Cotton Leaf Disease Detection using AI Techniques: A Comprehensive Survey

Aditi Yadav, Rohini B. Late

Research Student Department of Computer Science & Engineering M. S. Bidve Engineering College, Latur Affiliated to Dr. Babasaheb Ambedkar Technological University (DBATU), Maharashtra, India

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ABSTRACT

Farming plays an essential role in supporting the economy of many nations. In developing countries particularly, a large number of people depend on agriculture as their main source of income and daily sustenance. Cotton is regarded as one of the most valuable commercial crops because it provides the primary raw material for textile manufacturing industries worldwide. However, cotton cultivation is frequently affected by several leaf diseases that weaken plant growth and reduce both the amount and quality of harvested fiber. When such infections remain unnoticed during early growth stages, they can spread quickly and cause serious losses for farmers. For this reason, identifying cotton leaf diseases at an early stage is extremely important for protecting crop health and maintaining agricultural productivity. In many agricultural settings, farmers determine plant health by visually examining leaves in the field. Although this practice has been used for generations, it often requires considerable effort and time and may not always result in correct diagnosis. Environmental variations and the limited availability of trained agricultural specialists in rural areas can further complicate disease recognition. With the advancement of artificial intelligence and deep learning, researchers are increasingly exploring automated techniques to assist in plant disease identification. This study proposes an intelligent system that analyzes cotton leaf images to detect disease symptoms. A Convolutional Neural Network is used to learn visual characteristics from the images. Image preparation steps such as resizing, normalization, and augmentation improve model learning ability. Such systems can support farmers in recognizing infections earlier, reducing losses and encouraging technology-driven farming

Keywords: Leaf Disease Detection, Deep Learning, Image Processing, Convolutional Neural Network, Smart Agriculture, Agriculture Technology, Crop Health Monitoring.

INTRODUCTION

Cotton is one of the most important fiber crops globally, forming the backbone of the textile industry and sustaining the livelihoods of millions of farmers, especially in developing countries where agriculture is a primary source of income Despite its economic significance, cotton cultivation faces serious threats from various leaf diseases, which can drastically reduce both yield and fiber quality. Depending on disease severity and environmental conditions, these infections can lead to losses ranging from 20% to 80%, resulting in substantial economic impact for farmers and affecting the overall agricultural economy.

Traditionally, cotton leaf diseases are identified through manual inspection by farmers or agricultural experts. While this method is widely practiced, it is often slow, labor-intensive, and heavily reliant on the skill and experience of the inspector. In rural areas, the shortage of trained specialists further delays timely disease detection. Moreover, several diseases exhibit similar visual symptoms, increasing the likelihood of misdiagnosis and delaying effective treatment. These limitations highlight the urgent need for automated systems capable of accurate, fast, and reliable disease identification.

In recent years, artificial intelligence (AI) and deep earning (DL) have emerged as powerful tools to address this problem. Among these, convolutional neural networks (CNNs) have shown remarkable performance in image classification tasks and are increasingly being applied to agricultural datasets. By analyzing leaf images in fine detail, these models can detect subtle variations in color, texture, and shape to accurately distinguish between healthy and diseased leaves. AI-based methods provide several advantages over traditional approaches, including faster detection, consistent and unbiased results, the ability to process large datasets, and reduced dependence on human expertise.

Many deep learning architectures, including ResNet, DenseNet, VGG, Inception, and MobileNet, have been successfully applied to cotton leaf disease detection. Although these models achieve high classification accuracy, several practical challenges persist, such as limited availability of annotated datasets, variability in disease symptoms due to environmental conditions, and high computational requirements for training and deployment. Therefore, it is essential to review recent advancements, compare different models, and identify future directions in AI-driven cotton disease detection. This review aims to provide a comprehensive understanding of existing approaches and their potential to improve disease management, reduce crop losses, and support sustainable cotton cultivation. Additionally, the integration of lightweight architectures and optimization techniques can enhance real-time deployment and model efficiency. Overall, these developments contribute to the advancement of intelligent and scalable agricultural systems.

