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A Deep Learning Framework for Early Detection of Potato Plant Diseases

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Abstract— In our rapidly evolving world, technology has become an inseparable aspect of daily life, with digital tools serving as essential aids for various tasks. Despite this, individuals and farmers encounter persistent challenges arising from sluggish internet connectivity and needing external assistance to manage online resources. These obstacles significantly hinder their capacity to oversee crops and promptly address potential plant diseases. A noteworthy predicament farmers face involves sluggishly identifying diseases within their crops, often compounded by a lack of knowledge about appropriate remedies. Traditional techniques for pinpointing plant diseases tend to be time-intensive and demand specialised expertise. Such circumstances present formidable obstacles for farmers lacking access to expert guidance or those grappling with limited time for effective crop management.

We have developed a Deep Convolutional Neural Network (DCNN) model to address this predicament to detect disease. The core purpose of our application is to expedite and enhance disease recognition for burgeoning plants, ultimately benefiting farmers. The mobile/web interface provides users with a user-friendly means of querying plant diseases and their potential treatments by capturing images of their plants. Basic functionalities encompass disease identification, enabling users to ascertain afflictions swiftly. Furthermore, the application includes provisions for storing crop-related data and tracking progress, thereby empowering farmers to make well-informed decisions concerning crop management.

At its essence, our project seeks to empower individuals and farmers with tools indispensable for proficient crop oversight. The application is a conduit for expedited disease detection and prompt mitigation, fostering healthier plants and elevated yields. Ultimately, our innovation holds the potential to substantially contribute to sustainable agricultural practices, effectively addressing the modern challenges encountered by farmers within our technology-driven milieu.

Keywords- Potato, Disease, TensorFlow, CNN, Machine Learning

I. INTRODUCTION

Agriculture plays a pivotal role in diminishing poverty and propelling economic growth. Grasping the significance of agriculture in poverty reduction and economic advancement is imperative. The fundamental role of food production lies in ensuring food security and preventing malnutrition. Rural communities, predominantly engaged in agriculture, are particularly susceptible to food insecurity. According to the World Bank, around 80% of individuals in rural areas are engaged in farming [1].

The potato, a widely popular and thriving vegetable crop, flourishes in gardens worldwide. Typically cultivated from October to March as a winter crop, it holds the third-most critical position in bolstering economic growth in Bangladesh, trailing only rice and wheat. Bangladesh is the seventh-largest potato producer globally and the fourth-largest in Asia [2].

Potato plants face vulnerability to diverse diseases during the harvesting phase. Hence, the Early identification of conditions in potato fields and swift intervention emerge as effective strategies for augmenting potato production, constituting the primary aim of this study. Traditional machine learning algorithms have extensively been employed to categorise potato leaf diseases.

In this study, our objective was to enhance classification outcomes by integrating segmentation techniques with deep learning algorithms. Image segmentation was harnessed to mask potato leaf images, culminating in an enriched image dataset. Image segmentation, a technique commonly used for object and boundary recognition in images, entails assigning labels to each pixel based on shared traits. Various algorithms can be employed for image segmentation, such as Otsu's Binary threshold, Contour Detection, and the K-means clustering Algorithm. Among the most prevalent segmentation methods, the K-means algorithm clusters objects based on similarity and proximity, utilising the Euclidean distance to compute similarity distances, with K values generally ranging from 2 to 10 [3].

Several conventional machine learning techniques were used to identify plant diseases and perform diverse computer vision tasks. Md. Asif Iqbal and Kamrul Hasan Talukder proposed a methodology involving seven widely employed conventional machine learning algorithms. Their research incorporated image segmentation techniques on 450 images from the Plant Village dataset. Among these algorithms, the random forest model demonstrated the highest accuracy, reaching 97% [4].

Chaojun Hou et al. conducted a study exploring various machine-learning algorithms and leveraging graph-cut segmentation techniques to predict Early and late blight diseases on potato leaves. Their efforts culminated in a 91% accuracy rate achieved by an SVM classifier post-image segmentation [5].

