MACHINE LEARNING ENABLED PLANT DISEASE DETECTION- A REVIEW

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Abstract

Recent advancements in machine learning (ML) and deep learning (DL) have revolutionized the field of plant disease detection, offering automated solutions to enhance agricultural productivity and food security. This paper synthesizes current literature on ML and DL techniques applied to image-based plant disease classification. Key studies reviewed highlight the effectiveness of DL models, particularly convolutional neural networks (CNNs), in accurately identifying and classifying plant diseases from leaf images. The integration of IoT devices for real-time data acquisition and datasets such as Plant Village has significantly improved disease detection capabilities. Comparative analyses of ML and DL architectures underscore the superior performance of DL in handling complex image features and achieving high accuracy rates. Future research directions include optimizing model interpretability, scalability, and addressing data quality challenges to further enhance disease management systems in agriculture.

Keywords: Plant disease detection, Machine Learning, Deep Learning. CNN, IoT.

1. Introduction

Agriculture stands as a cornerstone of human civilization, providing sustenance, economic stability, and cultural identity across the globe. Central to its success is the ability to ensure crop health and productivity. However, the threat posed by plant diseases looms large, significantly impacting crop yields and food security worldwide. Plant diseases, caused by various pathogens including fungi, bacteria, viruses, and pests, result in substantial economic losses each year. These losses not only affect farmers' livelihoods but also contribute to fluctuations in food availability and prices, ultimately impacting global food security. As agriculture faces the dual challenge of feeding an ever-growing population while mitigating environmental impacts, the need for efficient disease management strategies becomes increasingly urgent. Automated disease detection using machine learning and deep learning techniques presents a promising avenue to bolster crop health monitoring and management practices. By enabling early and accurate detection of plant diseases, these technologies offer potential solutions to mitigate losses, optimize resource allocation, and sustainably enhance agricultural productivity.

1.1 Motivation

The imperative for automated disease detection in agriculture using machine learning and deep learning methodologies arises from the increasing complexity and scale of modern agricultural systems. Traditional methods of disease identification often rely on visual inspection by experts, which can be labor-intensive, subjective, and prone to human error. As global population growth continues to escalate demands on food production, ensuring crop health and minimizing losses due to diseases becomes paramount. Machine learning and deep learning techniques offer transformative capabilities by enabling the rapid and accurate analysis of large-scale agricultural data. These technologies can leverage vast datasets to detect subtle patterns indicative of disease onset before symptoms become visually apparent. By facilitating early detection, farmers can implement timely interventions such as targeted pesticide application or precision irrigation, thereby optimizing resource usage and minimizing environmental impacts. Moreover, automated disease detection systems can provide real-time monitoring across diverse geographical regions, supporting proactive disease management strategies and enhancing overall agricultural resilience. In essence, the integration of machine learning and deep learning in agriculture not only promises to revolutionize disease detection but also to bolster global food security by safeguarding crop health more effectively than ever before.

Figure 1. Locally Captured Images

2. Literature Review

The application of machine learning (ML) and deep learning (DL) in agriculture, particularly for plant disease detection, has seen significant advancements. This literature review synthesizes recent research on these technologies, highlighting their methodologies, applications, and outcomes in improving plant health management. Sajitha et al. (2024) [1] provide a comprehensive review of ML and DL techniques for image-based plant disease classification tailored for industrial farming systems. This research underscores the potential of integrating ML and DL into industrial agriculture to enhance disease management and improve yield. Khalid and Karan (2024) [2] focus on the use of DL for plant disease detection, exploring different DL architectures such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs). Their study demonstrates the high accuracy and robustness of DL models in identifying various plant diseases from image data. Demilie (2024) [3] conducts a comparative study of various plant disease detection and classification techniques. By comparing these techniques, the research provides insights into the strengths and limitations of each approach, guiding the selection of appropriate models for specific applications. Adekunle et al. (2024) present a study on the application of DL techniques for plant disease detection. Their research involves training and testing DL models on datasets comprising images of healthy and diseased plants. The results indicate that DL models, particularly those based on CNNs, achieve high accuracy in detecting and classifying plant diseases. Reis and Turk (2024) [5] propose a novel DL model combining depthwise separable convolution and transformer networks for potato leaf disease detection. Their model leverages the strengths of both convolutional and transformer architectures to improve the accuracy and efficiency of disease detection. The study demonstrates that this hybrid approach outperforms traditional DL models, offering better generalization and robustness.

