Journal of Advanced Zoology

ISSN: 0253-7214

Volume 44 Issue S-2 Year 2023 Page 1:13

Early Detection of Potato Leaf Diseases using Convolutional Neural Network

Gudepu Sridevi [#1], Dogga Aswani [#2], N.Chaitanya Kumar [#3], K.Bhargav [#4], Dr. Siva Rama Krishna. T [#5], Preethi Gonnabathula [#6]

[#1]*Assistant Professor, Department of Mechanical Engineering, Vignan's Institute Of Information Technology,Duvvada.*
[#2]*Assistant Professor, Department of Computer Science and Engineering, Anil Neerukonda Institute Of Technology and Sciences.*
[#3] *Assistant Professor, Department of Computer Science and Engineering, Avanthi's Research and Technological Academy.*
[#4]*Assistant Professor, Department of Computer Science and Engineering, GITAM School of Technology, GITAM (Deemed to be University) Rushikonda, Visakhapatnam.*
[#5]*Assistant Professor, Dept of Computer Science and Engineering, Jawaharlal Nehru Technological University Kakinada.*
[#6]*Assistant Professor, Dept of Computer Science and Engineering, Maharaj Vijayaram Gajapathi Raj College of Engineering (Autonomous)*
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Corresponding Email ids: sridevi.gudepu3011@gmail.com [1], ashwani.cse@anits.edu.in [2], chaitanya.india9@gmail.com [3], bhargavkandala@gmail.com [4], srktummalapalli@gmail.com [5], preethi.g203@gmail.com [6]

Article History

Received: 11 Jul 2023

Revised: 21 Aug 2023

Accepted: 15 sept 2023

Abstract

Potato is the most important tuber crop in the world, with over 125 countries farming it. Potato, after rice and wheat, is the crop consumed by a billion people worldwide virtually every day. However, due to different fungal and bacterial illnesses, the quality and quantity of the potato crop is deteriorating. Early disease detection is difficult due to differences in environmental conditions, plant type, and plant disease symptoms. Several machine learning algorithms have been developed in recent study to recognize potato leaf diseases. In this work, a multi-layer deep learning model for detecting potato leaf disease is constructed. The features of the potato leaves are recovered from the image of the potato plant in the first layer using the image segmentation approach. A new deep learning technique based on a convolutional neural network [CNN] was created at the second level to detect fungal and bacterial infections in potatoes. The dataset for leaf disease contains 12000 photos gathered in real time and from the database. The proposed deep learning approaches identified potato diseases with 99.76% accuracy.

Keywords: ***Machine Learning, Deep Learning, Convolutional Neural Network, PotatoLeaf Disease, Image Segmentation***

1. INTRODUCTION

Deep learning techniques, particularly Convolutional Neural Networks (CNNs), have changed many fields, including agriculture, in recent years. Early identification and diagnosis of plant diseases has been a key focus, which is critical for guaranteeing food security and maximizing agricultural productivity. Among the many crops impacted by pathogens, the potato (Solanum tuberosum) is a staple food crop around the world and is sensitive to a variety of illnesses that can result in significant yield losses. Potato leaf diseases caused by a variety of fungal, bacterial, and viral infections have the potential to destroy potato crops if not recognized and controlled promptly. In the agricultural industry, disease identification has traditionally relied on manual examination by professionals, which can be time-consuming, error-prone, and unscalable for large-scale farming operations. The need for reliable, efficient, and rapid illness identification methods has prompted researchers to investigate machine learning and computer vision techniques such as CNNs as a possible answer to this critical problem.

The potato (Solanum tuberosum) is one of the world's most important staple crops, accounting for a sizable share of worldwide food output. However, the potato crop is under constant attack from microorganisms that cause leaf diseases. These illnesses not only endanger farmers' livelihoods, but they also have broader ramifications for food security and the global economy. In this introduction, we will look at the various potato leaf diseases and the issues they represent to agricultural communities around the world.Potato leaf diseases are caused by a variety of fungus, bacteria, and viruses, each with its own set of symptoms and ways of transmission. Early Blight (Alternaria solani), Late Blight (Phytophthora infestans), Blackleg (Pectobacterium spp. and Dickeya spp.), and Potato Virus Y (PVY) are some of the most frequent and severe potato leaf diseases. These viruses can infect potato plants at various phases of development, from seedling to maturity, resulting in severe production, quality, and market value losses.