In contrast, deep learning algorithms are now acknowledged for their ability to enhance performance accuracy. A spectrum of deep learning algorithms has been harnessed to conduct diverse experiments on various agricultural products, including rice, tomatoes, bell peppers, and potatoes [6]. Image segmentation techniques bolster the precision of machine learning algorithms across diverse agricultural applications. This study endeavours to merge image segmentation techniques with deep learning algorithms to attain more robust outcomes in predicting potato leaf diseases.

II. RELATED WORK

In recent years, ensuring high-quality potato yields has become a crucial concern in the agricultural sector due to the economic and nutritional significance of this staple crop. Early disease detection is pivotal in maintaining potato crop health and maximising yield. This section reviews the existing literature on methods and techniques employed for Early disease detection in potato cultivation. Existing research utilised Machine learning (ML) and Deep learning (DL) based models to enhance the accuracy of identifying and categorising systems for detecting plant diseases. Traditional machine learning techniques, including Random Forest (RF), Support Vector Machine (SVM) and Artificial Neural Networks (ANN), have been put to use. Fuzzy logic, K-means, and Convolutional Neural Networks have also found application in empirical research for identifying and diagnosing plant illnesses. The automated detection of agricultural issues through the analysis of plant leaves is a noteworthy advancement in the field of agriculture. Furthermore, the Early and precise detection of plant diseases contributes positively to agricultural yield and overall quality [7, 8].

Parul Sharma et al. [9] utilised the CNN model methodology through the TensorFlow framework to execute their project. This model's benefit was that it could detect fungal diseases in sugarcane by only measuring the leaf area. However, the drawback was that it necessitated a high level of computational complexity to implement. Sandika Biswas et al. [10] utilised Fuzzy c-mean clustering and Neural Network to create the model. The model's main advantage was that it did not require special training for farmers, as it contained images captured from various angles. However, the disadvantage was that images captured by untrained farmers were not properly oriented and contained clusters of leaves with the background visible in several segments of the Potato Disease Detection Using Machine Learning research article utilised image processing technology. The CNN model was used, a major advantage of the project as it achieved a validation accuracy of 90%. However, a significant drawback of this model was the requirement for a large training dataset.

In recent times, ML-based algorithms have attracted considerable attention in academic circles for their efficacy in detecting diseases in plant leaves. These machine-learning methods have showcased impressive accuracy in disease detection. However, given the vast scope of machine learning, it can be broadly classified into two main categories: supervised and unsupervised learning. The diagram illustrates a variety of unsupervised machine-learning algorithms. While supervised algorithms encompass classification and regression-based approaches, unsupervised algorithms are subdivided into clustering-based methods such as K-means clustering and Fuzzy c-means clustering. Among these, most studies predominantly adopt supervised ML algorithms such as SVM, KNN, Naive Bayes, and Decision Tree (DT) for classification, with only a small subset opting for regression or clustering-based techniques.

Yao et al. [11] proposed an approach for detecting rice disease, utilising median filtering to mitigate image noise. This was followed by the extraction of features and subsequent SVM classification. Kan et al. [12] suggested a strategy for identifying and diagnosing diseases in agricultural leaf specimens involving preprocessing images, estimating shape and texture attributes, utilising colour, form, texture features, and an HSV colour histogram. Suja Radha [13] employed the K-means clustering approach for segmentation, utilising SVM classifiers within a higher-dimensional space to effectively differentiate between healthy and disease-afflicted leaves. In [14], Latha S proposed a novel method for detecting diseases, investigating Color Cooccurrence and Leaf colour extraction for feature extraction. They also employed the Otsu Threshold technique and the K-means algorithm for image segmentation. The performance of ANN and BPNN for disease categorisation was also evaluated.

Patil et al. [15] introduced an SVM technique for classification that leverages content-based image retrieval (CBIR) to retrieve features and facilitate the Early diagnosis of plant diseases. Pertot et al. [16] unveiled a real-time on-field imaging system for identifying damaged crops using mobile phones. Their methodology incorporated k-means clustering for leaf image segmentation and the subsequent identification of disease patches. In [17], Yang et al. presented a system for recognising microscope images, employing a decision tree-confusion matrix and a comprehensive assessment of texture and form features.