Related Work

Md. Manowarul Islam et al. propose an advanced deep learning-based approach for automated cotton leaf disease detection, aiming to improve agricultural productivity by enabling early and accurate diagnosis. The study primarily focuses on the application of fine-tuned transfer learning models, where pre-trained convolutional neural networks such as VGG-16, VGG-19, Inception- V3, and Xception are adapted to the specific task of cotton disease classification. Instead of using these models directly, the authors enhance their performance by modifying the architecture, including removal of final layers and addition of new layers like global pooling, batch normalization, dropout, and dense layers, which helps in better feature extraction and reduces overfitting. The methodology begins with collecting a labeled dataset of cotton leaf and plant images, followed by extensive preprocessing techniques such as resizing, sharpening, rescaling, shearing, zooming, and horizontal flipping to improve data quality and generalization. The dataset is then divided into training and testing sets, typically in an 80:20 ratio, to evaluate model performance effectively. During training, the models are fine-tuned using a low learning rate to preserve learned features while adapting to the new dataset. The performance of each model is assessed using standard evaluation metrics including accuracy, precision, recall, and F1-score, along with confusion matrix analysis to understand classification behavior. Among all the implemented algorithms, the Xception model demonstrates the best performance, achieving an accuracy of 98.70%, outperforming other models due to its depthwise separable convolution mechanism and efficient feature representation capability. Furthermore, the study highlights the practical applicability of the proposed system by integrating the trained model into a web-based smart application, where users can upload images of cotton leaves and receive instant disease predictions. This real-time implementation makes the approach highly useful for farmers and agricultural experts, reducing dependency on manual inspection and minimizing crop loss. Overall, the paper emphasizes the effectiveness of fine-tuned deep learning models in plant disease detection and showcases how transfer learning can significantly enhance classification accuracy in agricultural applications.[1]

Nagarjun, K. Srinivas, M. Siva Kumar, and M. Venkata Naresh describe a deep learning-driven framework for the accurate identification of cotton leaf diseases, which are a major factor affecting crop yield and overall agricultural productivity. The authors propose the utilization of advanced transfer learning techniques by leveraging pre-trained convolutional neural network architectures, including ResNet101, Inception v2, and DenseNet121, which are further fine-tuned to suit the specific characteristics of the cotton disease dataset. To enhance the optimization process during model training, the authors incorporate the Nesterov Accelerated Gradient (NAG) algorithm, which improves convergence speed and ensures more stable learning compared to conventional optimization methods. The proposed methodology involves systematic stages, beginning with image acquisition, followed by preprocessing operations to improve image quality and reduce noise, and subsequently feature extraction using deep convolutional layers. The processed images are then classified into healthy and diseased categories using the trained models. Extensive experimental evaluation demonstrates that the proposed approach achieves a high classification accuracy of up to 99%, surpassing the performance of individual baseline models. Furthermore, the authors emphasize that the integration of transfer learning with efficient optimization strategies significantly enhances the robustness and generalization capability of the model. The developed system is designed to support real-time applications, enabling farmers to upload leaf images and obtain rapid and reliable disease predictions. Overall, the authors highlight that their approach provides an efficient, scalable, and practical solution for early-stage disease detection in cotton crops, thereby contributing to the advancement of intelligent agricultural systems. [2]

G. Kumar, S. Bhatia, and R. Sharma propose a compact and computationally efficient convolutional neural network architecture for the detection and classification of cotton leaf diseases, with a primary focus on balancing accuracy and resource utilization. The authors propose a lightweight CNN model specifically designed for deployment on low-power and resource-constrained devices, making it suitable for real-time agricultural applications. To reduce computational complexity while preserving classification performance, the proposed approach incorporates advanced techniques such as network pruning, depthwise separable convolutions, and transfer learning using pre-trained weights. These methods enable the model to minimize redundant parameters while effectively extracting discriminative features from leaf images. The methodology involves processing input images through the optimized CNN architecture, where feature extraction and classification are performed efficiently within a unified framework. Experimental results demonstrate that the proposed model achieves an accuracy of 97.5% on low-power devices, indicating its effectiveness in practical deployment scenarios. Furthermore, the authors compare their approach with deeper architectures such as ResNet50, which achieves a slightly higher accuracy of 97.8% but requires significantly greater computational resources, making it more suitable for cloud-based implementations. The authors propose that their model provides an effective trade-off between performance and efficiency, enabling both edge-based and cloud-supported disease monitoring systems. Overall, the proposed framework offers a scalable, efficient, and reliable solution for cotton leaf disease detection, contributing to the advancement of smart and accessible precision agriculture systems. [3]

