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Potato Leaf Insight: An AI-Driven System for Detection of Potato Leaf Disease

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Abstract

Agricultural productivity is crucial for global economic development and growth. Crop diseases can severely risk to Nation's food security, economic resources, environmental sustainability and agricultural output. Crop disease detection at early stage not only reduce losses for farmers but also improve crop yields. As agricultural technology and artificial intelligence advance, research into sustainable agricultural development becomes increasingly crucial. Plant diseases significantly impact the yield and quality of potatoes, and manually diagnosing these diseases can be both time-consuming and complex due to the required expertise. This paper introduces PotatoLeaf Insight System that employs U-Net technique for image segmentation followed by VGG19, for feature extraction through transfer learning. The model is trained and evaluated using a dataset of potato leaf images, covering early blight disease, late blight disease, leaf roll disease, Verticillium wilt disease, and healthy leaves. This AI driven system provide overall accuracy of 94% and useful for farmers to take necessary care of their crops in case detected with disease.

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Disease Detection,
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Introduction

Across the globe, numerous occupations exist, in that the agriculture is the most fundamental occupation. Agriculture sector play a significant role in the economy of Indian. Among many crops, Potatoes play a crucial role as contributes 28.9% in India's total agricultural crop production.[1] Globally, Maize, wheat, rice are considered as top three food crops whereas Potato's crop is considered as fourth largest food crop in world. India stands as the

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second-largest producer of potatoes, generating about 48.5 million tons annually but its productivity has dropped over time due to environmental, and climatic factors.[2] In India, around 95% of potato cultivation occurs in Punjab.

Potatoes are essential for maintaining good health due to their ability to prevent heart diseases and their high fiber content. They are rich in antioxidants, which help combat issues such as high cholesterol and imbalanced sugar levels. Potato crops are susceptible to various several diseases[3] that manifest prominently on their leaves. Common afflictions include early blight, late blight, potato leaf roll and potato verticillium wilt.[4] Early blight disease caused by the fungal pathogen *Alternaria solani*, late blight disease triggered by Phytophthora infestans and potato leaf roll caused by the Polerovirus PLRV (*potato leafroll virus*) lead to leaf curling, whereas *potato verticillium* wilt, induced by the fungal infection of *Verticillium dahliae*, turns leaves yellow. All these diseases significantly impact potato production and affect national budgets.

To effectively manage these issues and minimize crop losses, farmers and local experts typically rely on visual inspection. However, this manual method is often impractical due to the time required, limited availability of experts, and the potential for human error. Therefore, an automated system for detecting and classifying these diseases with high accuracy is essential to improve crop management and reduce production losses.

In this paper, our focus is on identification of five category of potato leave—early blight diseased leaf, late blight diseased leaf, leaf roll diseased leaf, Verticillium wilt diseased leaf and healthy leaf. The key main objective of this work is to introduce PotatoLeaf Insight system which makes use of U-net for image segmentation and VGG19 model of CNN for feature extraction with transformers for classification, to achieve efficient and accurate disease prediction. In addition, this work validates PotatoLeaf Insight system on different evaluation measures like accuracy, precision, recall and f measure.

Related Work

In literature, several techniques were introduced to combat the crop diseases. Prominent techniques like Image processing, machine learning, artificial intelligence, deep learning has been evolved over time and shows significant improvement in the field of crop detection. In paper[5] the features of leaves like area, color and texture are extracted by utilizing K-meansclustering.[5] In paper,[6] Disease classification and identification carried out by Neural network algorithms.Methods related to deep learning are also employed for the disease detection[7,8] and various mechanisms[9] have been used for the fields analysis. Pavel[10] has applied Resnet 34 on the globally available potato plant village dataset for the classification purpose. Islam introduced support vector machine for multiclass classification of potato leaf disease.[11] Sladojevic implemented a deep CNN (Convolutional Neural Network) structure to classify multiclass diseases.[12] Singh developed a procedure that integrates image segmentation and soft computing techniques for detecting leaf diseases.[13] The features of leaf images are extracted using the color co-occurrence and then a SVM (Support Vector Machine) classifier is applied for disease classification. David presented Inception V3 network to learn general plant characteristics.[14] This method also incorporates a baseline CNN.[15] Tiwari projected Chan-Vase algorithm for image segmentation, followed by regression neural network and RPN (Region Proposal Network) algorithm.[16]

Materials and Methods

Figure 1 shows the system architecture where initially potato leaf images are collected from the plant village dataset available at Kaggle repository[17] downloaded by authors on 17th Dec. 2023. The Plant village dataset consist images of healthy leaves, early blight leaves and late blight leaves. In addition to plant village dataset, customized dataset is created by using standalone camera where images of leaf (Potato Verticillium_wilt and Leaf Roll) are collected and properly labeled in hybrid dataset using expert advice.