III. PROBLEM STATEMENT

Potato cultivation serves as a substantial income source for farmers globally. However, this crop is vulnerable to diverse diseases, resulting in considerable financial setbacks each year. Among these, Early Blight and Late Blight emerge as the most prevalent disorders affecting potato plants, and if not effectively addressed, they can lead to severe economic repercussions. Early Blight entails a fungal infection that generates brown spots on leaves, with the potential to propagate across the entire plant. The infection triggers the yellowing and death of leaves, severely curtailing potato yields. Conversely, Late Blight arises from microorganisms that infect leaves and stems, leading to browning and eventual collapse.

Prompt identification and suitable intervention are paramount to avert substantial wastage and economic setbacks in potato farming. Nevertheless, pinpointing the specific disease affecting the potato plant can pose a challenge, compounded by the nuanced differences in Early and Late Blight treatments. Hence, precise disease identification is a pivotal step to sidestep erroneous management practices and ensure the efficacy of treatments.

Convolutional Neural Network-Deep Learning technology has been harnessed to tackle this difficulty for accurate potato plant disease detection. Convolutional Neural Networks (CNN) exemplify a deep learning algorithm adept at recognising patterns and attributes in digital images. Leveraging extensive image datasets, these networks can be trained to adeptly classify images into distinct categories like healthy or afflicted plants.

The CNN model is trained on an expansive dataset containing images of healthy and diseased potato plants. Upon a farmer submitting an image of an ailing plant to the system, the CNN algorithm processes the image, extracts pertinent features, and cross-references them with the existing dataset. This comparison empowers the algorithm to ascertain the disease afflicting the plant reliably. Using CNN-Deep Learning technology equips farmers to precisely and efficiently spot potato plant diseases. This technological advancement enables farmers to make more informed decisions concerning crop management, translating to improved yields and substantial economic upshots. Farmers can curtail the need for costly treatments with adverse environmental and human health implications by preempting disease spread.

The integration of CNN-Deep Learning technology in potato farming constitutes a noteworthy stride in disease management. This technology empowers farmers with the tools to accurately identify and address diseases, resulting in diminished economic losses and ecological harm. Embracing sophisticated technology in agriculture contributes to sustainable farming practices while elevating the well-being of farmers worldwide.

IV. METHODOLOGY

The research involves several phases, as depicted in Figure 1 within the research framework. The suggested research framework comprises separate stages, which are delineated below:

A. Data Collection

Developing accurate leaf classification and disease detection algorithms holds immense significance within agriculture, serving as a pivotal aid for farmers to swiftly and effectively pinpoint and address crop diseases. During this research endeavour, two distinct datasets, specifically Plant Village and Mendeley, were harnessed to facilitate the training and evaluation of a model categorising potato plant leaves into Early, late, and healthy.

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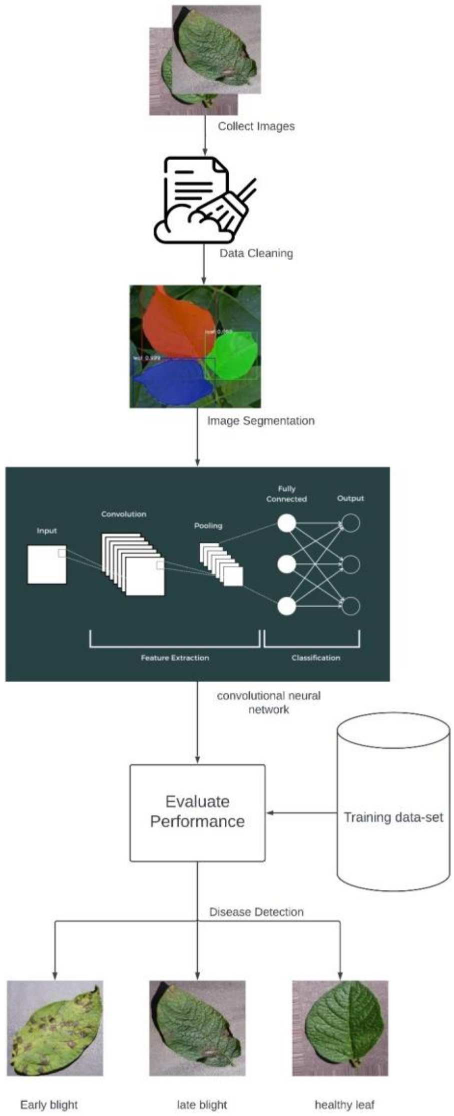