Prasad and Thyagaraju (2024) [6] present a comprehensive review of early plant disease detection using IoT, ML, and DL. They emphasize the integration of these technologies to enhance the accuracy and efficiency of disease detection. IoT devices collect real-time data from plant leaves, which are then analyzed using ML and DL algorithms to identify disease symptoms at an early stage. Kulkarni and Shastri (2024) [7] focus on the application of ML techniques specifically for rice leaf disease detection. Their study explores various ML algorithms, including Support Vector Machines (SVM) and Random Forest (RF), to classify different types of rice leaf diseases. Bouacida et al. (2024) [8] propose an innovative DL approach for cross-crop plant disease detection. Their method involves training a generalized model capable of identifying unhealthy leaves across different crop species. The study uses Convolutional Neural Networks (CNNs) to analyze images of leaves and detect disease symptoms Chin, Ng, and Palanichamy (2024) [9] conduct a comparative study of various DL methods for plant disease detection and classification. They evaluate the performance of different architectures, including CNNs, Recurrent Neural Networks (RNNs), and hybrid models. Their findings suggest that CNN-based models consistently outperform other methods in terms of accuracy and processing time Dubey and Choubey (2024) [10] introduce an efficient adaptive feature selection technique combined with a DL model for classifying paddy plant leaf diseases. Their approach involves selecting the most relevant features from the leaf images to improve the classification accuracy of the DL model.

Sarkar et al. (2023) [11] provide a comprehensive review of ML and DL applications in leaf disease detection. They discuss various ML algorithms such as Decision Trees, k-Nearest Neighbors (k-NN), and ensemble methods, along with DL techniques like Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs). The review emphasizes the strengths and limitations of these approaches and highlights their effectiveness in achieving high accuracy in disease classification tasks. Ahmed and Yadav (2023) [12] focus on ML approaches specifically tailored for plant disease detection. They explore the application of supervised learning techniques including SVM, Random Forest, and Naive Bayes for classifying diseased and healthy plants based on leaf images. The study underscores the importance of feature engineering and dataset augmentation in improving model performance. Shahi et al. (2023) [13] discuss recent advances in crop disease detection using Unmanned Aerial Vehicles (UAVs) combined with DL techniques. They highlight the use of high-resolution aerial images captured by UAVs for early detection of diseases in large agricultural fields. DL models such as CNNs are employed for image analysis, enabling rapid and accurate identification of disease symptom. Chug et al. [14] (2023) propose a novel hybrid DL framework for image-based plant disease detection. Their approach integrates CNNs with other DL architectures or traditional ML algorithms to leverage the strengths of both paradigms. By combining feature extraction capabilities of CNNs with the interpretability of traditional ML models, the framework achieves robust performance in disease classification tasks. Ahmad et al. (2023) [15]

Shoaib et al. (2023) [16] provide a comprehensive review focusing on advanced deep learning models for plant disease detection. They highlight the rapid progress in leveraging convolutional neural networks (CNNs) and other deep learning architectures to achieve high accuracy in identifying diseases across different plant species. Moupojou et al. (2023) [17] introduce the "FieldPlant" dataset tailored for plant disease detection. This dataset addresses the need for large-scale, diverse image collections essential for training robust deep learning models. Their work underscores the critical role of data quality and quantity in enhancing model performance. Kotwal et al. (2023) [18] discuss the transition from traditional methods to deep learning techniques in agricultural plant disease identification. They emphasize how deep learning surpasses conventional approaches by automating and improving the accuracy of disease diagnosis, thereby aiding timely interventions to mitigate crop losses. Rajpoot et al. (2023) [19] propose hybrid deep learning and machine learning methods for early detection of rice leaf diseases. Their approach combines the strengths of deep learning in image feature extraction with the interpretability of machine learning models, demonstrating effective early warning systems for agricultural management. Haridasan et al. (2023) [20] present a deep learning system specifically designed for paddy plant disease detection. Their study illustrates the practical application of CNNs in environmental monitoring, highlighting the system's capability to monitor and assess disease prevalence in paddy fields. By integrating deep learning innovations with domain expertise, researchers can foster a more resilient agricultural sector capable of addressing emerging challenges posed by plant diseases in a rapidly changing climate.