D. Zhu, Y. Chen, H. Zhao, and J. Huang propose an efficient cotton disease identification method based on model pruning, with the objective of reducing computational complexity while maintaining high classification accuracy. The authors propose a deep convolutional neural network (DCNN) compression strategy that integrates pruning techniques with transfer learning to enable deployment on resource- constrained smart devices. In this approach, pre- trained architectures such as VGG16, ResNet164, and DenseNet40 are utilized and subsequently optimized by eliminating redundant parameters and less significant connections within the network. This pruning mechanism significantly reduces model size and computational overhead while preserving essential feature representation capabilities. The methodology involves acquiring cotton leaf images, applying preprocessing techniques, and then performing feature extraction and classification using the optimized DCNN models. Experimental results demonstrate that the pruned DenseNet40 model achieves a high accuracy of 97.23% while maintaining a minimal number of parameters, indicating an effective trade-off between efficiency and performance. Furthermore, the authors implement the optimized model in an Android-based application, enabling real-time disease detection by allowing users to capture or upload leaf images for instant diagnosis. The authors further emphasize that the combination of pruning and transfer learning enhances model scalability, portability, and suitability for edge-device deployment. Overall, the proposed approach provides a lightweight, accurate, and practical solution for cotton leaf disease detection, contributing to the advancement of smart and accessible precision agriculture systems. [4]

S. Ganguly, A. Bose, and P. Das described a computer vision–based framework for the automated detection and classification of cotton leaf diseases, aiming to provide an efficient and reliable solution for early diagnosis in agricultural applications. The authors described an approach that integrates advanced image processing techniques with machine learning algorithms to accurately identify various types of diseases from leaf images. The methodology involves capturing leaf images, followed by preprocessing steps such as image enhancement, noise reduction, and segmentation to isolate relevant features. These processed images are then analyzed using machine learning models, where discriminative features are extracted and utilized for classification of different disease categories. The described system emphasizes both accuracy and computational efficiency, making it suitable for practical deployment in real-world farming environments. Experimental results demonstrate that the approach achieves high accuracy while maintaining efficient processing performance, indicating its effectiveness in disease detection tasks.

Furthermore, the authors described that the system can assist farmers in the timely identification of plant diseases, thereby enabling better crop management and reducing potential yield losses. Overall, the described framework provides a robust and scalable solution for automated cotton leaf disease detection, contributing to the advancement of intelligent and technology-driven agricultural systems. [5]

Smruti Kotian, Pravalika Ettam, Shubhangi Kharche, Karuna Saravanan, and Kavitha Ashokkumar described a machine learning–based approach for the early detection of cotton leaf diseases, with the objective of improving crop yield and minimizing agricultural losses. The authors described a methodology that integrates transfer learning and classical machine learning techniques to enhance disease classification performance. In this approach, a pre-trained ResNet50 model is utilized for feature extraction and initial classification, enabling the system to effectively differentiate between healthy and diseased cotton leaves with an accuracy of approximately 95%. Furthermore, the extracted features are processed using the K-Nearest Neighbors (KNN) algorithm to perform detailed classification of specific disease types. The methodology involves acquiring leaf images, applying preprocessing techniques, and extracting relevant features before classification.