Figure 1: Proposed model

An inherent aspect of ensuring the model's precision lies in including a healthy leaf class within the dataset, enabling the model to differentially diagnose sound leaves and those afflicted by Early or late Blight. The dataset underwent division along an 80:20 ratio to foster a balanced assessment, with 80% earmarked for training and the remaining 20% allocated for testing the models.

Central to this study was assessing the proposed network's capacity to classify potato plant accurately leaves across the three delineated classes. The ensuing results substantiated the network's adeptness in distinguishing between the diverse classes, registering commendable performance. This outcome is promising, signifying the potential viability of the proposed network as a tool to support farmers in identifying and managing potato plant diseases. The augmented strength of this research effort is underscored by its utilisation of multiple datasets, a facet that bolsters the model's precision by affording a more comprehensive spectrum of data. Furthermore, segregating the dataset into discrete training and testing sets contributes to objectively evaluating the proposed network's capabilities, ensuring its ability to extrapolate to novel, unseen data. In a broader context, this research underlines the latent capabilities of machine learning techniques in fashioning precise leaf classification and disease detection algorithms tailored for potato plant diseases.

Table 1: Dataset statistics

Samples	Number
Healthy leaf	152
Early Blight	1000
Late Blight	1000
Total	2152

The proposed network's prowess in discriminating Early Blight, late Blight, and healthy leaves evinces its potential value as a discerning instrument in the arsenal of farmers to identify and effectively manage diseases affecting potato plants. The dataset utilised was sourced from the Kaggle platform under the "PlantVillage Dataset" banner.

B. Augmentation

Data augmentation is a technique employed to enhance the accuracy of image classifiers. This study employed multiple augmentation approaches to bolster the model's performance and ability to recognise images. One of the techniques encompassed applying a shear range of 0.2 to training images, wherein one axis remained fixed while the other was stretched to a predefined angle. This manipulation was instrumental in rectifying perception angles and generating images from diverse perspectives.

In addition, the utilisation of zooming with a range of 0.2x and horizontal flipping further contributed to the enrichment of the dataset. These augmentation methods collectively yielded a substantial collection of 10,320 images, out of which 8,256 were designated for training purposes, leaving 2,064 for the critical task of testing the model's capabilities.

C. Classification

The Convolutional Neural Network (CNN) architecture is widely recognised as a preferred choice for tasks involving image classification, encompassing the vital role of identifying diseases in potato leaves. This architecture operates within supervised learning, harnessing an established dataset to train a model in image recognition grounded in their distinctive attributes. In the scope of this project, we are poised to harness the power of CNN to effectively categorise potato leaf images into three distinct classes: healthy leaves, Early Blight, and Late Blight.

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The intrinsic value of CNN architecture is prominently showcased in its adeptness at discerning the attributes of potato leaves. The convolutional layer within the CNN deploys filters onto leaf images, unearthing features and patterns instrumental in distinguishing between sound leaves and those afflicted by Early Blight or Late Blight. Following this, the output image traverses a pooling layer, a process that reduces image resolution while retaining its intrinsic quality.

Figure 2: Healthy Leaves

Figure 3: Early Blight

Figure 4: Late Blight

Within the framework of this project, the leaf images are slated to undergo resizing, resulting in dimensions of 150x150x3 pixels. This configuration allocates three channels to each image—red, green, and blue. The image resultant from the pooling process subsequently undergoes MaxPooling, a transformative step that scales down the spatial dimensions while conserving the most salient data. To empower CNN with image classification capabilities, the output emerging from the MaxPooling layer is flattened into a vector format. The proposed model, designed to identify diseases in potato leaves, leverages four convolutional layers and an equal count of MaxPooling layers. The CNN architecture embarks on a training journey, utilising a dataset teeming with potato leaf images. This rigorous training regimen enables the model to ascertain the features demarcating healthy leaves from those beset by Early Blight or Late Blight. In summation, the envisioned CNN architecture stands as a promising avenue for identifying potato leaf diseases, galvanising the intrinsic potency of CNN to discern the intricate tapestry of patterns and features embedded within potato leaf images. Through meticulous training on a curated collection of potato leaf images, CNN is primed to adroitly classify potato leaves as either healthy or afflicted by Early Blight or Late Blight.

