VGG16-PotatoGuard: A Deep Learning Approach to Detecting Leaf Diseases in Potatoes

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***Abstract*— Potato cultivation plays a pivotal and exceedingly significant role in global agriculture, serving as an indispensable staple food source for millions of people around the world. Nevertheless, the sustained well-being of potato crops faces incessant threats from a myriad of diseases, exerting a pronounced and adverse influence on both yield and quality. In recent years, the domain of machine learning, particularly the realm of deep learning, has emerged as a formidable arsenal of tools for the early identification and diagnosis of potato leaf diseases, simultaneously ensuring a remarkable level of precision and accuracy in the executed model. This comprehensive review paper undertakes the task of presenting a thorough and all-encompassing overview of the state-of-the-art within the sphere of machine learning applications specifically designed for the classification of Potato Leaf Disease (PLD). While a multitude of models may be conceivably deployed for this purpose, this review paper meticulously directs its focus toward the exploration and examination of deep learning-based projects. The extensive research conducted in this domain, albeit following various trajectories, collectively aids in arriving at a resounding consensus on the development of an efficacious model and a highly effective technique to combat and mitigate such devastating diseases that cast a shadow on the health and vitality of the potato plant. All of these meticulously considered steps are meticulously examined and weighed in the tapestry of research endeavors.**

***Keywords*: VGG16, potato leaf disease, deep learning, machine learning, potato cultivation, agriculture**

I. INTRODUCTION

Agriculture is the most common occupation in the world. Indian economy with such a massive population is highly reliant on this occupation. Potato secured its place as the fourth largest agricultural food crop after maize, wheat, and rice and India proudly takes the spotlight as the world's second-largest producer of potato crops. Countries like India directly or indirectly are economically dependent on agriculture. India produces an annual potato yield of 48.5 million tonnes. The study in the field of plant growth involves observing the biochemical and biophysical characteristics of the plant. The levels of chlorophyll and nitrogen influence the growth of plant leaves. Moreover, provides insights into stress levels and nutrient availability in plant leaves. India's agricultural landscape is enhanced with various crops and among them stands the mighty potato. With over three-fourths of the population incorporating potato in their daily diet, potato has earned its status as one of the most India's top yielding crops. Uttar Pradesh emerges as India's primary potato producer with a contribution of more than 30.33% to the total production. Indo-Gangetic plains in North India host the cultivation of about 85% of the total crop production produced by India. The crop thrives in a variety of agro-climatic conditions, maintaining its presence in almost every state of the country. This resilient crop flourishes in diverse agro-climatic conditions.

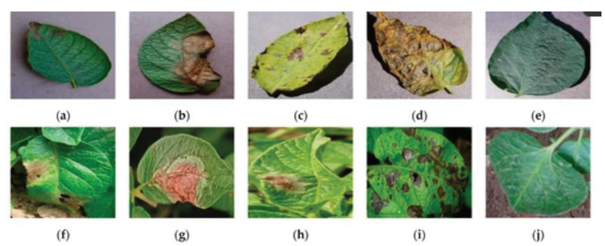

Fig. 1. Examples of PLDD images. (a) Early stages of late blight leaf in a single context. (b) End stages of late blight leaf in a single context. (C) Early stages of early blight leaf in a single context. (d) End stages of early blight leaf in a single context. (e) Healthy leaf in a single context. (f) Early stages of late blight leaf in a natural context. (g) End stages of late blight leaf ina natural context. (h) Early stages of early blight leaf in a natural context. (i) End stages of early blight leaf in a natural context. (j) Healthy leaf in a natural context.

Therefore, plant health is very crucial. Unfortunately , potato leaf diseases are primarily caused by fungi and bacteria. Some are fungal like early blight and late blight also known as Phytophthora Infestans and Alternaria solani respectively in scientific terms. Soft rot and common scab are bacterial. Identification and classification of these diseases will, fortunately, lead to no yield and financial losses.

