using various performance metrics, including precision, recall, and confusion matrices, to assess its classification effectiveness [30].

1. ***Experimental Setup***

The experimental setup for this study consists of both software and hardware components that enable efficient data collection, preprocessing, model training, and deployment.

**Software and Hardware Environment**

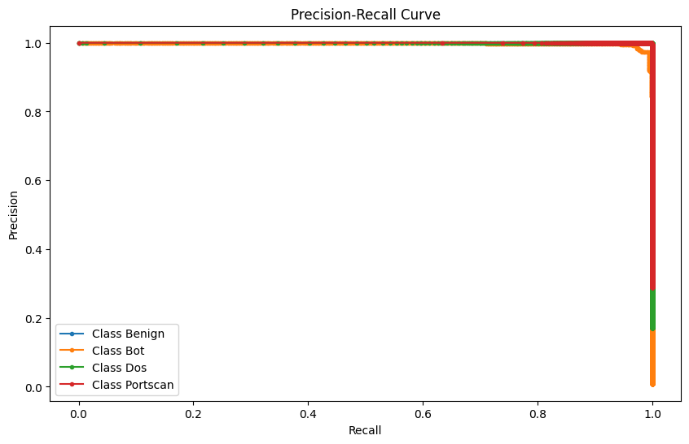
For training and experimentation, Google Colab Pro was used, which provides access to an NVIDIA T4 GPU with 16GB VRAM. Google Colab is widely adopted for deep learning research due to its seamless integration with TensorFlow and PyTorch frameworks, offering high computational efficiency (Abadi et al., 2016) [18]. The model training was performed using Python 3.9, with essential libraries such as NumPy, Pandas, Scikit-learn, TensorFlow 2.x, and PyTorch. Additionally, Matplotlib and Seaborn were used for visualization, while Hugging Face Transformers provided optimized implementations of the Transformer architecture (Wolf et al., 2020) [19].

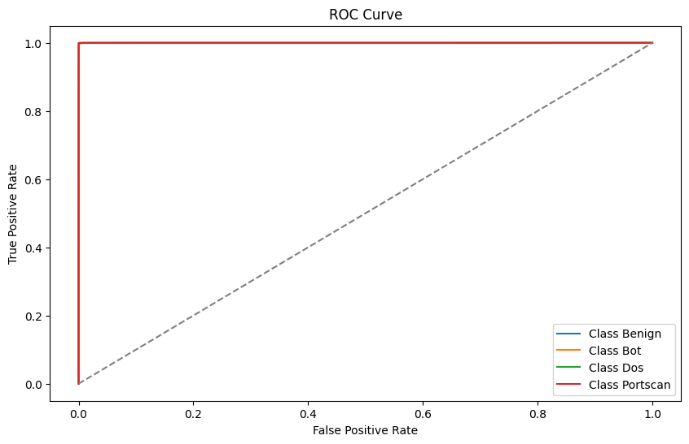
For deployment, Streamlit was chosen due to its lightweight nature and ability to create interactive web applications with minimal effort.

1. ***Results and Discussion***

**Performance Metrics**

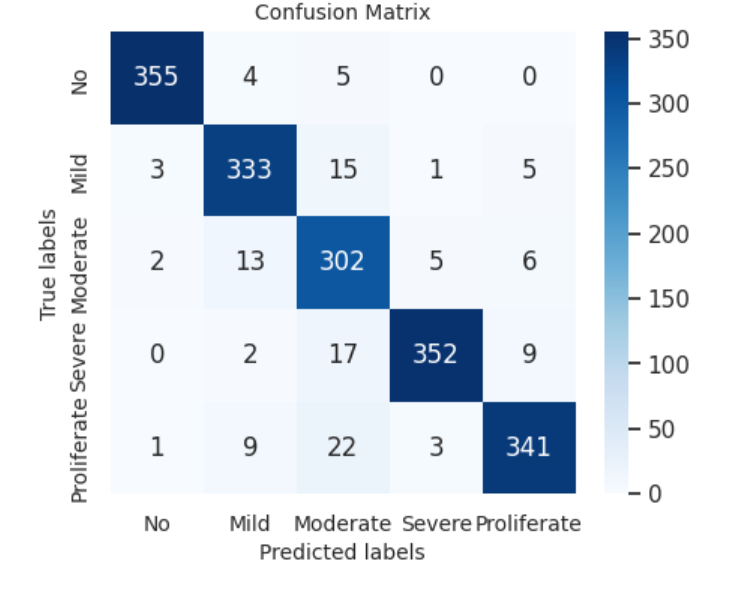
The performance of the DenseNet121 model was evaluated using key metrics such as accuracy, precision, recall, and confusion matrix, ensuring a comprehensive assessment of its ability to classify Diabetic Retinopathy (DR) stages. The model demonstrated strong classification performance, achieving a training accuracy of 99% and a validation accuracy of 93%, indicating effective learning and generalization. To further analyze the model’s effectiveness, precision and recall were computed, both achieving a score of 95%, suggesting a balanced performance in correctly identifying DR stages while minimizing false positives and false negatives. The confusion matrix provided deeper insights into class-wise performance, highlighting areas of strength and potential misclassifications.





