

GRAPE LEAF DISEASE DETECTION USING CONVOLUTIONAL NEURAL NETWORKS FOR INTELLIGENT CROP HEALTH MONITORING

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Abstract

Grapevine diseases, such as Black Rot, Esca (Black Measles), and Leaf Blight, significantly impact viticulture, leading to reduced yields and economic losses. Traditional disease detection methods are often labor-intensive and prone to inaccuracies. This study presents a machine learning-based system employing Convolutional Neural Networks (CNNs) for the early detection and classification of grape leaf diseases. Utilizing a curated dataset from the Plant Village repository, images were pre-processed through resizing, normalization, and augmentation to enhance model performance. A CNN model based on the VGG16 architecture was developed using transfer learning techniques. The dataset was divided into training and validation sets in a 75:25 ratio, achieving high accuracy in classifying grape leaf conditions. The trained model was deployed in a user-friendly web application using Streamlit, enabling users to upload images and receive real-time diagnostic feedback. To cater for local farmers, the application includes multilingual support, particularly in Yoruba. This system offers a rapid, accessible, and non-invasive method for grape leaf disease identification, reducing reliance on expert inspections and facilitating timely interventions. Future enhancements include mobile application development, integration with Internet of Things (IoT) devices for real-time monitoring, and expansion of the dataset to encompass more disease categories.

Keywords: Grape Leaf Disease, Convolutional Neural Network (CNN), VGG16, Machine Learning, Precision Agriculture

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1. Introduction

Grapevines (*Vitis vinifera*) are a vital crop globally, with significant economic importance in regions like Nigeria. However, grape production is often hindered by diseases such as Black Rot, Esca, and Leaf Blight, which can lead to substantial yield losses. Traditional disease detection methods rely on manual inspections, which are time-consuming and may lack accuracy, especially in rural areas with limited access to agricultural experts. (Ji, Y., et al., 2020)

Advancements in machine learning, particularly CNNs, have shown promise in automating plant disease detection through image classification. CNNs can learn complex patterns from images, enabling accurate identification of diseases. Recent studies have demonstrated the efficacy of CNNs in detecting grape leaf diseases with high accuracy, emphasizing their potential in precision agriculture Liu, X., et al. (2020). Despite these advancements, there is limited adoption of such technologies for grape crops

in Nigeria. This study aims to bridge this gap by developing a web-based application that leverages CNNs for the early detection of grape leaf diseases, providing farmers with a reliable and accessible tool for crop health monitoring.

2. Specific Objectives

The objectives of this research are to:

1. Collect and annotate a dataset of healthy and diseased grape leaf images.
2. Train and evaluate a CNN model for classifying grape leaf diseases.
3. Develop a web interface for users to upload images and receive diagnostic feedback.
4. Assess the system's performance using standard evaluation metrics such as accuracy, precision, and recall.

3. Methodology

a. Research Design

An experimental research design was employed, encompassing data collection, pre-processing, model development, training, evaluation, and deployment. The approach was iterative, focusing on optimizing model accuracy and user accessibility.

b. Data Source and Description

The dataset was sourced from the publicly available Plant Village repository, focusing on grape leaf images categorized into:

- Healthy
- Black Rot
- Esca (Black Measles)

A total of 1,950 images were selected, with 650 images per class. All images were resized to 150x150 pixels to ensure uniformity and computational efficiency.

c. Data Pre-processing

Pre-processing steps included:

1. **Resizing:** Standardizing image dimensions to 150x150 pixels.
2. **Normalization:** Scaling pixel values to the [0,1] range.
3. **Label Encoding:** Applying one-hot encoding to class labels.
4. **Augmentation:** Implementing techniques such as rotation, flipping, and zooming to enhance model generalization.

d. Model Architecture and Design

The model architecture was based on the VGG16 CNN, utilizing transfer learning to leverage pre-trained weights. The architecture included:

- i. **Base Model:** VGG16 without the top classification layers.
- ii. **Custom Layers:** Added GlobalAveragePooling2D, Dense layers, and a final softmax output layer with three nodes corresponding to the classes.