Potato leaf diseases cause numerous and significant issues. For starters, they cause significant economic losses for farmers. Infected potato plants frequently have lower yields and quality, resulting in lower income for growers. Furthermore, the cost of disease management, which may include the use of chemical pesticides and fungicides, can be too expensive for farmers. These costs not only have an impact on company profitability, but they also have environmental and health ramifications. Second, potato leaf diseases are a major danger to food safety. Potatoes are a dietary mainstay for millions of people around the world, and any disturbance in potato production can have disastrous effects for populations who rely on this crop for survival. Furthermore, there is a major global potato trade, and disease outbreaks can affect international markets, resulting in food shortages and price volatility. Third, factors such as climate change and evolving pathogen populations compound the difficulties associated with managing potato leaf diseases. Climate change can modify the geographical distribution of diseases and affect disease severity by creating conditions favorable for disease development. Pathogens can also acquire resistance to routinely used chemical controls, making disease management more difficult and ineffective.

In view of these issues, there is an urgent need for creative and long-term solutions to potato leaf diseases. To lessen the burden of these illnesses, research efforts have increasingly focused on advanced technologies like as genetic resistance breeding, precision agriculture, and machine learning-based disease diagnosis systems. The use of Convolutional Neural Networks (CNNs) for potato leaf disease identification is one such technical technique investigated in this research, with the goal of contributing to the development of a more efficient and effective tool for disease control in potato farming. We may work toward a more resilient and sustainable potato business by tackling the difficulties connected with potato leaf diseases, maintaining a steady food supply for a growing global population.

2. LITERATURE SURVEY

In this section we are going to discuss about some authors who already worked on potato leaf diseases and what are the challenges that are faced by several authors in order to identify the potato leaf diseases.

1) Paper Title: Early Detection of Potato Leaf Diseases using Convolutional Neural Network with Web Application (2023)

Authors : P. K. Shukla[1] and S. Sathiya et.al.

Key Aspects:

1. This work guarantees the potato leaf disease detection using CNN.
2. The proposed work is conducted using CNN model with web application on PlantVillage Dataset.
3. The proposed work can achieve an accuracy of nearly 91 % on plant village dataset for three types of diseases.
4. In this proposed work the authors concentrated on Potato diseases.
5. The dataset for leaf disease contains 2250 photos gathered in real time and from the database.

2) **Paper Title:** Potato Leaf Disease Classification using Convolutional Neural Networks

Authors: Y. P. Wasalwar [2], K. S. Bagga, V. K. Joshi and A. Joshi et.al.

Key Aspects:

1. This work guarantees the potato leaf disease detection using CNN.
2. The proposed work is conducted using CNN model with sub dataset of PlantVillage Dataset.
3. The proposed work can achieve an accuracy of nearly 89 % on potato leaf dataset for four different categories of potato plants.
4. In this proposed work the authors concentrated on Potato diseases

3) **Paper Title:** Local Directional Patterns for Plant Leaf Disease Detection.

Authors: P A. Mezenner[3], H. Nemmour, Y. Chibani and A. Hafiane et.al.

Key Aspects:

1. This work guarantees the Plant leaf disease detection using LDP.
2. The proposed work is conducted using LDP model on plant leaf Dataset.
3. The proposed work can achieve an accuracy of nearly 91 % using Support Vector Machine classifier
4. In this proposed work the authors concentrated on plant diseases based on leaves and its characteristics.

4) Paper Title: Potato Disease Detection Using Machine Learning

Authors: M. I. Tarik[4]-[5], S. Akter, A. A. Mamun and A. Sattar et.al.

Key Aspects:

1. This work guarantees the potato disease detection using ML Classifiers.
2. The proposed work is trained on several ML classification algorithms and then try to check best algorithm for identifying the potato diseases.
3. The proposed work can achieve an accuracy of nearly 99.23 % on plant village dataset for three types of diseases.
4. In this proposed work the authors concentrated on Potato diseases.
5. This is having one limitation like overfitting problem when we take large input dataset.

5) Paper Title: Disease Detection in Potato Leaves Using Swin Transformer

Authors: Li-Hua Li[6] and Radius Tanone et.al.