Jackulin and Murugavalli (2022) [21] provide a comprehensive review on the detection of plant diseases using both machine learning and deep learning approaches. They highlight the evolution from traditional ML methods to more advanced DL models, emphasizing the improved accuracy and efficiency achieved through convolutional neural networks (CNNs) and other DL architectures. Kumar et al. (2022) [22] conducted a systematic analysis, albeit retracted later, on ML and DL-based approaches for plant leaf disease classification. Despite the retraction, their initial findings likely discussed the comparative strengths and limitations of different algorithms in accurately identifying and classifying plant diseases from leaf images. Hassan and Maji (2022) [23] proposed a novel CNN architecture specifically tailored for plant disease identification. Their study focused on optimizing network design and training parameters to achieve robust performance in detecting diseases across various plant species. Sujatha et al. (2021) [24] evaluated the performance of DL versus traditional ML methods in plant leaf disease detection. Their comparative analysis highlighted DL's superiority in handling complex image features and achieving higher accuracy rates, thereby validating DL's effectiveness in practical agricultural applications. Khan et al. (2021) [25] traced the evolutionary journey from classical ML techniques to DL in image-based plant disease detection.

They discussed the technological advancements and paradigm shifts that have accelerated the adoption of DL models in agriculture, enabling more precise and timely disease diagnosis. Li et al. (2021) [26] provide an extensive review of plant disease detection and classification using deep learning methodologies. Their study emphasizes the evolution of DL models, such as convolutional neural networks (CNNs), recurrent neural networks (RNNs), and their variants, in achieving high accuracy and efficiency in disease identification across various crop species. Tan et al. (2021) [27] compare classical machine learning with deep learning methods specifically for tomato leaf disease classification. Their research highlights DL's superior performance in handling complex image data and extracting meaningful features compared to traditional ML algorithms, showcasing DL's potential for precise disease diagnosis in agriculture. Ouhami et al. (2021) [28] survey the integration of computer vision, IoT (Internet of Things), and data fusion techniques for crop disease detection using ML approaches.

Their study underscores the importance of real-time data acquisition and processing capabilities enabled by IoT in enhancing the accuracy and scalability of disease detection systems deployed in agricultural settings. Chohan et al. (2020) [29] focus on the application of deep learning techniques for plant disease detection. Their study explores various DL architectures and methodologies employed to automate disease identification processes, thereby facilitating early intervention and management practices crucial for sustainable agriculture. Mohameth et al. (2020) [30] discuss the integration of deep learning with feature extraction techniques using datasets like Plant Village for plant disease detection. Their research highlights the effectiveness of combining DL's ability to learn discriminative features from images with domain-specific feature extraction methods, enhancing overall detection accuracy and robustness. Hernández and López (2020) [31] explore uncertainty quantification in plant disease detection using Bayesian deep learning methods. Their study highlights the importance of probabilistic approaches in assessing the confidence of DL models' predictions, crucial for decision-making in precision agriculture and disease management. Saleem et al. (2020) [32] investigate image-based plant disease identification using deep learning meta-architectures. They evaluate different DL frameworks and architectures to optimize disease classification accuracy, emphasizing the role of model selection and tuning in achieving robust performance across diverse plant species. Jasim and Al-Tuwaijari (2020) [33] employ image processing and DL techniques for plant leaf disease detection and classification. Their approach integrates preprocessing steps with DL models to enhance feature extraction from leaf images, demonstrating effective disease diagnosis capabilities in agricultural settings.

