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A Systematic Analysis on Leaf Disease Detection and Classification Using Machine Learning

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Abstract: One of the most crucial areas of precision agriculture research is the identification of plant diseases using images of their leaves. Since most plant diseases have a variety of outwardly visible symptoms, learning models should be highly observant to identify the telltale indicators of any disease. Currently, several kinds of machine learning techniques are employed to identify plant diseases. This study presents a Survey on Leaf Disease Classification and Detection Techniques offers a thorough investigation into the application of various algorithmic approaches. Hence, this extensive review highlights the nuances and capabilities of machine learning and deep learning models, particularly in their application to diverse various plants. This comprehensive overview showcasing the evolving landscape of plant pathology research driven by advanced computational techniques.

***IndexTerms* -** Leaf Disease Detection, Machine Learning (ML), Support Vector Machine (SVM), Convolutional Neural Network (CNN,) Deep Learning (DL)

I. INTRODUCTION

A significant field of study in agriculture is plant disease investigation, which aims to identify, classify, and diagnose plant diseases. It is essential for preserving environmental balance and agricultural output [1, 2]. As plants are fundamental to food security and environmental health, the study of their diseases is crucial for sustaining agricultural outputs and preserving biodiversity [3]. Plant leaf diseases can be classified based on their causative agents: fungi, bacteria, viruses, and other factors like environmental stress or nutritional deficiencies. Common symptoms of leaf diseases include discoloration, spots, wilting, and stunted growth. However, accurately diagnosing plant diseases is challenging, requiring specific expertise and often sophisticated laboratory analysis. Misdiagnosis can lead to ineffective treatment and further spread of the disease.

The epidemiology of plant diseases involves understanding the life cycle of pathogens and the environmental factors influencing disease development and spread. Plant diseases spread mostly because of external elements including soil quality, humidity, and temperature. Comprehending these variables is essential for forecasting disease epidemics and executing efficient containment strategies.

To minimize damage and losses in farming, early detection of plant diseases is essential.. There are drawbacks to traditional illness detection and management techniques, including labor intensity and the requirement for specialized knowledge. Modern technologies, particularly machine learning and deep learning, are emerging as powerful tools in plant pathology.

Machine Learning holds significant promise for disease detection and classification. By processing and analyzing images of plant leaves, ML algorithms can identify disease symptoms with high accuracy. This capability marks a substantial improvement over traditional methods, offering enhanced accuracy and efficiency. These models can analyze visual patterns such as spots, color changes, and leaf shape deformities, which are indicative of specific plant diseases, thus aiding in timely and accurate disease identification and management.

Deep learning, and particularly convolutional neural networks (CNNs), have been game-changers in image-based plant disease detection. CNNs are exceptionally skilled in processing visual data, identifying complex patterns and variations in images, such as differentiating between healthy and diseased plant tissues. Recent advancements in deep learning have led to the development of more accurate and robust models capable of classifying a wide range of plant diseases, often surpassing human-level accuracy in some tasks. These developments signify a major step forward in automating and improving the accuracy of plant disease diagnosis.

The primary purpose of this survey is to comprehensively explore and synthesize the current state of research in applying machine learning (ML) and deep learning (DL) techniques to the classification and detection of plant leaf diseases. This involves a meticulous examination of various methodologies, tools, and approaches that have been developed and employed in recent years.

The remaining portion of the study is organized as follows: The various types and consequences of leaf diseases are covered in Section II. Researchers use a variety of classification strategies, which are described in Section III. In section IV, leaf disease classification and Identification approaches are presented. Section V presents the problems with identifying plant diseases and the topic is concluded in Section VI.

II. Leaf Disease Types And Impacts

Numerous diseases related to agriculture can strike plants at different phases of their growth, impairing their ability to produce crops as a whole [2, 4, 5]. Numerous factors at different stages of a plant's lifecycle might lead to plant diseases [14]. The causes that cause crop diseases can be broadly divided into two groups, according to [4] biotic influences and abiotic ones.

Plant growth is inhibited by abiotic factors such as water, temperature, irradiation, and lack of nutrients, whereas biotic factors such as fungi, bacteria, viruses, mites, and slugs are produced when microbes infect plants. [9, 15–18].