Key Aspects:

1. This work guarantees the potato disease detection using Swin Transformer is one of the Indonesia's mainstay agriculture products.
2. The proposed work is mainly concentrated on disease prevention for increasing the potato production.
3. The proposed work can achieve an accuracy of nearly 97.70 % % using Swin Transformer Model.
4. In this proposed work the authors concentrated on Potato diseases.
5. This is having one limitation like agriculture dataset need to be developed prior of training any model, if not the model cannot generate accurate results.

6) Paper T**itle:** A Survey on Disease Detection of a potato Leaf Using CNN

Authors: Sindhuja Bangari[7]; P Rachana; Nihit Gupta; Pappu Sah Sudi and Kamlesh Kumar Baniya et.al.

Key Aspects:

1. The survey focuses on the crucial role of detecting disease in potato leaves. This is a major worry for potato farmers, as it can have an impact on crop yields and quality.
2. CNNs, a form of deep learning model noted for its success in image recognition tasks, are predominantly used in the survey. CNNs are ideal for assessing leaf pictures to detect illnesses.
3. The study is likely to employ a dataset of photos of healthy and damaged potato leaves to train and test the CNN models. This dataset is critical for the creation and validation of models.
4. The survey will most likely use classification metrics including accuracy, precision, recall, and F1 score to evaluate the effectiveness of CNN-based illness detection models. These metrics provide a quantitative assessment of the model's performance.

3. EXISTING SYSTEM

The present Potato Leaf Disease Detection system often combines conventional methods and modern technologies, with an increasing emphasis on automation and machine learning techniques. Here is a breakdown of the existing system's components:

Farmers' Visual Inspection:Farmers and agricultural specialists examine potato plants visually for symptoms of illness. Examining the leaves, stems, and tubers for signs of discolouration, spotting, wilting, or other abnormalities.

Sampling by Hand: Farmers may manually harvest samples of diseased leaves or other plant parts in some circumstances for further analysis. Typically, these samples are forwarded to agricultural extension offices or laboratories for analysis.

Laboratory Examination: Agricultural laboratories staffed by trained experts can do extensive studies on the samples gathered. Microscopic inspection, pathogen culture, and other classic diagnostic procedures may be used to determine the specific disease causing the symptoms.

Reference Materials and Visual Aids: To diagnose common potato leaf diseases, farmers frequently use reference materials such as books, pamphlets, or digital tools. These resources include photographs and descriptions of symptoms to help with manual identification.

Knowledge of Agricultural Experts: Based on their skills and experience, local agricultural specialists or extension workers play an important role in counseling farmers on disease identification and management.

Application of Pesticides: Farmers may use pesticides or fungicides to address diseases that have been discovered. The timing and selection of chemicals are frequently based on a visual assessment of illness severity.

Technologies in Development: There has been a shift in recent years toward incorporating emerging technology into the old system, including:
Image Capturing Devices: Farmers and professionals use smartphones or specialised cameras to photograph diseased potato leaves.

Computer Vision and Machine Learning: Advanced machine learning models, such as Convolutional Neural Networks (CNNs), are used to evaluate images and detect disease symptoms automatically.

Internet of Things (IoT) Sensors: Internet of Things (IoT) sensors can be used in the field to monitor environmental conditions and communicate data to a central system for disease risk assessment.