V. EXPERIMENTAL SETUP AND RESULT ANALYSIS

Plant leaf diseases pose a significant concern for farmers worldwide due to their potential to cause substantial crop productivity and quality losses. In recent years, deep learning techniques have emerged as a promising approach for detecting and diagnosing plant leaf diseases. These techniques offer the potential to aid farmers in managing biotic factors that lead to severe crop yield losses, thereby improving overall crop productivity and quality.

This research employs a multi-level deep learning model to identify potato leaf diseases. A Convolutional Neural Network (CNN) is a powerful deep learning algorithm for visual data analysis. By employing convolutional filters, activation functions for non-linearity, pooling layers for down-sampling, fully connected layers, and generating output probabilities for classification, CNNs directly learn and extract features from raw input data. Training CNNs involves utilising backpropagation and gradient descent to optimise the network's weights. These operations enable CNNs to learn hierarchical representations of visual data, making them effective for tasks such as image classification, object detection, and image segmentation.

The proposed model is efficient and straightforward, capable of classifying various potato leaf diseases. The model's initial level processes input images of potato leaves, extracting the leaves from the images. Subsequently, a convolutional neural network at the second level is developed to detect potato leaf diseases. This network can classify Early Blight and late blight potato diseases based on the images of the potato leaves. Moreover, the proposed model considers environmental factors such as temperature, humidity, and light, which can impact potato leaf diseases. By considering these factors, the model enhances its ability to predict and diagnose potato leaf diseases, thereby assisting farmers in implementing appropriate measures to control disease spread and enhance crop productivity and quality. In summary, our project showcases the effectiveness of deep learning techniques in detecting and diagnosing plant leaf diseases, particularly in the context of potato crops.

This statement implies that the CNN techniques proposed for detecting potato leaf diseases were evaluated on a dataset distinct from the one used for initial training. The results indicated that the proposed approach outperformed alternative methods for the same purpose.

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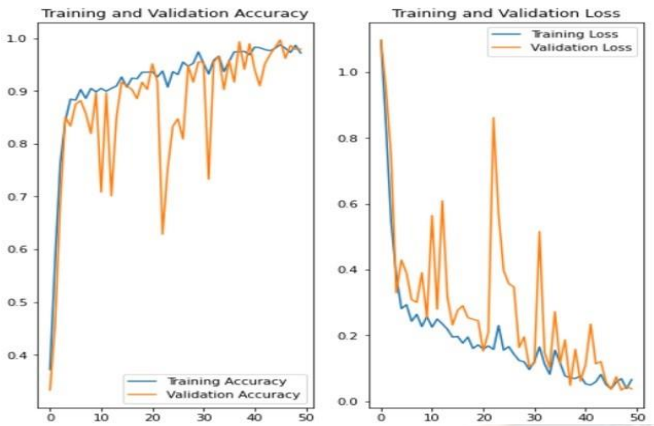

Figure 5: Model Training and Validation

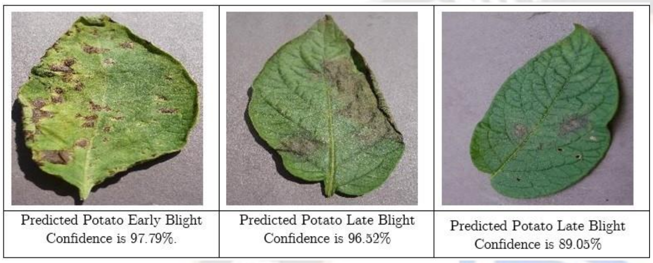

Figure 6: Prediction confidence of model

The technique was trained on two versions of the PLD dataset - one utilising data augmentation techniques and the other without. In spite of this, it achieved an impressive accuracy of 96.41% while also demonstrating high precision, recall, F1-score, and ROC curve metrics. Interestingly, despite its simplicity and fewer parameters than existing state-of-the-art methods, the proposed CNN technique showcased superior performance, significantly saving computational costs and processing speed.