The necessary identification of these diseases has been performed by the same methodology for decades which is the human eye which has no guarantee to identify in the required time and correct identification. But to avoid any further losses there is an urgent need to change this way of identification. The image analysis methodology can be a boon in this case. Diseases on plant leaves will cause patches and scars on the leaf which can be easily identified by pictures. One way to

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identify through pictures is to compare it with the historical data of the leaf patterns stored and identify the problem. This methodology will be efficient and easy to work upon and the stored instances will be fruitful in fulfilling the required need. The identification and diagnosis of identification of these diseases in essential vegetation fuel has turned out to be an automatic strategy. This approach aims to boost crop yield, bolster farmer profits, and deliver a substantial impact on the nation's economic growth.

The resulting diseases in fruits and plants have resulted in decrease in quality and quantity of crops. The population that suffers the most due to this issue are the farmers as there are various diseases that happen to occur in these leaves. Sometimes herbalists are unable to diagnose the infection in the plant leaves which leads to no proper treatment and crop damage. .

A. *Symptoms of Early Blight and Late Blight*

The term early and late refers to the relative time of appearance of the disease. Both of the diseases actually correspond to the same disease just at different stages of the disease cycle.

Early Blight is also known as target spot. It generally does not attack young leaves they attack older leaves first and infect them. Early blight emerges in the environment that marks an increase in temperature and humidity. Initially can be seen as small, dark, dry, papery flecks, evolving into brown-black, circular to oval areas. The spots afterward take an angular shape, creating a pattern consisting of concentric rings of raised and depressed dead tissue. As infection advances on the lower part of the leaves where it occurs in the early stage and makes the spot grow wider turning the complete leaf yellow and eventually dead. Even after destroying the whole leaf, the infection can pass on to the stem also.

Late Blight is the worst potato disease. It advances itself in the environment of its favorable conditions like cool and moist weather that can infect the plant completely and make it dead in just two weeks if conditions tend to remain the same. The initial effects mark the onset of small, irregular-shaped spots on leaves exhibiting hues from pale to dark green. These are often rings from pale green to yellow tones. Continuing the conditions advancing infection with an occurrence of white fungal growth on the perimeter of the affected leaves emitting an unbearable odor.

B. *Prevention of Early Blight and Late Blight*

The prevent the diseases like Early Blight we need to keep some things in consideration healthy plants are not much vulnerable to this type of disease so we need to take proper care of the plants, this could be done by avoiding overhead irrigation to the plants. We should not harvest them into the fields until and unless they reach their full maturity stage and do not use the same field that was used last year for the production of either tomatoes or potatoes. Now produce the crops at least 225 to 450 yards away from last year's used field. Moreover, use of low phosphorous levels so that the disease doesn't reach its severity level.

For the prevention of diseases like Late Blight, we need to take care of some points like the use of disease-free seeds for potatoes to reduce the risk of disease emerging in plants. And take special care of waste management in the surrounding areas by the potato plants to protect the plants. Remove any tubers that show any evidence of disease to prevent the spread at the time of storage .

II. Literature Review

Potato is a food crop holds a great importance all over the world. To detect the disease just by analysing the leaves images weather leaf is Healthy leaf , Early-Blight leaf or Late-Blight leaf is a ongoing research. The main goal of all the research is to detect the disease at early stage. The reason behind this is to provide a immediate cure and solution so that the crop damage can be prevented. If the disease can be detected at early stage a proper treatment can help in preventing loss and increasing the production of potatoes. All the research in disease detection is to predict the disease with high accuracy. Living in a world where technology is the future , finding solution of the problem through traditional methods in quite inefficient. The traditional methods are time consuming , unreliable and costly. Research has been done and Machine Learning and Computer Vision proven to be a better option and solution in a agriculture sector. A number of models has been introduced. Some examples of different models being worked on to detect the diseases in potato and many more crops are CNN (Convolutional Neural Network), VGG-16, ResNet-50 , CVT.

The [1] research paper in "International Journal of Progressive Research in Science and Engineering" highlighted the need better approach for for disease detection in potato crop. Potato is one of highly consumed crop all over the world its production need to be increased as per the the consumption rate. In modern days how the crop is being affected by the disease can't be leftover to the visibility of naked eyes. It need to be detected at early stage for proper treatment. Young farmers should have proper and early knowledge of disease infecting the crop. This need to be done to increase the quality and quantity of crop. The study also suggests the various approaches for disease detection in potato leaf. From the models used for comparison like CNN. K-Means clustering , Random Forest, and proposed system(using HOG) the proposed system gained the highest accuracy while predicting the results of the testing dataset.