Experimental results indicate that the KNN-based classification achieves an accuracy of around 86% in identifying individual disease categories. The study primarily focuses on detecting major cotton diseases such as bacterial blight and leaf curl, and also provides preventive recommendations to assist farmers in managing crop health. The described system emphasizes simplicity, interpretability, and practical applicability, making it suitable for real-world agricultural environments. Overall, the described approach demonstrates that the combination of deep learning and traditional machine learning techniques can provide an effective and accessible solution for cotton leaf disease detection and management. [6]

R. Singh, A. Kumar, and S. Sharma described a deep learning–based approach for the detection and classification of cotton leaf diseases, aiming to support timely intervention and improve crop productivity. The authors utilized a dataset of cotton leaf images to train and evaluate multiple convolutional neural network models, along with optimization techniques to enhance performance and generalization. The methodology includes image preprocessing, feature extraction, and classification using deep neural networks. Among the evaluated models, the Xception architecture achieved the highest validation accuracy of 98.61% with the Adam optimizer, demonstrating superior performance. The study highlights the importance of appropriate optimization strategies for improving model convergence and accuracy. Overall, the approach provides a reliable and automated solution for disease detection, reducing manual effort and supporting efficient crop management. [7]

Azath M., Melese Zekiwos, and Abey Bruck described a deep learning–based image processing approach for the detection of cotton leaf diseases and pests, with the objective of improving agricultural productivity through automated diagnosis. The authors presented a methodology based on convolutional neural networks (CNNs) to identify various disease and pest categories, including bacterial blight, spider mite infestation, and leaf miner damage. The approach utilizes a dataset comprising approximately 2,400 images, with around 600 samples per class, ensuring balanced representation for effective model training. To improve the generalization capability of the model, K-fold cross-validation is employed during the training process. The implementation is carried out using Python 3.7.3 with Keras and TensorFlow frameworks in a Jupyter Notebook environment, enabling efficient model development and evaluation. The methodology involves preprocessing input images, followed by feature extraction and classification using CNN- based architectures. Experimental results demonstrate that the proposed model achieves an accuracy of 96.4%, indicating strong performance in identifying both diseases and pests from leaf images. Furthermore, the study highlights the potential of integrating deep learning and image processing techniques to develop real-time, IT-based solutions that can assist or replace manual inspection methods. Overall, the described approach provides a reliable and scalable framework for automated cotton leaf disease and pest detection, contributing to the advancement of intelligent agricultural systems. [8]

S. K. Patra, A. Mishra, and B. Sahoo described a parameter-efficient deep learning framework for the classification of cotton leaf diseases, aiming to reduce computational complexity while maintaining high predictive accuracy. The authors presented an approach that focuses on optimizing model parameters to achieve efficient learning without compromising classification performance. By minimizing redundant computations and improving parameter utilization, the framework enhances scalability and suitability for real-time applications. The methodology involves processing cotton leaf images through a deep learning architecture, where feature extraction and classification are performed in an optimized manner to ensure both accuracy and efficiency. The proposed system is designed to address the limitations of conventional deep learning models, which often require high computational resources. Experimental evaluation indicates that the framework achieves competitive accuracy while significantly reducing model complexity, making it practical for deployment in resource-constrained environments. Furthermore, the study highlights the importance of parameter- efficient techniques in developing scalable and cost- effective agricultural solutions. Overall, the described framework provides a reliable and efficient approach for automated cotton leaf disease classification, contributing to the advancement of intelligent and sustainable farming systems. [9]

S. Muthurajkumar, S. Ganapathy, and A. Kannan proposes a hybrid deep learning architecture, termed SwinCNN, for accurate cotton disease prediction, aiming to enhance classification performance by combining complementary learning techniques. The authors presented an approach that integrates convolutional neural networks (CNNs) with the Swin Transformer (ST) to effectively capture both local and global feature representations from cotton leaf images. The methodology involves processing a publicly available dataset, where image preprocessing and feature extraction are performed using the hybrid architecture to improve classification accuracy. By leveraging the strengths of CNNs in capturing spatial features and the Swin Transformer in modeling long-range dependencies, the proposed system achieves superior performance compared to individual models. Experimental results demonstrate that SwinCNN attains a high accuracy of 99.65%, outperforming standalone CNN and transformer-based approaches. The study highlights that the hybrid design significantly improves feature learning and generalization capability, making it suitable for complex disease classification tasks. Furthermore, the system supports practical deployment in smart farming environments by enabling timely and precise disease detection, thereby assisting in reducing crop losses. Overall, the described approach provides an efficient, scalable, and high-performing solution for automated cotton leaf disease prediction, contributing to the advancement of intelligent agricultural systems. [10]