Among the most common illnesses are fungi, which can cause powdery mildew, rusts, and leaf spots. These diseases are identified by specific symptoms such as black spots on leaves, orange or yellow pustules, and white powdery particles. While viral infections cause signs like mosaic patterns, leaf bending, and stunted growth, bacterial diseases frequently show up as wilting, leaf blight, and canker. Each type of pathogen has a unique mode of infection and spread, often exacerbated by environmental conditions like humidity and temperature. Fig-1 shows the specifics of the variables that cause diseases in plants.

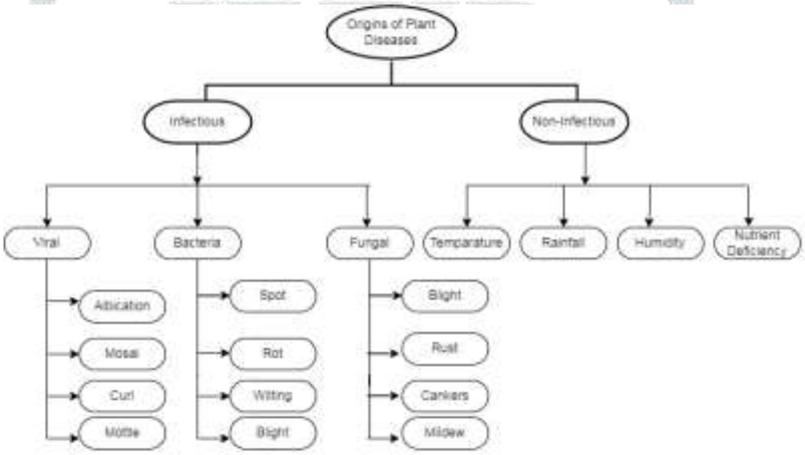

Fig-1: Plant disease causing factors [43].

The impact of these diseases extends far beyond the visible symptoms; they can drastically reduce crop yields, affect the quality of produce and in severe cases, lead to total crop failure. Economically, this translates into substantial losses for farmers and can disrupt food supply chains, particularly in regions heavily reliant on agriculture.

Given that plants are essential to preserving the health of the environment, widespread plant diseases have the potential to cause an imbalance in ecosystems and a loss of biodiversity. Furthermore, chemical treatments are frequently used to manage leaf diseases, which may have additional negative effects on the ecosystem. Plant health continues to face problems from the introduction and spread of new and more severe disease strains, which are partially linked to climate change and global trade. This situation emphasizes how urgently we need efficient methods for managing and detecting diseases, and how cutting-edge technology like deep learning and machine learning may help with early detection and control. By understanding the types and impacts of leaf diseases, researchers and agricultural professionals can better strategize for sustainable and effective disease management, ensuring the health of crops and, by extension, the stability of ecosystems and economies dependent on agriculture.

Fig-2: Types of Leaf Diseases [44]

III. RELATED LITERATURE

This study is vital for showcasing how advanced machine learning techniques can be used in the agricultural sector. The research offers insightful perspectives into the capabilities and limitations of these technologies in the context of plant pathology by providing a thorough comparison of several machine learning models.

Pushpa et al. [24], utilizes the CNN-based AlexNet model, comparing its effectiveness with the help of VGG-16 and Lenet-5 models. The dataset includes 7070 images of diseased and healthy leaf samples from various plants like corn, rice, and tomato. The proposed AlexNet model outperforms the other models, achieving an accuracy of 96.76% in identifying different plant related diseases. This study underlines the potential of deep learning in improving the accuracy and efficiency of plant disease diagnosis.

Sue Han Lee et al.'s study [25] focuses on using leaf feature analysis and deep learning to identify plant species. In order to extract and show features directly from unprocessed leaf data, the study makes use of convolutional neural networks (CNN) and deconvolutional networks (DN). In order to enhance plant classification systems, it presents research showing that distinct venation orders are important representative characteristics for leaf identification. This research provides fresh insights into hybrid feature extraction models. By highlighting the hierarchy and intricacy of leaf data, the research advances our understanding of how deep learning may be used for botanical classification.