The research [2] implemented the kNN model including the [16] Artificial Neural Network which performs the steps. After image acquisition the segmentation is performed through kNN. Features extracted are used for model training to classify the target spot of leaf in future.This model resulted the average accuracy of 92.5% . From the accuracy we can further conclude that their is need for an improvement.The limitation of kNN model is that the result is dependent on K and it need to be dealth with. The model introduced by author[3] the k is generated by model only , makes it more efficient than regular kNN model. Model evaluates the class of data based on the multiple values of k. This makes the result independent of the exact value of K.Even this model have limitation as it can only work if their are less number of classification classes.

One such study[4] proposed a model ICVT (Inception Convolutional Vision Transformer). This model has been trained on 224 x 224 image dataset. The ratio distribution of training dataset and testing dataset is based on the the different dataset only . The researchers introduced various elements in this model to work efficiently to detect disease in a plant leaf. The model has been introduced in four parts- Soft Split Token Embedding , Depth-wise convolutional transformer block , Inception transformer block and ICVT with transfer learning. Every part contributes for the betterment and accuracy of plant leaf disease detection. The depth-wise convolutional transformer block concept is implemented by researchers as it helps in coll. Another part which is Inception transformer block is used by researchers as it is more successful in analysing the finest features on leaf and also quite efficient in giving deep focus on local spatial context information. And finally the transfer learning is to implement the model on any given dataset where the number of layer changes based on the number of categories of diseases . This helps to overcome the situation of overfitting and under-fitting.

The study [5] aims to investigate the best model for the potato leaf disease detection. For this researchers made a comparison between different methods - k-NN(k-Nearest Neighbour) , LR(Logistic Regression), [14] SVM (Support Vector Machine) and ANN (Artificial Neural Network) . Researchers first worked on Image Processing like converting a image to gray-scale to reduce the processing time and using Gaussian filters to reduce the noise. Then researchers worked on Feature Extraction and Feature Selection. Here researchers included 30 features groups among 150. This was performed to reduce time and complexity. After applying model to it the result was evaluated through Accuracy, Sensitivity and Specificity. Researches observed k-NN holds 83.39 % accuracy , LR 89.72% , ANN 92.54% and SVM 99.75 % .Through the resultant accuracy researchers determined that SVM was much more efficient than any other algorithm and is much better for the potato leaf disease detection. Also it has been observed from all the mentioned classifiers that SVM also exhibits high sensitivity it means SVM is more capable of detecting true positive than any other mentioned. To be assure by the results cross-validation being performed by 10 processes. Even the study[6] depicts the importance of SVM as it is the model which can deal with multi-dimensional data. It signifies that while dealing with real life example where we cannot classify the data into classes SVM transfers from low dimensional space to high dimensional space to look for hyperplane. Comparing to other models it is a huge advantage . Another advantage where SVM leads is it works in very structured way . Even if the dataset size is small SVM can work in methodical way. Our aim is to analyse the model more precisely. As mentioned researchers decreased the features to a large extent for ease. This also can affect the results as some features which could have been impacted the results were not considered.Our aim to consider a features as much as possible for more appropriate results. [14] This could be achieved through CNN (Convolutional Neural Network) by implementing it.

Deep Learning is a field which gained more popularity in smart farming . As per the work [7] Deep Learning is considered more reliable and over period of time getting more efficient in terms of prediction and Accuracy. The research article outlines reason behind its wide implementation is a multiple layer of implementation and deep model. Deep Learning is implemented using the model known as CNN (Convolutional Neural Network)[15]. It generates the complex model suitable for precise analysis. Deep Learning models facilitates the self learning Feature. It can automatically detect the most significant features.Challenges which the author addressed is that the fusion designs of leaves, location of stems , brightness ans luminosity and environmental factors. These factors create a intersection of features and noises where the distinguishing the descriptors accurately becomes challenging. One more challenge that author mentioned is the predicting and analysing the blockage in real time. To concur this challenge it becomes highly important to study neural network, training the model through past knowledge and preparing human visual perception model .Limitations that author addressed of a Deep Learning model is that it required a large amount of pre-labelled data to classify the the image ,it required a high computational power and resources to run model efficiently and it is likely possible that model.