Table 2: Performance comparison of different models

Models	Accuracy (%)
VGG16 (K-Means Clustering)	97.00
SVM (K-Means Clustering)	95.99
Deep CNN	99.75

Lastly, the results obtained from this study were compared with previous research on potato leaf disease detection for purposes of comparison. Overall, the statement underscores the effectiveness of the proposed CNN technique for detecting potato leaf diseases and its potential to contribute to developing more efficient and cost-effective methods for crop disease detection.

VI. DISCUSSION

The outcomes of this research underscore the considerable potential of employing deep learning algorithms to detect potato diseases. The notable accuracy achieved by the system implies its potential value as a valuable resource for farmers and researchers who require swift and precise identification of diseases in potato plants. An inherent advantage of utilising deep learning algorithms lies in their ability to be trained on extensive datasets, enabling them to discern intricate patterns within images. This characteristic renders them more accurate than traditional disease detection methods, which rely heavily on human expertise and visual scrutiny.

However, several limitations need consideration when using deep learning algorithms for disease detection. A primary challenge involves requiring large and diverse datasets to train the models effectively. Collecting and annotating such datasets can be time-intensive and costly, potentially restricting the scalability of these systems. Moreover, deep learning algorithms can be susceptible to overfitting, wherein they become excessively tailored to the training dataset, hindering their capacity to generalise effectively when confronted with new data.

In conclusion, the findings of this project strongly indicate the potential effectiveness of deep learning algorithms as a tool for detecting potato diseases. Subsequent research efforts should address these systems' limitations and explore their adaptability in various agricultural contexts.

VII. CONCLUSION AND FUTURE WORK

Potato farming constitutes a pivotal source of income for numerous farmers in India. However, susceptibility to various diseases among potato plants annually leads to substantial economic losses. Two prevalent diseases, Late Blight and Early Blight, significantly impact potato yield and quality. Regrettably, many farmers lack knowledge about potato diseases and struggle to access the latest management technologies.

To address this challenge, a deep learning-based approach employing a Convolutional Neural Network (CNN) was proposed for detecting Late Blight, Early Blight, and healthy leaf images of potato plants. This innovative methodology empowers farmers to swiftly and accurately identify the disease afflicting their plants, enabling timely intervention and reduced economic losses.

The proposed approach harnesses CNN technology to categorise potato plant images into three groups: Late Blight, Early Blight, and healthy leaves. The training dataset was meticulously prepared using three distinct augmentation techniques, amplifying the pool of training samples and elevating model accuracy. Moreover, the experiment employed k-means clustering segmentation with varying values to enhance disease detection precision. Notably, the approach was evaluated using two versions of the PLD dataset – one incorporating data augmentation techniques and the other without. Despite this distinction, an impressive accuracy of 91.41

The proposed methodology possesses the potential to revolutionise potato disease detection and management in India. This approach can curtail economic losses and elevate crop yields by furnishing farmers with an efficient and precise disease detection mechanism. Additionally, the technology is an educational tool, enabling farmers to make well-informed decisions concerning their crops.

Moreover, integrating deep learning-based methodologies into agriculture holds immense promise for enhancing global crop management and productivity. This project is a prime example of technology's potency in addressing pivotal agricultural challenges, particularly in developing nations like India.

In summation, the proposed deep learning-based approach, employing a CNN for identifying Late Blight, Early Blight, and healthy leaf images in potato plants, has the potential to impact India's potato cultivators profoundly. This technology empowers farmers with effective disease detection and management capabilities, culminating in economic savings and augmented crop yields. The infusion of advanced technology into agriculture is poised to catalyse transformative change, fostering sustainable farming practices and ultimately enhancing farmers' livelihoods worldwide.

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