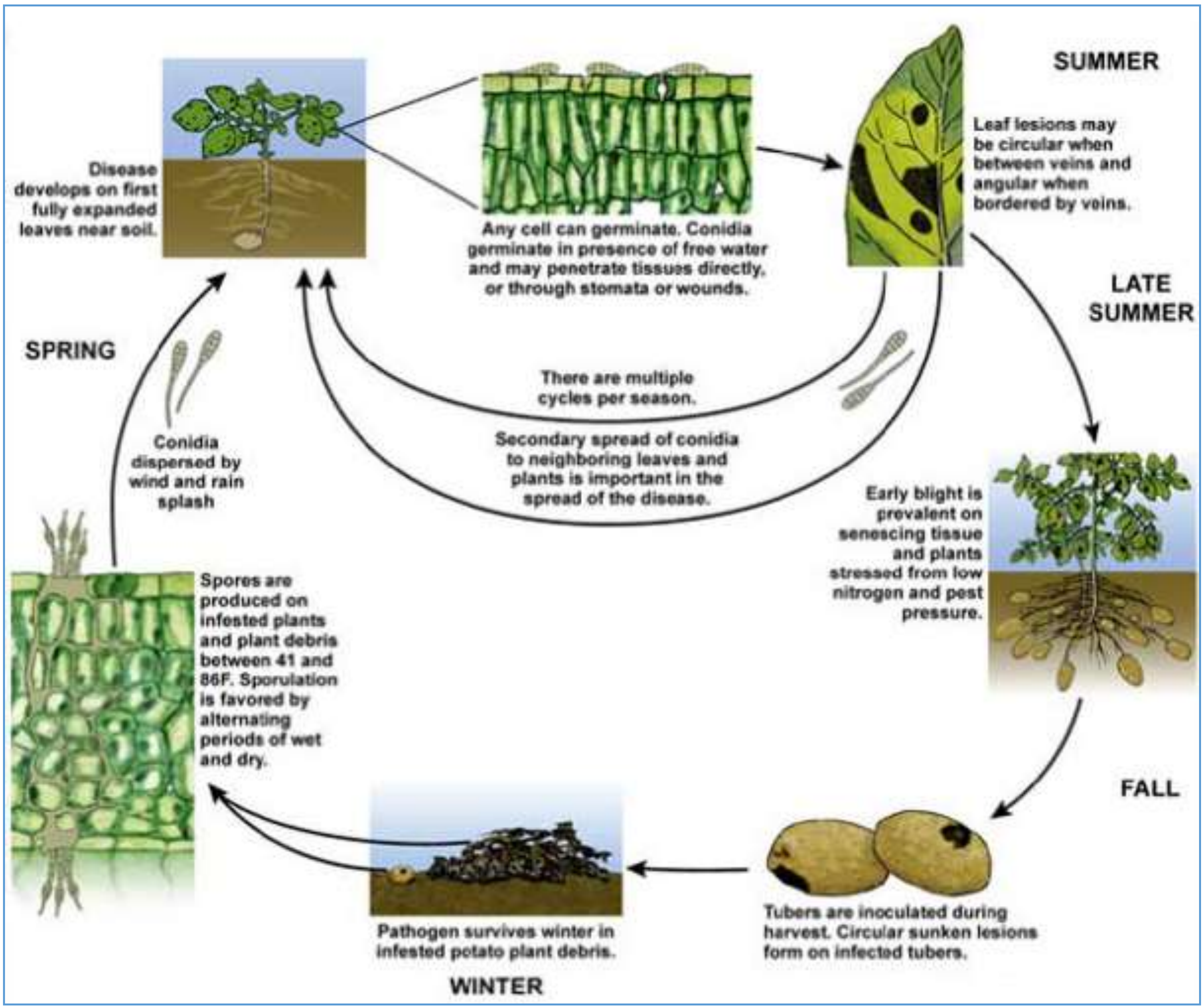


Figure 1. Represent the Lifecycle of Potato Leaf Disease across all Seasons

From the above figure 1, we can clearly identify the several stages of potato leaf which is varied in life span, the life span of potato leaf diseases varies based on the disease, the environment, and the geographic region. I can, however, provide a brief summary of the normal lifetime of numerous common potato leaf diseases throughout multiple seasons:

1) **Early Season Spring:**

Early Blight (Alternaria solani): Early blight spores can overwinter on plant waste in the soil in the spring.As temperatures rise and circumstances improve, the spores can germinate. Inoculum can be obtained from infected plant debris and soil.On older leaves and stems, lesions appear.

2) **Summer (middle of the season):**

Phytophthora infestans (Late Blight):

Late blight flourishes in chilly, damp environments. Sporangia are produced by infected plants and spread by wind, rain, or irrigation. Sporangia can cause new infections on the leaves and stems of plants. During wet seasons, disease development might be rapid.

Blight in the Early Stages:

Lesions of early blight continue to spread on leaves, particularly lower leaves.
Warm and humid temperatures can hasten the progression of this disease.

3) **Late summer through early autumn (Late Season):**

Early and late blight: Disease severity may grow as the season advances, particularly if the meteorological conditions stay favorable to the pathogens.To control the illnesses, fungicide treatments and cultural measures are frequently utilized.

4) **Autumn (the end of the growing season):**

Late Blight: Late blight becomes less active when temperatures cool and daylight hours decrease.The disease may progress further, but at a reduced rate.Late blight has the capacity to survive in potato tubers and plant debris that has been left in the field.