Image preprocessing involves intensity normalization, resizing, and annotation to improve prediction accuracy. During intensity normalization all pixels of leaf image are adjusted in range of [0, 255] and leaf images are resized to a standard dimesnion of 256×256 pixels ensuring consistent parameter training and enhancing overall model performance for both segmentation and classification tasks.

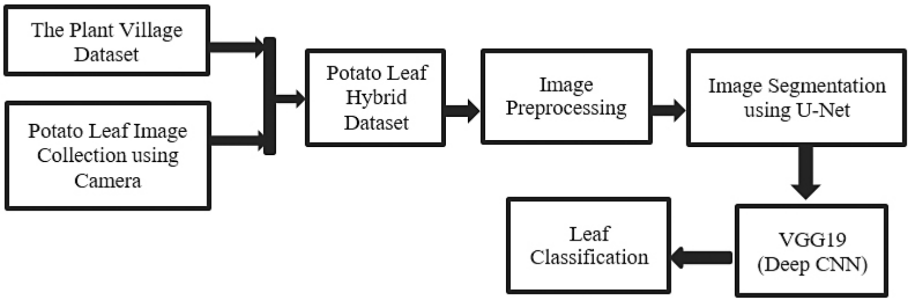


Fig. 1: Modules of PotatoLeaf Insight System

After image preprocessing, to automatically identify diseases on potato leaf images, U-Net model (Encoder-Decoder CNN) is applied for image segmentation. The PotatoLeaf Insight system utilizes segmentation of potato leaf diseases through the U-Net architecture without human intervention, which improves prediction accuracy. The U-Net architecture is structured with an encoder, a bridge, and a decoder. The purpose of encoder is to progressively reduces the image size while increasing the depth, and the purpose of decoder is to reverse this process by enlarging the image size and reducing the depth. To generate a binary mask as output, the U-Net architecture employs activation function like sigmoid.The output leaf of U-Net model looks like as in figure 2.

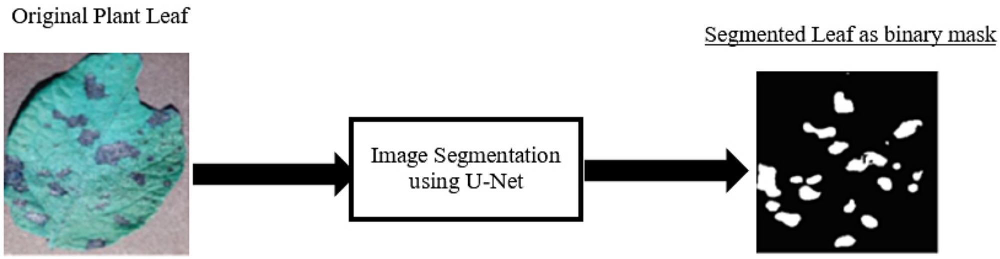
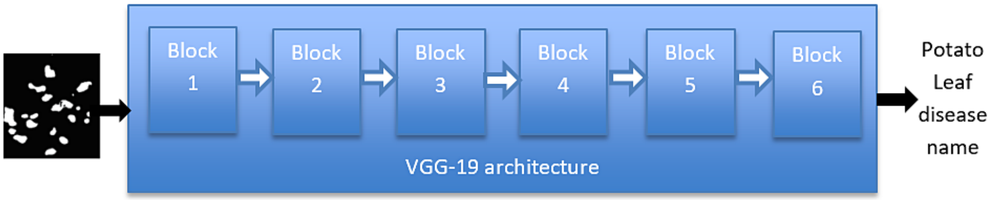


Fig. 2: Image Segmentation using U-Net



- Block1: Conv3x3 (64)->Conv3x3 (64)->MaxPool
- Block2: Conv3x3 (128)->Conv3x3 (128)->MaxPool
- Block3: Conv3x3 (256)->Conv3x3 (256)->Conv3x3 (256)->Conv3x3 (256)->MaxPool
- Block4: Conv3x3 (512)->Conv3x3 (512)->Conv3x3 (512)->Conv3x3 (512)->MaxPool
- Block5: Conv3x3 (512)->Conv3x3 (512)->Conv3x3 (512)->Conv3x3 (512)->MaxPool
- Block6: Fully Connected (4096)->Fully Connected (4096)->Fully Connected (1000)->SoftMax

Fig. 3: VGG Architecture

After Segmentation, VGG-19 is used for classification of segmented image where multiclass classification is carried out by trained model. The segmented image of leaf as binary mask is traversed through 6 blocks, where each block performs the convolution and max polling at the end of block 6 the disease class label is retrieved.

In block 1, 64 convolutional filter of size 3x3 applied to input image and creating 64 feature maps, then another layer of 64 convolutional filter of size 3x3 applied on intermediate image to get 64 feature map. At the end of block 1 max pooling layer reduce the dimension of feature map and retain only important and relevant features.

Similar Process is followed at Block 2 to Block 5 considering different convolutional filters and feature maps.