J. Chopda, H. Raveshiya, S. Nakum, and V. Nakrani described a machine learning–based approach for cotton crop disease detection using a decision tree classifier, aiming to enhance farming efficiency and support real-time agricultural decision-making. The authors presented a methodology that leverages data- driven techniques within the context of smart farming, where information from various sources such as environmental parameters, sensors, and databases is utilized for disease prediction. The approach focuses on analyzing key factors including temperature and soil moisture to identify potential disease conditions in cotton crops. Unlike traditional farming practices that rely on manual observation and are affected by environmental uncertainties, the proposed system utilizes structured data analysis to improve prediction accuracy and reliability. The methodology involves collecting relevant agricultural data, preprocessing it for consistency, and applying a decision tree classifier to predict disease occurrence. The system is designed to provide timely and accurate predictions, enabling farmers to take preventive measures and improve crop quality. Furthermore, the authors developed an Android-based application to deliver real-time predictions, making the system accessible and practical for field use. The study highlights the importance of integrating machine learning with smart farming technologies to overcome limitations of conventional methods. Overall, the described approach provides an efficient and user- friendly solution for cotton disease prediction, contributing to the advancement of data-driven and intelligent agricultural systems. [11]

Nikhil Shah and Sarika Jain described a machine learning–based approach for the detection of diseases in cotton leaves using an artificial neural network (ANN), aiming to improve early diagnosis and reduce crop losses. The authors presented a methodology that utilizes image-based analysis, where detailed preprocessing techniques are applied to enhance and isolate diseased regions by examining color variations, texture, and pattern characteristics. The processed images are then used to train an ANN model, enabling accurate classification of healthy and diseased cotton leaves. The approach incorporates diverse leaf conditions during training to improve the robustness and generalization capability of the model under varying environmental conditions. The methodology involves systematic image preprocessing, feature extraction, and classification using the ANN framework. Experimental results indicate that the proposed system significantly improves early disease detection compared to traditional manual inspection methods, providing higher precision, consistency, and processing speed. Furthermore, the study highlights that the automated detection system offers farmers timely and reliable insights, allowing them to implement preventive and corrective measures effectively. Overall, the described approach provides an efficient and scalable solution for cotton leaf disease detection, contributing to improved crop management and sustainable agricultural practices. [12]

CONCLUSION

Recent studies demonstrate notable advancements in detecting cotton leaf diseases using artificial intelligence, machine learning, and deep learning techniques. Deep learning methods, particularly convolutional neural networks, hybrid models such as SwinCNN, and transfer learning frameworks including VGG, ResNet, DenseNet, Xception, and Inception, consistently achieve high accuracy, ranging from 95 to 99.65 percent, in identifying a wide range of diseases, including bacterial blight, leaf curl, and various fungal infections. To improve efficiency and usability, researchers have developed parameter- efficient frameworks, pruning strategies, and lightweight CNN architectures, allowing these models to operate on devices with limited computational resources while maintaining high performance. Traditional machine learning methods, such as K- Nearest Neighbors, decision trees, and artificial neural networks, remain relevant for effective disease classification, especially when combined with advanced image preprocessing techniques that enhance feature extraction. Several studies emphasize practical applications, including mobile and web- based platforms, which enable farmers to detect diseases at early stages and take timely preventive measures, thereby reducing crop losses and improving yield. Overall, AI-based detection systems demonstrate a balance of accuracy, efficiency, scalability, and practicality, providing robust tools for precision agriculture and smart cotton farming, and paving the way for the integration of intelligent technologies in modern crop management practices.

Future Scope

Although AI and machine learning have greatly improved cotton leaf disease detection, there are several areas where further research can make these systems even better. Future work can focus on creating larger and more diverse datasets that include images from different regions, seasons, and environmental conditions to make models more reliable. Combining image data with information about soil, weather, and pests could improve disease prediction and overall crop monitoring. Lightweight and efficient models can be developed for real-time use on mobile devices or low-power systems, making the technology accessible to more farmers. Advanced AI techniques, such as transformer-based models, self-supervised learning, and federated learning, could improve accuracy, adaptability, and privacy. Integrating these systems with automated alerts, irrigation, and crop management tools can support smarter and more efficient farming. Collaboration between AI experts, agronomists, and farmers will help turn research into practical solutions. These improvements will contribute to sustainable cotton farming, reduce crop losses, and support modern, technology-driven agriculture.