Jing Wei Tan et al. [26] explores deep learning applications in plant species classification using leaf vein patterns. It introduces a CNN-based method, D-Leaf, for feature extraction from leaf images, applying pre-trained AlexNet, fine-tuned AlexNet, and D-Leaf models. The features are classified using SVM, ANN, k-NN, Naïve-Bayes, and CNN classifiers. The study demonstrates D-Leaf's effectiveness in plant species identification with a significant accuracy, showcasing the potential of deep learning in botanical research.

M.Sardoganet al. [27] focuses on employing Convolutional Neural Networks (CNN) in conjunction with the Learning Vector Quantization (LVQ) algorithm to identify and categorize tomato leaf diseases. It uses LVQ for classification and a CNN model for feature extraction to handle four common tomato leaf diseases. The method demonstrates effective recognition of different disease types, highlighting the potential of combining CNN with LVQ in plant pathology.

Muhammad Attique Khan et al. [28] presents a method for cucumber leaf disease detection and classification. It incorporates image enhancement, infected region segmentation, deep feature extraction, feature selection, and classification. The approach uses pre-trained models like VGG-19 and VGG-M for feature extraction, and selects prominent features based on local entropy, standard deviation, and interquartile range. The features are then classified using a multi-class support vector machine, achieving an impressive classification accuracy of 98.08%.

Geetharamani G. et al. [29] has been proposed a novel model for applying a deep convolutional neural network (Deep CNN) to diagnose plant leaf diseases. The model uses six different forms of data augmentation techniques to improve performance, and it is trained on a dataset of 39 distinct classes of plant leaves and backdrop images. The suggested model outperforms conventional machine learning techniques with a high classification accuracy of 96.46%, exhibiting consistency and dependability in its outcomes.

Veni S, et al. [30] focuses on developing an automated system for recognizing plant leaves and detecting diseases. It utilizes image processing techniques and employs Support Vector Machine (SVM) and K-Nearest Neighbours (KNN) for classification. The study examines five plant varieties: corn, tomatoes, apples, grapes, potatoes, and potatoes. These were selected because they are very susceptible to disease and are often found in India. The study demonstrates effective leaf recognition and disease detection, comparing the performance of SVM and KNN classifiers. The conclusion highlights SVM's higher accuracy and precision compared to KNN in disease classification.

Stephen Gang Wu et al. [31] demonstrates a neural network method for recognizing plant leaves. The study uses image and data processing methods in conjunction with Probabilistic Neural Networks (PNN) to classify 32 different plant species according to their leaf characteristics. Twelve leaf characteristics are extracted by the approach, and five principal variables are orthogonalized into them for PNN input. The PNN, trained with 1800 leaves, achieves an accuracy greater than 90%. The study demonstrates the effectiveness and efficiency of this algorithm in plant classification, emphasizing its fast execution and ease of implementation.

Kiran R et al. [32] provide a thorough analysis of numerous image processing methods for identifying diseases that affect plant leaves. It discusses different image acquisition methods, preprocessing steps, feature extraction techniques, and classification algorithms used in this field. The study highlights the importance of these strategies while discussing several ways for early and effective disease detection in agriculture, including neural networks and statistical approaches. It also identifies challenges such as the impact of background data on image analysis and the need for optimized techniques for specific plant diseases.

Li S Zhang, et al. [34] give an extensive an examination of deep learning methodologies used for identifying plant leaf diseases. The paper discusses advancements in deep learning, its application in agriculture, especially when identifying plant illnesses, and highlights the challenges and future directions in this area. It highlights how deep learning may significantly improve agricultural operations by facilitating the quick and precise identification of plant diseases. Understanding the present situation and future prospects of deep learning in agricultural applications may be gained from this review, which is an invaluable tool.

Waleed Albattah et al. [35] introduce a Custom CenterNet framework using DenseNet-77 as the fundamental network for robust plant disease classification. Creating annotations to pinpoint areas of interest, utilizing an enhanced CenterNet featuring DenseNet-77 to extract deep keypoints, and utilizing the one-stage detector CenterNet to identify and classify different plant diseases are the three stages of the method. In comparison to other previous approaches, the method proved to be proficient and reliable in determining and categorizing diseases of plants when evaluated on the PlantVillage Kaggle database.