At block 6, take the output from the block 5, flatten it, and connect every neuron in one layer to every neuron in the next. The first two layers here have 4096 neurons. At second stage, similar deep flattening is carried out for deep representation diseases. Third stage, reduce 4096 neurons to 1000 neurons and contribute significantly in classification process. Softmax layer make use of activation function and converts the output into probabilities and data appropriate for disease name detection.

The model is trained over 100 epochs with a minimum batch size of 32. The trained model is evaluated by using accuracy, precision, recall, and F1-score.

Experimental Results and Discussion

The implementation PotatoLeaf Insight System is conducted in python using Kera library. A hybrid dataset is used for training and testing of potato leaf disease. The hybrid dataset is combination of the Plant Village dataset[17] and customized dataset prepared by using camera. Plant Village dataset is downloaded from Kaggle repository which consist of 54,306 images of both diseased and healthy plant leaves across 14 crop species. The customized dataset consists of images of leaf (Potato Verticillium_wilt and Leaf Roll).Table1 shows the customized dataset detail and data distribution consider in this work.

Table 1: Dataset details and Data Distribution of Customized Dataset

Type of Disease	Sample Image	Total Samples	Training dataset	Test dataset
Potato leaves affected by early blight		1000	800	200
Potato leaves affected by late blight		1000	800	200
Potato Leaf Roll		750	600	150
Potato Verticillium Wilt		750	600	150
Potato Healthy		350	280	70

The trained model is evaluated by using accuracy, precision, recall, and F1-score as shown in table 2. Table 3 show the evaluation of trained model by considering 20% samples as training data.

Table 2: Evaluation Measures of Classification on PotatoLeaf Insight

Measure	Derivations
Recall/Sensitivity	TPR = TP / (TP + FN)
Precision	PPV = TP / (TP + FP)
Accuracy	ACC = (TP + TN) / (P + N)
F1 Score	F1 = 2TP / (2TP + FP + FN)

Table 3: Evaluation of PotatoLeaf Insight

Class/Leaf Disease	Testing dataset	True positive	True Negative	False Positive	False Negative	Accuracy	Precision	Recall	F-score
Early blight	200	189	0	3	8	94.5%	98.4%	95.94%	97.17%
Late blight	200	193	0	5	2	96.5%	97.4%	98.9%	98.2%
Potato Leaf Roll	150	141	0	6	3	94%	95.9%	97.9%	96.9%
Potato Verticillium Wilt	150	142	0	5	3	94.6%	96.6%	97.9%	94.6%
Potato Healthy	150	141	0	5	4	94%	96.5%	97.2%	96.9%

Experimental results show that the validity of the system as overall accuracy of proposed system is 94.72%, precision is 96.96%, recall is 97.5 and F-score is 96.7%. Table 4 shows the proposed work comparison with existing work which carried out on PlantVillage dataset with VGG19 architecture.

Table 4: Comparison of PotatoLeaf Insight results with other existing AI driven systems

Related work Reference	Model	Accuracy	Precision	Recall	F-score
Sujatha.[18]	VGG19	87.40	87.70	-	87.40
Subetha.[19]	VGG19	87.70	-	-	-
PotatoLeaf (Proposed)	VGG19	94.72%	96.96%	97.5%	96.7%

Conclusion

This paper introduces AI based PotatoLeaf Insight framework for predicting potato leaf diseases in a multi-classification manner named as early blight, late blight, leaf roll, Verticillium wilt, and healthy leaves. This work employs U-Net technique for image segmentation followed by VGG19, for potato leaf disease detection. The model is trained and evaluated using a hybrid dataset. The hybrid approach improves the detection and prediction of potato crop diseases, positioning it as a promising tool for practical applications. The experimental results also prove the validity of PotatoLeaf Insight framework as contribute significantly by achieving overall accuracy of 94.72%, precision of 96.96%, recall of 97.5 and F-score of 96.7%. The framework can be used for other similar application area for crop disease detection in future.

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Conflict of Interest

The authors do not have any conflict of interest.

Data Availability Statement

A hybrid dataset is used for training and testing of potato leaf disease. The hybrid dataset is combination of the Plant Village dataset[16] and customized dataset prepared by using camera. Plant Village dataset[16] is downloaded from Kaggle repository which consist of 54,306 images of both diseased and healthy plant leaves across 14 crop species. The customized dataset consists of images of leaf (Potato Verticillium_wilt and Leaf Roll).

Ethics Statement

This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Author Contributions

- **Meenakshi Thalor:** Initiated the research work by outlining, mentioning objectives and prepared the system architecture.
- **Mrunal Pathak:** Contributed in customized data collection using camera and in documentation of paper.
- **Riyazahemed Jamadar:** Implementation of system starting from data collection to classification task.
- **Shahbaz Khan:** Performed the validation of model by using different evaluation measures like precision, recall and f score.

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