5) **Off-Season: Winter**

Late and early blight: Pathogens may lie dormant in areas with hard winters. Infected plant debris and tubers left in the field might overwinter and serve as possible inoculum sources for the following growing season.

4. PROPOSED SYSTEM

In this section, we try to discuss about the proposed CNN model[8]-[10] for potato leaf disease detection involves several key steps. Here are the primary algorithmic steps for creating a CNN-based system for this purpose:

1. Data Collection and Preparation:

In this first stage we can see following stages are applied to detect the diseases of potato plants**.**

Data Gathering: Collect a dataset of labeled images of potato leaves, including healthy leaves and leaves affected by various diseases (e.g., late blight, early blight, common scab).

Data Augmentation: Augment the dataset by applying transformations such as rotation, scaling, and flipping to increase its diversity.

Data Split: Divide the dataset into training, validation, and testing sets, ensuring that each set contains a representative distribution of healthy and diseased samples.

2) Model Architecture Design:

Here we try to apply several layers in order to process the model.

- **Convolutional Layers:** Design the CNN architecture by stacking multiple convolutional layers to automatically learn hierarchical features from input images.
- **Pooling Layers:** Add pooling layers (e.g., max-pooling) to downsample feature maps and reduce the computational load.
- **Fully Connected Layers:** Append one or more fully connected layers to learn high-level representations and perform disease classification.
- **Activation Functions:** Use activation functions like ReLU (Rectified Linear Unit) to introduce non-linearity and enhance the network's expressive power.
- **Dropout Layers:** Integrate dropout layers to prevent overfitting by randomly dropping a fraction of neurons during training

3) Model Training:

Here we try to apply model training and then find the accuracy of our proposed model.

- Loss Function: Define an appropriate loss function, typically categorical cross-entropy for multi-class classification, to measure the difference between predicted and actual disease labels.
- Optimizer: Select an optimization algorithm (e.g., Adam, SGD) to minimize the loss function and update network parameters during training.
- Hyperparameter Tuning: Experiment with hyperparameters[11] such as learning rate, batch size, and the number of layers/neurons to optimize model performance.
- Training: Train the CNN using the training dataset and monitor its performance on the validation set. Training may involve multiple epochs.

4) Evaluation Stage :

In this stage we try to check the performance of our proposed model using some sample test data and then check the performance metrics.

- **Testing:** Assess the model's performance on the separate testing dataset to evaluate its accuracy, precision, recall, F1-score, and other relevant metrics.
- **Confusion Matrix**: Analyze the confusion matrix to understand how well the model classifies different diseases and distinguish between false positives and false negatives.
- **ROC Curve and AUC:** If applicable, plot Receiver Operating Characteristic (ROC) curves and calculate the Area Under the Curve (AUC) to evaluate classification performance.