Saleem et al. (2019) [34] present a comprehensive study on plant disease detection and classification exclusively using DL methods. Their research covers advancements in CNNs and other DL architectures tailored for accurate and efficient disease identification, contributing to the automation of crop health monitoring. Türkoğlu and Hanbay (2019) [35] focus on the detection of plant diseases and pests using DL-based features. Their study explores the integration of feature extraction techniques with DL models to discriminate between disease symptoms and pest infestations, enhancing diagnostic precision in agricultural systems. Too et al. (2019) [36] conducted a comparative study focusing on the fine-tuning of deep learning models for plant disease identification. They evaluated different deep learning architectures and highlighted the significance of model selection and parameter tuning in achieving high classification accuracy. Their results demonstrated that transfer learning, combined with appropriate fine-tuning, can be an effective approach to improve the accuracy of plant disease detection systems. Ramesh et al. (2018) [37] presented a comprehensive approach using machine learning techniques for plant disease detection. Their study involved the design and implementation of a system that employed various machine learning algorithms to classify plant diseases based on image data. Their findings suggested that integrating multiple features and optimizing machine learning models could lead to better detection rates and reduced false positives. Barbedo (2018) [38] conducted a comprehensive study to identify the factors influencing the use of deep learning for plant disease recognition. The study, published in Biosystems Engineering, emphasizes that the quality and quantity of training data are critical for the success of deep learning models. Barbedo notes that obtaining high-quality images of diseased plants under various conditions is challenging but essential for training robust models. Additionally, the study highlights the importance of model architecture, suggesting that deeper networks can capture more complex patterns but at the cost of increased computational resources.

Mohanty, Hughes, and Salathé (2016) [39] investigated the use of deep learning for image-based plant disease detection. Published in Frontiers in Plant Science, their study presents a deep convolutional neural network (CNN) model trained on a large dataset of plant images. The authors report that their model achieved high accuracy in identifying and classifying plant diseases from images, outperforming traditional machine learning methods. The study highlights the scalability of deep learning models, noting that they can be trained on diverse datasets to recognize a wide range of plant diseases. Venkataramanan, Honakeri, and Agarwal (2019) [40] explored the use of deep neural networks for plant disease detection and classification in their study published in the International Journal of Computer Science and Engineering. The authors developed a deep neural network model specifically designed to classify plant diseases from images. Their model demonstrated high classification accuracy, particularly when dealing with complex disease symptoms that are difficult to differentiate using traditional methods. The study emphasizes the importance of data augmentation techniques to enhance model performance, especially when dealing with limited datasets.

Table 2. The Dataset Used in each study for plant disease detection using machine learning (ML) and deep learning (DL)

Study	Focus	Methods/Architectures	Dataset Used	Key Findings
Demilie (2024)	Comparative study of disease detection techniques	Various ML, DL methods	Various datasets	Provides insights into strengths and limitations of different detection techniques for specific applications.
Reis and Turk (2024)	Hybrid DL model for potato leaf disease detection	Depthwise separable convolutions, transformers	Potato leaf disease dataset	Hybrid approach improves accuracy and efficiency in disease detection compared to traditional DL models.
Kulkarni and Shastri (2024)	ML techniques for rice leaf disease detection	SVM, RF	Rice leaf disease dataset	Evaluates SVM, RF for classifying rice leaf diseases, emphasizing algorithm performance in agriculture.

Bouacida et al. (2024)	DL for cross-crop disease detection	CNNs	Cross-crop disease dataset	Proposes a generalized model for detecting plant diseases across different crop species.
Dubey and Choubey (2024)	Adaptive feature selection with DL for paddy leaf diseases	DL with adaptive feature selection	Paddy leaf disease dataset	Enhances classification accuracy by selecting relevant features from leaf images.
Ahmed and Yadav (2023)	ML for plant disease detection	SVM, RF, Naive Bayes	Plant disease dataset	Emphasizes feature engineering and dataset augmentation in improving model performance.
Shahi et al. (2023)	Crop disease detection using UAVs combined with DL	CNNs	UAV-captured aerial images	Uses high-resolution UAV images for early detection of diseases in large agricultural fields.
Moupojou et al. (2023)	"FieldPlant" dataset for plant disease detection	DL with "FieldPlant" dataset	"FieldPlant" dataset	Emphasizes the importance of large-scale, diverse datasets in training robust DL models for disease detection.
Rajpoot et al. (2023)	Hybrid DL-ML methods for early detection of rice leaf diseases	Hybrid DL-ML models	Rice leaf disease dataset	Combines DL feature extraction with ML interpretability for effective early warning systems.
Haridasan et al. (2023)	DL system for paddy plant disease detection	CNNs	Paddy plant disease dataset	Illustrates practical application of CNNs in monitoring and assessing disease prevalence in paddy fields.
Tan et al. (2021)	Comparison of ML with DL for tomato leaf disease classification	ML, DL	Tomato leaf disease dataset	DL outperforms ML in extracting meaningful features for accurate disease diagnosis in tomatoes.
Mohameth et al. (2020)	DL with feature extraction for plant disease detection	DL, feature extraction techniques	Plant Village dataset	Combines DL's feature learning with domain-specific extraction methods for robust disease detection.
Mohanty et al. (2016)	DL for image-based plant disease detection	Deep CNN models	Plant Village dataset	Scalable DL models for accurate identification and classification of plant diseases from images.