Lili Li et al. [36] provides an extensive review of deep learning techniques used for plant leaf disease detection. The paper discusses advancements in deep learning, its application in agriculture, particularly in the identification of plant diseases, and highlights the challenges and future directions in this area. It emphasizes the significant role of deep learning in enhancing agricultural practices by enabling rapid and accurate plant disease detection. This review is a valuable resource for understanding the current state and potential of deep learning in agricultural applications.

Sharada P et al. [37] focuses on plant disease identification using deep learning. It employs a convolutional neural network to classify 14crop species and 26 diseases based on a collection of 54,306 images. With an accuracy of 99.35%, the model shows that deep learning may be used to diagnose plant diseases. The research suggests a direction toward global crop disease diagnostics supported by smart phones.

M.V.Applalanaidu et al. [39] offers a thorough study of techniques for identifying and categorizing plant diseases using machine learning (ML) and deep learning (DL). It analyzes over 45 papers from 2017 to 2020, detailing various ML and DL algorithms like SVM, KNN, Naïve Bayes, AlexNet, GoogLeNet, and VGGNet used in this context. The paper organizes the analysis into well-formed tables, discussing image segmentation, feature extraction, and classification accuracy. It serves as a valuable resource for researchers, highlighting potential mobile-based applications of these MAL/DL approaches to enhance agricultural productivity.

Muhammad Hammad Saleem et al. [40] provides an in-depth review of deep learning (DL) techniques in plant disease detection. It covers well-known DL architectures, their implementation, visualization techniques, and new or modified architectures specifically for plant disease detection. The paper discusses hyper spectral imaging combined with DL models and concludes with future research directions. This work is significant for its comprehensive analysis of DL applications in plant pathology, highlighting both existing methods and potential advancements [19].

Nithish et al. [42], introduces an innovative method for employing image segmentation techniques to automatically detect and classify plant leaf diseases. The paper explores the application of genetic algorithms for image segmentation, A vital phase in identifying plant leaf diseases. This paper emphasizes the efficacy of the recommended approach and discusses the necessity of accurate disease detection in large agricultural areas. Additionally, it provides a summary of various classification schemes that can be utilized for this purpose. Several researchers utilize the leaf disease classification methods to improve the system's accuracy, as shown in Table 1.

Reference	Sample Image	Data set	Methodologies Used	Results
[6]	Corn	Custom	AlexNet	Achieved 98.4% Accuracy
[7]	Tomato	Plant Village	CNN	Achieved 98% Accuracy
[8]	Soybean	PDDB	CNN	Achieved 98.14% Accuracy
[10]	Tomato	TPMD	Hybrid SVM	Achieved 94% Accuracy

[12]	Tomato	Plant Village	AlexNet, GoogleNet	Achieved accuracy 99%
[13]	Various crops	Plant Village	Inception V3, ResNet 50 &101, DenseNet 121 & 201, NasNet Mobile	Achieved High accuracy
[19]	Tomato	Custom	Random Forest	Achieved 95% Accuracy
[20]	Tomato	Plant Village	Ensemble model	Achieved 99.60% Accuracy
[21]	Tomato	Plant Village	Faster-RCNN (RESNET-34)	Achieved 99.97% Accuracy
[24]	Various crops	Custom	Deep CNN	Achieved 96.46% Accuracy
[27]	Various crops	Turkey –Plant Dataset	Hybrid CNN, SVM	Achieved 97.5% Accuracy
[30]	Various crops	Custom	KNN, SVM	SVM Achieved 91% Accuracy
[31]	Various crops	Custom	PNN	Greater than 90% accuracy
[35]	Various crops	Plant village	Custom CenterNet framework with DenseNet-77	Achieved accuracy 99.98%
[36]	Various crops	Plant village	AlexNet, VGG-16, Lenet-5	AlexNet outperformed others with 96.76% accuracy
[42]	Soya bean	Custom	CNN	Achieved 96% Accuracy

Table 1: Summary of Plant Disease Detection Methods

IV. Leaf Disorders Classification and Identification Techniques

Leaf disease classification and detection techniques in machine learning involve the use of various algorithms and models to identify and categorize diseases affecting plant leaves. Here’s a general overview:

Data Collection and Preprocessing: For leaf disease detection, large datasets of leaf images are needed. Images are preprocessed by resizing for uniformity and normalizing pixel values to facilitate computation. Data augmentation techniques like flipping, scaling, or rotating images ensure the model can recognize diseases in various leaf orientations, enhancing its robustness.