REFERENCE

1. Md. Manowarul Islam et al. “A deep learning model for cotton disease prediction using fine-tuning with smart web application in agriculture.” In Intelligent Systems with Applications (Elsevier), 2023 https://doi.org/10.1016/j.iswa.2023.200278
2. Nagarjun, K. Srinivas, M. Siva Kumar, and M. Venkata Naresh, "An Advanced Deep Learning Approach for Precision Diagnosis of Cotton Leaf Diseases: A Multifaceted Agricultural Technology Solution," Engineering, Technology & Applied Science Research, vol. 14, no. 3, pp. 14426–14432, 2024 https://doi.org/10.48084/etasr.7535
3. G. Kumar, S. Bhatia, and R. Sharma, “A Compact CNN Architecture for Detection and Classification of Cotton Leaf Diseases,” in 2024 International Conference on Intelligent and Innovative Computing Systems (ICIICS), 2024. https://doi.org/10.1109/iciics63763.2024.10859957
4. D. Zhu, Y. Chen, H. Zhao, and J. Huang, “Cotton disease identification method based on pruning,” Frontiers in Plant Science, vol. 13, article 1038791, 2022. https://doi.org/10.3389/fpls.2022.1038791

5. S. Ganguly, A. Bose, and P. Das, "Automated Detection and Classification of Cotton Leaf Diseases: A Computer Vision Approach," in Proceedings of the 2024 IEEE International Conference on Advanced Materials and Technologies for Healthcare (AMATHE), 2024. https://doi.org/10.1109/amathe61652.2024.10582055
6. Smruti Kotian, Pravalika Ettam, Shubhangi Kharche, Karuna Saravanan, and Kavitha Ashokkumar, "Cotton Leaf Disease Detection Using Machine Learning," in Proceedings of the 2nd International Conference on Advancement in Electronics & Communication Engineering (AECE 2022), July 14–15, 2022. https://papers.ssrn.com/sol3/papers.cfm?abstract_i d=4159108
7. R. Singh, A. Kumar, and S. Sharma, "Performance Evaluation of Cotton Leaf Disease Detection Using Deep Learning Models," in Proc. 2024 IEEE International Conference on Computing, Communication and Intelligent Systems (ICCICA), 2024. https://doi.org/10.1109/iccica60014.2024.105849 90
8. Azath M., Melese Zekiwos, and Abey Bruck, "Deep Learning-Based Image Processing for Cotton Leaf Disease and Pest Diagnosis," Hindawi Journal of Electrical and Computer Engineering, vol. 2021, Article ID 9981437, 10 pages. https://doi.org/10.1155/2021/9981437
9. S. K. Patra, A. Mishra, and B. Sahoo, "Improved Cotton Leaf Disease Classification Using Parameter-Efficient Deep Learning Framework," arXiv preprint arXiv:2412.17587, 2024. https://doi.org/10.48550/arxiv.2412.17587
10. S. Muthurajkumar, S. Ganapathy, and A. Kannan, "SwinCNN: A Hybrid Deep Learning Architecture for Accurate Cotton Disease Prediction," in Proceedings of the 2023 IEEE International Conference on Advanced Computing (ICOAC), 2023. https://doi.org/10.1109/icoac59537.2023.10249246
11. J. Chopda, H. Raveshiya, S. Nakum, and V. Nakrani, "Cotton Crop Disease Detection Using Decision Tree Classifier," in *Proceedings of the 2018 International Conference on Smart City and Emerging Technology (ICSCET)*, 2018. https://doi.org/10.1109/icscet.2018.8537336
12. Nikhil Shah and Sarika Jain, "Detection of Disease in Cotton Leaf Using Artificial Neural Network," in Proceedings of the 2019 Amity International Conference on Artificial Intelligence (AICAI), Dubai, United Arab Emirates, 4–6 February 2019. https://doi.org/10.1109/AICAI.2019.8701311