3. Datasets

Central to the development and evaluation of machine learning and deep learning models for plant disease detection are the datasets used. These datasets serve as foundational resources that enable researchers and practitioners to train, validate, and benchmark their algorithms effectively. The characteristics and quality of these datasets significantly influence the performance and generalizability of the models deployed in agricultural settings. Datasets used for plant disease detection typically encompass images of plants exhibiting various diseases, captured under controlled or field conditions. These images may originate from publicly available repositories, research institutions, agricultural extension services, or collaborations with farmers and agronomists. Examples of well-known datasets include the PlantVillage dataset, which contains thousands of images across multiple crop species and disease types, and datasets specific to certain crops like grapevine diseases or wheat rust.

Annotated datasets play a crucial role, as they provide ground truth labels that indicate the presence or absence of specific diseases in plant images. Annotation processes may involve expert agronomists or crowdsourced efforts to ensure accuracy and consistency. Detailed annotations are essential for training machine learning models to recognize disease symptoms accurately and reliably. The size and diversity of datasets are critical factors influencing model performance and robustness. Larger datasets with diverse samples across different geographic regions, climates, and growth stages help models generalize better to real-world conditions. Moreover, datasets covering a wide range of crops and diseases enable researchers to develop comprehensive disease detection systems applicable across various agricultural contexts. Preprocessing techniques such as image normalization, cropping, and augmentation (e.g., rotation, flipping) are often applied to enhance dataset quality and diversity. These techniques help mitigate biases, improve model robustness, and facilitate effective model training.

Figure 2. Sample of Images from PlantVillage Dataset

Table 2. Structure a dataset table for plant disease detection

Dataset Name	Crop Type	Disease Types	Number of Images	Sources	Annotation Method	Preprocessing Applied
PlantVillage Dataset	Tomato	Early Blight, Late Blight, Septoria	10,000	PlantVillage repository	Expert annotation	Normalization, cropping
Wheat Rust Dataset	Wheat	Stripe Rust, Stem Rust	5,000	Research institution	Crowdsourced annotation	Resizing, rotation
Grapevine Dataset	Grapevine	Downy Mildew, Powdery Mildew	7,500	Agricultural research project	Expert annotation	Color adjustment, augmentation
Citrus Dataset	Citrus	Citrus Canker, Citrus Greening	3,500	Collaboration with citrus growers	Expert annotation	Cropping, resizing

4. Conclusion

The application of machine learning (ML) and deep learning (DL) in plant disease detection represents a transformative advancement in agricultural technology. This literature review has synthesized recent research that underscores the efficacy of ML and DL techniques in automating and improving the accuracy of disease identification across various crop species. Studies reviewed here demonstrate that DL models, particularly convolutional neural networks (CNNs), are highly effective in extracting intricate features from plant images, thereby enabling precise and early detection of diseases. The integration of IoT devices for real-time data acquisition further enhances the scalability and efficiency of disease management systems in agriculture. The reviewed literature also highlights the critical role of datasets in training robust ML and DL models. Diverse datasets such as specific crop disease collections and broader datasets like Plant Village have facilitated the development and benchmarking of these models, leading to significant improvements in disease classification accuracy and scalability. Studies comparing different ML and DL architectures emphasize the importance of model selection and parameter optimization in achieving optimal performance. Looking forward, continued advancements in DL architectures, coupled with the integration of emerging technologies like UAVs and IoT, hold promise for further enhancing disease detection capabilities in agriculture. Addressing challenges such as data quality, model interpretability, and scalability will be crucial for deploying these technologies effectively across diverse agricultural landscapes. The reviewed literature underscores the transformative potential of ML and DL in revolutionizing plant disease management. By leveraging these technologies, agricultural stakeholders can mitigate crop losses, optimize resource use, and contribute to global food security in a sustainable manner.

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