Feature Selection and Extraction (SVM): SVMs identify key visual features-such as color changes, spots, blight patterns, or vein discolouration-that differentiate diseased leaves from healthy ones. This process is crucial for accurate classification.

Choosing a Classifier (Neural Networks): Since CNNs are so good at picture identification, they are frequently used to identify leaf diseases. They can identify intricate patterns and textures in leaf images, crucial for distinguishing different types of leaf diseases.

Training the Classifier (Decision Trees): Images of both healthy and damaged leaves are used as training data for decision trees. The trees use features like color, texture, and shape to make decisions, effectively categorizing the leaves.

Model Evaluation (KNN): The K-Nearest Neighbors algorithm evaluates the model's performance by comparing its disease classification on test data against known results. Recall, accuracy, and precision are computed to assess the model's effectiveness.

Parameter Tuning (Random Forest): Adjusting the parameters of a Random Forest model, like the number of trees or their depth, to improve the model's accuracy and ability to generalize. This helps in accurately detecting various leaf diseases under different conditions.

Prediction (Logistic Regression): Applying a Logistic Regression model to classify new leaf images. The model uses the patterns it learned during training to predict whether a leaf is diseased, aiding in proactive plant health management.

4.1 Machine Learning Techniques In Leaf Disease Prediction

A branch of artificial intelligence is called machine learning. Machine learning is the study and creation of algorithms that can evaluate, understand, and forecast data. It originated from the study of pattern recognition and computational learning theory in artificial intelligence. These techniques help in identifying diseases early, minimizing crop losses and enabling prompt intervention.

4.1.1 Support Vector Machines (SVM)

For regression and classification, SVM is a reliable machine learning model. In leaf disease detection, SVMs classify leaves into categories (healthy or diseased) based on features extracted from the images. It works by choosing the hyperplane that optimally separates the classes in the feature space [2]. The effectiveness of SVM in leaf disease detection resides in its capacity to handle high-dimensional information and perform well with a limited amount of training samples, provided the features are well-selected and informative.

4.1.2 K Nearest Neighbors (KNN)

KNN is a fundamental algorithm that works well for classification problems. The closest training examples in the feature space are used to categorize the data. For leaf disease detection, KNN considers the features of a leaf image and identifies its class based on the most similar images in the training dataset[30]. This technique is particularly useful when the data is well-segregated, and the feature space accurately represents the differences between healthy and diseased leaves.

4.1.3 Random Forest

As part of its ensemble learning process, Random Forest builds a large number of decision trees during training and outputs the class that is the mean of the classes of each individual tree[19]. It's effective in leaf disease detection as it can handle large datasets with multiple features and provides a metric for feature significance. By using an ensemble technique, Random Forest becomes less prone to overfitting than it would be with a single decision tree.

4.1.4 Artificial Neural Networks (ANN)

It have become a powerful tool in plant disease detection, particularly in identifying leaf diseases. By mimicking the human brain's neural structure, ANNs can analyze complex patterns in leaf images and predict diseases with high accuracy.

4.2 Deep Learning Techniques In Leaf Disease Prediction

Deep learning has significantly advanced leaf disease prediction by automating feature extraction and improving accuracy. Below are the primary deep learning techniques used in leaf disease prediction:

4.2.1 Deep Learning Architectures

Robust deep learning models such as ResNet, Inception, and AlexNet are developed for particular applications, such as the identification of leaf disease. [36]. These architectures, with their deep layers and complex structures, are capable of learning high-level features from images. They are particularly effective in scenarios where the disease symptoms are subtle or varied, as they can learn from large datasets to identify intricate patterns and variations in leaf images.

