NUTRIENT DEFICIENCY DETECTION IN PADDY LEAVES USING DEEP LEARNING AND COMPUTER VISION TECHNIQUES

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Abstract : **Nutrient deficiencies in paddy crops can severely affect plant health and yield if not detected at an early stage. Traditional monitoring methods are manual, time-consuming, and inefficient for large agricultural fields. This study presents a deep learning–based approach for automated detection of nutrient deficiencies in paddy leaves using image analysis. A convolutional neural network integrated with the YOLOv8 object detection framework is employed to enable real-time identification and localization of deficient regions on leaf images. Image preprocessing techniques such as grayscale conversion and median filtering are applied to enhance image quality, while transfer learning and data augmentation are used to improve model robustness under varying field conditions. The proposed system supports early diagnosis and precision agriculture, helping farmers improve crop yield and reduce losses.**

Keywords: Nutrient deficiency, Paddy leaf, Deep learning, CNN, YOLOv8, Precision agriculture

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I. INTRODUCTION

Agriculture forms the backbone of food security, and maintaining crop health is essential for achieving sustainable agricultural productivity. Paddy is one of the most important cereal crops cultivated across the globe, serving as a primary food source for a large portion of the population. Deficiency of essential macronutrients such as nitrogen, phosphorus, and potassium adversely affects plant growth and leads to visible symptoms on paddy leaves, including discoloration, necrosis, and abnormal development. These visual indicators can be effectively utilized for early-stage diagnosis.

Traditional approaches for detecting nutrient deficiencies depend largely on manual field inspection and expert knowledge. Such methods are labor-intensive, time-consuming, and often inconsistent when applied to large cultivation areas. With the advancement of computer vision and deep learning technologies, automated plant health monitoring systems have emerged as reliable alternatives. This work proposes an intelligent framework for identifying nutrient deficiencies in paddy leaves by integrating image processing techniques with machine learning and deep learning models.

II. YOLO-BASED OBJECT DETECTION

You Only Look Once (YOLO) is a real-time object detection framework that performs detection and localization in a single forward pass of a neural network. Unlike conventional multi-stage detection pipelines, YOLO treats object detection as a regression problem, directly predicting bounding boxes and class probabilities from the entire image. This unified approach significantly reduces computational overhead and enables high-speed inference.

The YOLO architecture divides the input image into grid cells, with each cell responsible for predicting bounding boxes and confidence scores. The latest version, YOLOv8, introduces architectural optimizations that enhance detection accuracy and inference speed. These features make YOLO particularly suitable for agricultural applications where real-time analysis under varying environmental conditions is required, such as paddy leaf nutrient deficiency monitoring.

III. LIMITATIONS OF EXISTING SYSTEMS

Existing plant disease detection systems are typically designed to identify a single disease in a specific crop. In one such approach, Anthracnose disease in mango leaves is detected using histogram-based contrast enhancement and central cropping for preprocessing, followed by classification using a multilayer convolutional neural network.

However, these systems exhibit several shortcomings. Manual or semi-automated detection methods are susceptible to human error and lack scalability. Moreover, the focus on a single disease and crop restricts the system's adaptability, rendering it unsuitable for comprehensive agricultural monitoring or nutrient deficiency assessment.

IV. PROPOSED SYSTEM

The proposed system aims to automatically detect and classify nutrient deficiencies in paddy leaves, addressing a major factor responsible for yield reduction. A dataset comprising 1,156 paddy leaf images is collected from a public Kaggle repository. The dataset includes samples affected by nitrogen, phosphorus, and potassium deficiencies. Nitrogen deficiency is indicated by pale green or yellow leaves, phosphorus deficiency by darkened older foliage, and potassium deficiency by irregular necrotic or rust-colored spots.

To improve model generalization, data augmentation techniques are applied, expanding the dataset to 8,072 images. Image preprocessing is performed to enhance quality and normalize inputs. Leaf images are segmented into multiple regions, and edge features are extracted using the Canny edge detection algorithm. The system is evaluated using real-time images collected under field conditions. Classification is performed using CNN, ResNet, Inception, Random Forest, and Support Vector Machine models. The framework is designed to be computationally efficient and suitable for real-world agricultural deployment.

V. METHODOLOGY

A. Image Acquisition

Leaf images are used as primary indicators of plant nutritional status. Images are sourced from publicly available datasets and real-time field acquisition. The images vary in resolution and dimensions and are captured in RGB color space.

B. Image Preprocessing

To reduce computational complexity, RGB images are converted to grayscale representations using 8-bit luminance values. Noise introduced during image acquisition is minimized using median filtering, which preserves important edge information while eliminating unwanted artifacts.

C. Segmentation

Segmentation separates healthy and affected regions of paddy leaves, enabling precise localization of deficiency symptoms. Techniques such as thresholding, edge detection, and deep learning-based segmentation are employed. Accurate segmentation improves diagnostic reliability and supports early intervention strategies.

D. Feature Extraction

Structural features are extracted using the Canny edge detection algorithm. The process includes Gaussian smoothing, gradient computation, non-maximum suppression, double thresholding, and hysteresis-based edge tracking. These steps highlight lesion boundaries and textural irregularities associated with nutrient deficiencies.

VI. CLASSIFICATION MODELS

The extracted features are used to train multiple classifiers, including Convolutional Neural Networks, ResNet, Inception, Random Forest, and Support Vector Machine models. Deep learning models automatically learn hierarchical representations, while traditional machine learning models utilize handcrafted features. Performance comparison is carried out to identify the most effective approach for real-time deployment.

VII. RESULTS AND DISCUSSION

The system is evaluated using the augmented dataset of 8,072 images, divided into training and testing sets in an 80:20 ratio. Performance metrics include accuracy, precision, recall, F1-score, and mean Average Precision for object detection.

Experimental results indicate that deep learning models outperform traditional classifiers in terms of accuracy and robustness. CNN-based architectures effectively capture complex visual patterns related to nutrient deficiencies. ResNet achieves improved performance due to residual learning, while Inception excels at identifying multi-scale features. Random Forest and SVM demonstrate acceptable results but are less resilient under varying illumination conditions.

YOLOv8 successfully detects and localizes nutrient-deficient regions on paddy leaves in real time. Its ability to provide both classification and spatial localization offers a significant advantage over classification-only approaches, enabling better assessment of deficiency severity and distribution.

VIII. CONCLUSION

This study presents a comprehensive framework for automated detection of nutrient deficiencies in paddy leaves using image processing and deep learning techniques. The proposed system overcomes the limitations of manual inspection by delivering accurate, fast, and scalable detection. Experimental results confirm the effectiveness of the approach in identifying nitrogen, phosphorus, and potassium deficiencies. The integration of YOLOv8 further enhances real-time applicability, making the system suitable for precision agriculture and smart farming applications.

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