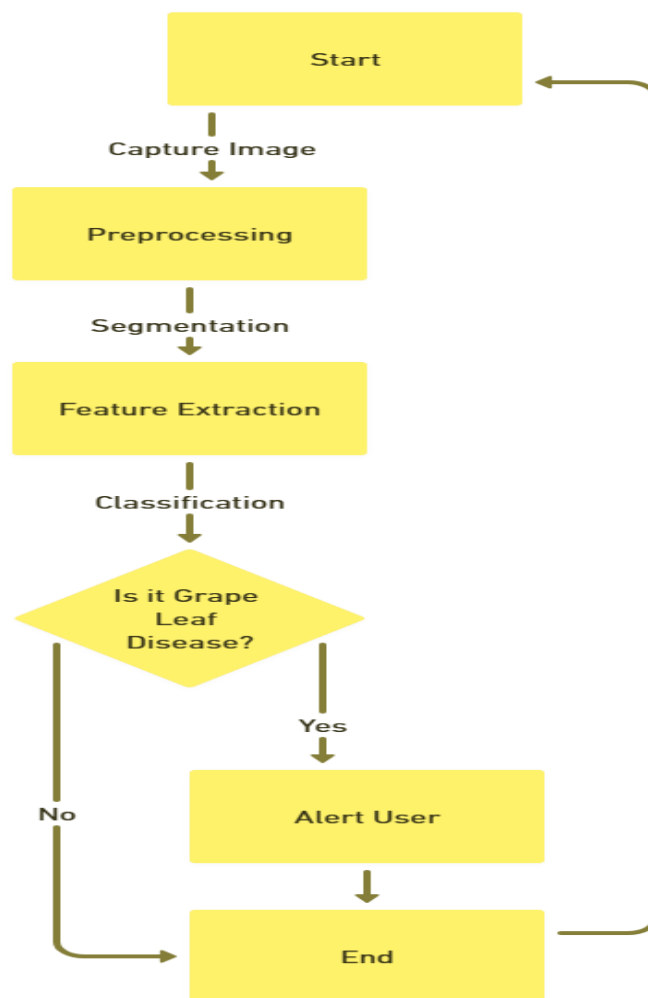


Fig. 1: System Flowchart

e. Training Configuration

- Optimizer:** Adam
- Loss Function:** Categorical Crossentropy
- Evaluation Metric:** Accuracy
- Epochs:** 5
- Learning Rate:** 0.001
- Batch Size:** 32
- Early Stopping:** Implemented to prevent overfitting
- Train/Validation Split:** 75% / 25%

f. Model Evaluation Metrics

Model performance was evaluated using:

- Training and Validation Accuracy
- Validation Loss

- Precision, Recall, and F1-Score

- Confusion Matrix

g. Deployment Strategy

The trained model was deployed using Streamlit, providing a web-based interface for users to upload grape leaf images and receive real-time predictions. The application includes:

- Image upload functionality
- Display of prediction results with confidence scores

4. Results and Discussion

a. Model Training Metrics

After training, the model achieved:

- Training Accuracy:** 96.23%

- ii. **Validation Accuracy:** 89.41%
- iii. **Validation Loss:** 0.3278

These results indicate strong predictive capabilities with minimal overfitting.

b. Classification Report

Class	Precision	Recall	F1-Score
Healthy	0.91	0.92	0.92
Black Rot	0.88	0.87	0.88
Esca (Black Measles)	0.89	0.88	0.88
Macro Average Accuracy	0.89	0.89	0.89
			89.41%

The model demonstrated balanced performance across all classes.

c. Sample Predictions

Image Description	Actual Label	Predicted Label	Confidence
Grape Leaf with Black Rot	Black Rot	Black Rot	95%
Healthy Grape Leaf	Healthy	Healthy	94%
Leaf with Esca Symptoms	Esca	Black Rot	81%

Misclassifications were primarily between Esca and Black Rot, likely due to visual similarities. Future work could explore attention mechanisms to improve differentiation.

5. Conclusion and Recommendations

Conclusion

The developed CNN-based system effectively detects and classifies grape leaf diseases, providing a valuable tool for farmers to monitor crop health. The integration of the model into a web application enhances accessibility, enabling timely

interventions and promoting sustainable agricultural practices.

Recommendations

To further improve the system:

1. **Dataset Expansion:** Incorporate additional grape diseases and diverse environmental conditions.
2. **Model Enhancement:** Explore architectures like ResNet or EfficientNet for improved performance.
3. **Mobile Application Development:** Develop a mobile version using TensorFlow Lite for offline use.
4. **IoT Integration:** Combine with IoT devices for real-time field monitoring.

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