4.2.2 Convolutional Neural Networks (CNNs)

CNNs are specialized deep learning models designed to interpret grid-like input, including images. In leaf disease detection, CNNs automatically extract and learn features from leaf images, such as color patterns, spots, and textures. They are composed of fully connected layers for classification, pooling layers to lower dimensionality, and convolutional layers to apply filters to the input. [14, 30]. CNNs are highly efficient in recognizing complex patterns in images, rendering them perfect for identifying subtle indications of leaf diseases.

4.2.3 Transfer Learning

In transfer learning, the foundation of a model created for one task is applied to another activity. For leaf disease detection, using pre-trained networks (like those trained on ImageNet) and adapting them to the specific task can significantly improve performance, especially when the available dataset for the specific task is small [45]. This approach leverages the feature extraction capabilities of networks trained on large and diverse datasets, fine-tuning them to the nuances of leaf disease characteristics.

4.2.4 Recurrent Neural Networks (RNNs)

RNNs can be used in conjunction with CNNs to predict diseases in images containing time-sequenced data, while being more frequently utilized for sequential data.

4.2.5 Autoencoders(AE)

Autoencoders are strong deep learning models that are mostly used for image denoising, feature extraction, anomaly detection, and unsupervised learning in the prediction of leaf diseases. Autoencoders try to recover the original image after compressing it into a latent space representation (encoding). Meaningful features, such as the texture, color, and form of leaves, are extracted by the encoder.To distinguish between healthy and diseased leaves, the collected features can be passed into a classifier (such as CNN, SVM, or Random Forest).

4.2.6 Generative Adversarial Networks (GANs)

The main applications of these networks, which are strong deep learning models, in leaf disease detection are data augmentation, image synthesis, and disease localization. The two neural networks that make up GANs—the Generator, which produces phony images, and the Discriminator, which separates real from false images—train in a competitive environment.

V. Problems With Identifying Plant Diseases

After analyzing machine learning and deep learning techniques to identify and categorize diseases on a widely used dataset, this study discovered few obstacles in the real applications of plant disease detection.

- Discolorations, lesions, patches, deformities, and other appearances are some of the ways that leaf diseases can present. Different factors, including the type of pathogen, infection stage, and environmental conditions, can affect how symptoms arise. Developing algorithms that can accurately detect diverse symptoms is challenging.
- Collecting large and diverse datasets of leaf images with labeled disease symptoms can be challenging and time-consuming. It is frequently necessary for specialists to manually annotate images, which can be subjective and error-prone.
- Additionally, ensuring that the dataset captures the variability of symptoms across different conditions is crucial for training robust models.
- There may be an imbalance in the classes within the dataset due to diseased leaves being comparatively less numerous than healthy leaves in real-world circumstances. Unbalanced datasets can bias the model towards the majority class (healthy leaves) and result in poor performance in detecting minority classes (diseased leaves).

- Novel diseases or untrained environmental variables may be challenging for machine learning models that are trained on specific datasets to generalize to. Ensuring that models are robust and can adapt to unseen variations is essential for real-world applicability.
- Early detection of leaf diseases is essential for prompt action to stop their spread. It is difficult to achieve real-time inference with high accuracy on devices with limited resources, such smartphones or drones.
- Background clutter, variations in lighting, and occlusions from surrounding vegetation can interfere with disease detection algorithms, leading to false positives or negatives.
- Machine learning-based leaf disease detection systems need to integrate seamlessly with existing agricultural practices and decision-making processes. Providing actionable insights to farmers, such as recommended treatments or interventions, requires careful consideration of user interface design and information delivery.

VI. Conclusion

In order to wrap up, this study offers a thorough overview of plant pathology's use of machine learning and deep learning approaches for the detection and classification of leaf diseases. This study examined the various approaches and procedures used by researchers to identify plant diseases throughout the previous several years. The main intention is to identify plant diseases as soon as possible so that appropriate action can be taken to stop their spread. This would make it possible to increase the product's agricultural yield.

For future research, the potential lies in integrating more advanced AI techniques, such as reinforcement learning and generative adversarial networks, to enhance leaf disease detection. Exploring the use of larger, more diverse datasets, including rare disease manifestations, can improve model robustness. Additionally, there's scope in developing real-time, field-level diagnostic tools using mobile platforms, and incorporating environmental factors for predictive analytics. This would lead to more precise, proactive plant disease management, benefiting agricultural practices and food security globally.

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