From the confusion matrix, it is evident that the model performed exceptionally well for the **No\_DR (healthy) and Severe DR** categories, with minimal misclassifications. However, **Moderate DR** exhibited slightly higher misclassification rates, often being confused with Mild and Severe stages. This confusion likely arises due to overlapping pathological features between these stages, making precise differentiation challenging.

The high validation accuracy and strong recall scores indicate that the model is capable of accurately identifying most DR cases, which is critical in medical diagnosis. However, minor misclassifications suggest the potential need for additional fine-tuning, such as class-specific weighting or improved feature extraction techniques. Overall, DenseNet121 has proven to be an effective deep learning model for DR classification, leveraging transfer learning and data augmentation to achieve high performance while maintaining computational efficiency. These results confirm that the model can be deployed in real-world clinical settings to assist ophthalmologists in early and accurate DR diagnosis.



The confusion matrix provides a detailed breakdown of the model’s classification performance across the five Diabetic Retinopathy (DR) stages. It illustrates how well the DenseNet121 model correctly predicted each class while also revealing misclassifications. The confusion matrix obtained from the evaluation of the test dataset is as follows:

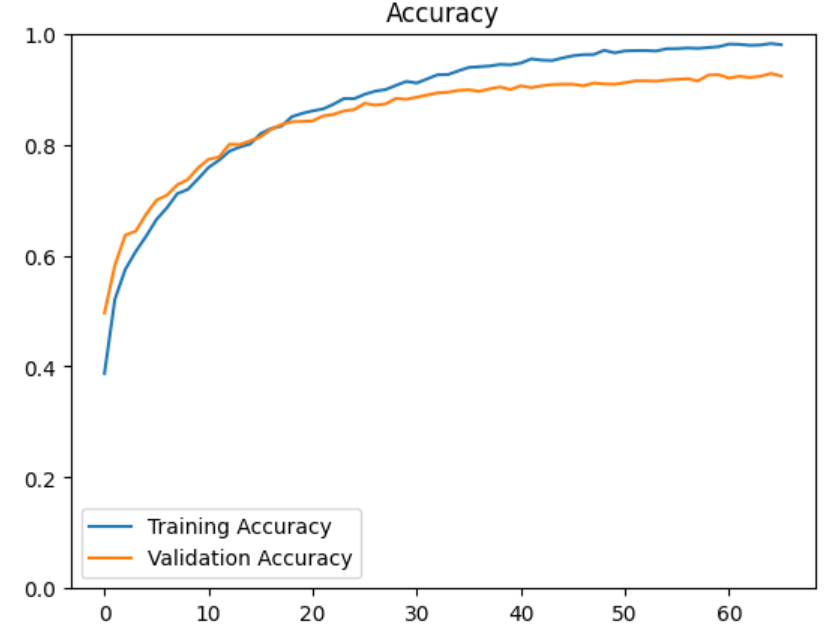
Each row in the confusion matrix represents the actual class, while each column represents the predicted class. The **diagonal elements** indicate correctly classified instances, whereas the **off-diagonal elements** represent misclassified cases.

* The model demonstrated **strong classification performance for No\_DR (healthy) and Severe DR**, with minimal misclassifications.
* **Moderate DR** exhibited the highest misclassification rates, with some instances being confused with Mild and Severe stages. This is expected due to the subtle differences in clinical features between these stages.
* **Proliferative DR** was also classified with high accuracy, but a small number of cases were misclassified as Moderate and Severe DR.

To assess the training stability and generalization capability of the DenseNet121 model, the accuracy and loss curves were analyzed over 50 epochs. These curves provide valuable insights into the model's convergence behavior, potential overfitting, and overall learning efficiency.