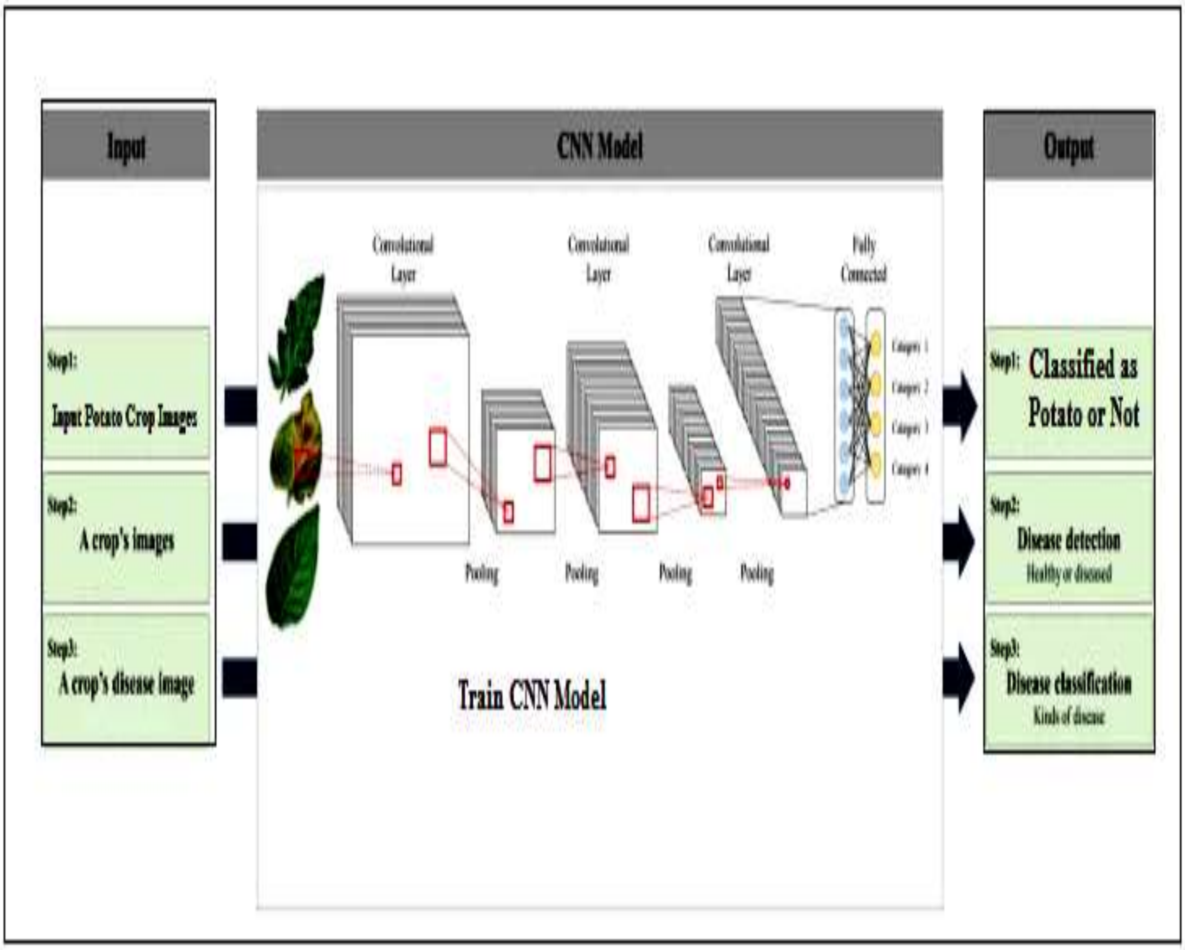


Figure 2. Represent the Proposed CNN Architecture of Potato Leaf Disease Detection

We can see from Figure 2 that the CNN model[12] has an input layer, hidden layers, and an output layer. Here, we try to load crop photographs as input and then determine whether it is a potato crop or not, as well as whether any disease is present on that leaf. Here, we try to process the input image with numerous hidden layers and then see whether any disease has been detected.

5. RESULTS AND DISCUSSIONS

In this section,we try to construct CNN model on potato crop images dataset using Python as programming language and google collab as platform to execute the model.

Load Dataset

```
# import libraries
import tensorflow as tf
from tensorflow.keras import models, layers
import matplotlib.pyplot as plt
import numpy as np
import pathlib
import os
os.environ['TF_CPP_MIN_LOG_LEVEL'] = '2' # to disable all deb
ugging logs

# importing dataset
dir = os.listdir('../input/plant-village/PlantVillage')
for filenames in dir:
    print(filenames)
```

Explanation: From the above window,we can clearly identify important libraries are loaded and then dataset is also imported.

Dataset Pre-Processed

```
#Folders(classes) in 'Dataset' directory
class_name = dataset.class_names
class_name

['Potato___Early_blight', 'Potato___Late_blight', 'Potato___healthy']

len(dataset) # Number of Batches = (total number of files belonging to all cl
asses / Batch_Size)
```

Explanation: We are able to see from the above window that the dataset may comprise photographs of multiple crops, and in our present model, we are trying to identify potato diseases.As a result, we separated potato crop photos [13] and then classified them into various datasets.

Plotting the Image

```
# Plotting the image
plt.figure(figsize = (15,15))
# dataset.take(count) : Creates a Dataset with at most 'count' elements(batch) from the dataset
for image, label in dataset.take(1):
    for i in range(12):
        plt.subplot(3, 4, i+1) # many plots at a time ==subplots
        plt.imshow(image[i].numpy().astype('uint8')) #converting all data of image into numpy
and than to intiger type as they were in float.
        plt.title(class_name[label[i]])  # title of the class_name of image
        plt.axis("off") # Hide the values of graph
```

Explanation: Once the dataset is pre-processed, sample photos are plotted, and all of the images are potato leaf images sorted into three categories: healthy leaves, late blight, and early blight.