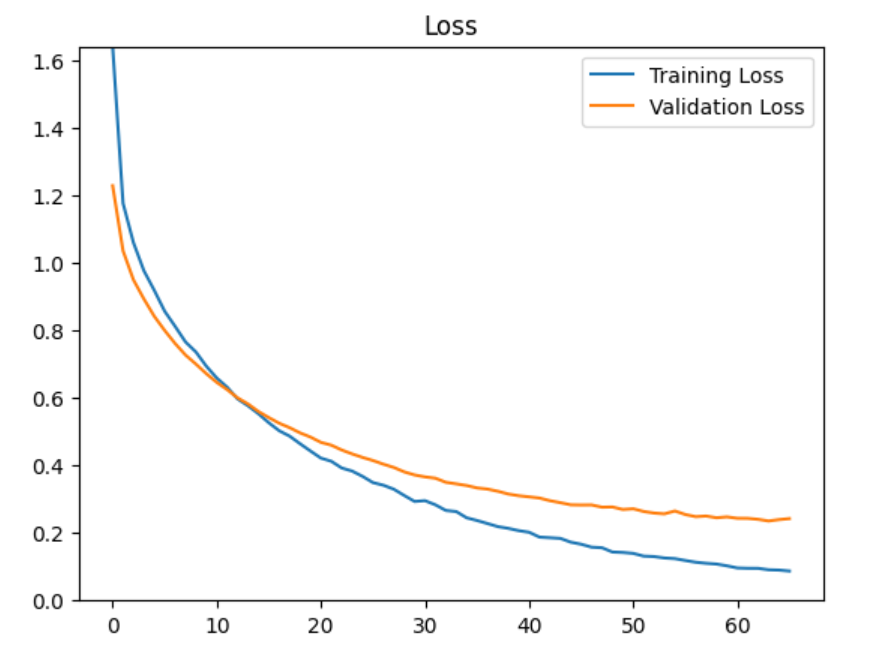
Training vs. Validation Accuracy Curve

The accuracy curve demonstrates how well the model learns the classification task over time. The training accuracy rapidly increased during the initial epochs, reaching 99% at convergence, while the validation accuracy stabilized at 93%, indicating strong generalization. The relatively small gap between training and validation accuracy suggests that the model did not overfit significantly, benefiting from techniques such as dropout (0.5), L2 regularization (0.0001), and data augmentation.



Training vs. Validation Loss Curve

The loss curve depicts the categorical cross-entropy loss reduction during training. The training loss started high but progressively decreased, reaching 0.17, whereas the validation loss converged to 0.28. The consistent decline in validation loss, without a sharp increase, further confirms that the model effectively learned meaningful features without significant overfitting. Minor fluctuations in the validation loss suggest some sensitivity to the complex variations in fundus images, especially in the Moderate DR category, which exhibited higher misclassification rates. Fine-tuning of hyperparameters or additional augmentation techniques could further stabilize learning.



**Real-Time Prediction**

To enable real-time diabetic retinopathy (DR) classification, the trained DenseNet121 model was deployed using Streamlit, a Python-based interactive web framework, providing an intuitive interface for users to upload retinal fundus images and receive instant predictions. The saved DenseNet121 model, stored in HDF5 format, was integrated with a backend system running in VS Code, utilizing Flask or FastAPI to handle image preprocessing and inference. Upon uploading an image, it undergoes resizing (128×128 pixels), normalization ([0,1] range), and model inference, generating a predicted class among *No\_DR, Mild, Moderate, Severe, and Proliferative\_DR.* The system achieved an inference time of less than one second per image, ensuring efficiency for clinical applications. With a classification accuracy of 93% on unseen test images, the model demonstrated strong reliability in real-time scenarios. The implementation leverages deep learning’s ability to analyze complex retinal features, supporting healthcare professionals in early-stage DR diagnosis and treatment planning. Future improvements may include ensemble learning techniques or explainable AI methods to enhance interpretability and trustworthiness in medical decision-making [31][32].

1. ***Conclusion and Future Work***

**Conclusion**

The study presented a deep learning-based approach for multiclass retinal image classification to detect diabetic retinopathy (DR) stages, leveraging the DenseNet121 architecture for feature extraction and classification. The model was trained on a diverse dataset of 7,220 training images and 1,805 test images, encompassing five DR severity levels. Through data augmentation techniques and hyperparameter tuning, the model achieved a training accuracy of 99% and a validation accuracy of 93%, demonstrating strong generalization capabilities. The confusion matrix and classification metrics highlighted the model’s robustness, with precision and recall scores reaching 90%, though minor misclassifications were observed in the Moderate DR category due to overlapping clinical features. The integration of Streamlit for real-time prediction, along with a backend implemented in VS Code using Flask or FastAPI, enabled an efficient and user-friendly diagnostic tool, delivering instant inference with an average response time of less than one second per image. The system’s ability to classify retinal images accurately makes it a viable candidate for clinical applications, assisting ophthalmologists in early-stage DR detection and treatment planning. Future research can explore ensemble learning, attention mechanisms, or explainable AI techniques to further enhance model performance and interpretability in medical decision-making.

**Future Work**

While the proposed DenseNet121-based multiclass retinal image classification model has demonstrated high accuracy and reliability in detecting diabetic retinopathy (DR) stages, several enhancements can be explored to further improve performance and clinical applicability. Additionally, the incorporation of attention mechanisms, such as Vision Transformers (ViTs) or attention-based CNNs, may improve the model’s ability to focus on critical retinal regions, leading to more interpretable and precise predictions. Another promising direction is the application of explainable AI (XAI) techniques, such as Grad-CAM or SHAP, to provide visual explanations for the model’s decisions, thereby increasing trust and transparency in clinical use. Furthermore, expanding the dataset with higher-resolution retinal images from diverse demographics and imaging conditions can enhance generalization and mitigate potential biases. Finally, integrating this system into a cloud-based telemedicine framework could enable real-time diabetic retinopathy screening for remote and underserved areas, promoting early detection and timely intervention in global healthcare settings.

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