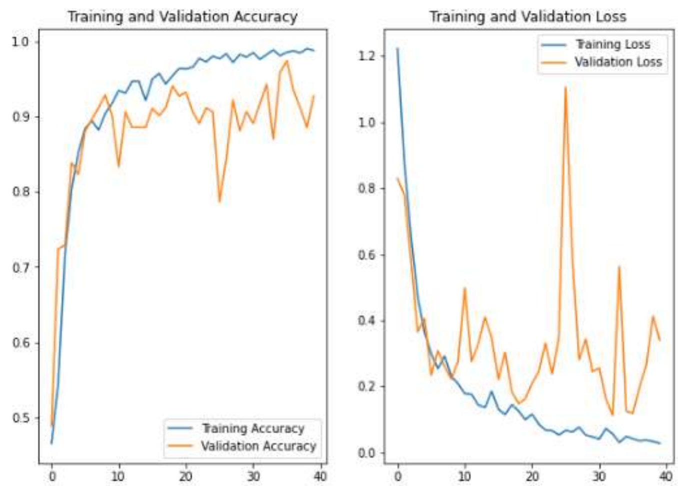
Build CNN Model

```
# Creating Convolution layer
input_shape = (Batch_Size, Image_Size, Image_Size, Channels)
model = models.Sequential([
    resize_and_rescale,
    data_augmentation,
    layers.Conv2D(filters = 16, kernel_size = (3,3), activation = 'relu',
e),
    layers.MaxPool2D((2,2)),
    layers.Conv2D(64, (3,3), activation = 'relu'),
    layers.MaxPool2D((2,2)),
    layers.Conv2D(128, (3,3), activation = 'relu'),
    layers.MaxPool2D((2,2)),
    layers.Conv2D(64, (3,3), activation = 'relu'),
    layers.MaxPool2D((2,2)),
    layers.Conv2D(128, (3,3), activation = 'relu'),
    layers.MaxPool2D((2,2)),
    layers.Conv2D(64, (3,3), activation = 'relu'),
    layers.MaxPool2D((2,2)),
    layers.Flatten(),
    layers.Dense(128, activation = 'relu'),
    layers.Dense(64, activation = 'softmax'),

])

model.build(input_shape = input_shape)
```

```
10/10 [==============================] - 0s 12ms/step - loss: 0.0427 - accuracy: 0.9967
```

Explanation: Here we try to build the CNN model by taking activation function as "relu".Here we got an accuracy of 99.67 % which is more accurate compared with several other pre-trained models.

Training and Validation Accuracy/Loss



Explanation: Here we can see both training and validation accuracy along with loss,which is almost having accuracy near to 100 % and loss of 0.42 % on the potato crop image dataset.

6. CONCLUSION

In conclusion, the use of Convolutional Neural Networks (CNNs) to identify potato leaf disease is a promising and new strategy in modern agriculture. This method uses deep learning to automate the identification of illnesses in potato plants, providing numerous major benefits. The CNN model, trained on a broad collection of potato leaf pictures, exhibits outstanding accuracy in distinguishing between healthy leaves and those affected by various diseases. Even with insufficient data, the model may adapt and generalize well using approaches such as data augmentation and transfer learning. CNN-based disease detection has a significant potential influence in potato farming. It provides early disease detection, which is critical for executing timely crop yield protection treatments. We can improve crop management methods, minimize pesticide use, and increase overall agricultural sustainability by providing farmers with a powerful tool for monitoring the health of their potato plants. However, it is critical to recognize that the performance of CNN models in illness diagnosis is dependent on variables such as data quality, model architecture, and ongoing monitoring and updates. Collaboration among researchers, agricultural specialists, and technology developers is critical to the ongoing refinement and practical application of these models in the field. Integrating CNN-based disease detection systems with other new technologies, including as Internet of Things (IoT) sensors and mobile applications, has the potential to transform potato farming and promote precision agriculture in the future. These innovations, when combined, have the potential to contribute to more efficient, sustainable, and resilient potato production systems, ultimately benefiting both farmers and consumers worldwide.

CONFLICT OF INTEREST

The author declares there is no conflict of interest.

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