Another study [8] where researchers implemented the Deep Learning approach to classify the Potato Leaf Disease. Here researchers focused on the practical implementation of a Deep Learning concept. To create a model researcher used CNN(Convolutional Neural Network). Here researchers followed a four methodical steps like Data gathering , Data preprocessing , Data Augmentation and at last the Classification. The work has been done on dataset expansion . Apart from using a Kaggle dataset researchers collected 7848 images directly from the potato crop field. Large dataset helps in proper training and testing of a model as model gets more prepared for real time data. Another way to make model ready for upcoming data is data Augmentation. It is just looking a image in various ways either by scaling , rotating, flipping and transforming . Here CNN model consist of various layers [15] first an input layer, secondly the convolutional layer, after then the pooling layer then the output layer . Even the dropout layer is used to avoid overfitting. Here the Accuracy has been compared by researchers at various epochs values. The results shows the best performance at 40 epoch value.

Applying multiple models in different research and studies can increase the risk of overfitting the model and create hurdles in actually getting up accurate results. One of the reasons for an overfitting model must be the lack of images in the dataset. In study[9] the model has used 900 images to train the model and 300 to validate the model. In the data preprocessing procedure the data is augmented to increase the quantity of data. In the process, creation of various authentic variations and added up to the initial dataset. Used various CNN architectures like GoogleNet, and Resnet and checked accuracy for the various dataset images. The accuracy rate observed in this study is 97% helping to identify the disease in a very early stage. After the accuracy detection by different models, Google Net turns out to be the best accuracy model in the final 50 epochs but not initially while VGG16 has the worst accuracy detection and processing time.

The upcoming new technologies have been the resolution to various emerging daily life issues. Likewise the implementation of Machine Learning on Mobile Phones, multiple IOT devices, cameras. And thus machine learning is implemented to detect the infection in potato plant leaves. I t allows to take the precaution by early phase identification. The study followed in [11] uses a dataset a package of 2152 different images of potato leaf in different sizes , shapes. The treatment of both disease differs so we need to efficiently identify the type of disease caused in the leaf. The model proposed in the study follows the following steps processing the leaf images of the potato dataset then splitting up the dataset followed by training the CNN model followed by training CNN model and evaluation process. The following model has attained the accuracy of 34.6% in identifying the images.

For whole classification of images of leaf to a Healthy , Early Blight and Late Blight in real time required a YOLO and then through that image analysis is done .Also now days classification is highly computational task. To perform so a proper interconnected software tools along with framework are required to implement the model. The researchers [13] introduced a platform NiftyNet. This is platform where image analysis can be dome easily. It is comprises of features to visualize image and contains frameworks and layers as component. It can be concluded that it is future of image processing and visualization , now is at early stage.

III. Methodology

Recognized as a fundamental and universally consumed crop, the potato serves as an indispensable cornerstone in safeguarding global food security. However, the vast realm of potato agriculture faces a persistent and looming threat: potato leaf disease. These diseases, arising from a diverse array of pathogens, not only inflict a detrimental toll on crop yields but also cast a shadow of compromise over the quality of harvested potatoes. To prevent such massive losses, it is imperative to develop technologies that enable the early detection of potato leaf diseases, empowering farmers to implement preventive measures and mitigate extreme losses. In the agricultural field, [16] artificial intelligence plays a crucial role in these endeavors. Due to changing climatic conditions and the scarcity of natural resources, maintaining crop health and protection from damage has become increasingly challenging. In response, a plethora of innovative technologies has emerged in the field of agriculture, including crop and soil monitoring, predictive analysis, livestock health monitoring, intelligent spraying, and insect and plant disease detection. Insect and plant disease detection, in particular, has become a recent focus of machine learning research, with the aim of developing predictive models to combat agricultural losses caused by such diseases. In this case, we studied potato leaf disease detection using a dataset from Kaggle [reference]. Our dataset is broadly divided into three folders: valid, test, and train. Each folder contains three categories of image data: Potato____healthy, Potato____late_blight, and Potato____early_blight.

Data visualization is being performed on image data within these three categories. The general steps included in machine learning for building any machine learning model are as follows:

- Define the problem
- Collect and prepare the data
- Choose a machine learning algorithm
- Train the model
- Evaluate the model
- Tune the model
- Deploy the model
- Monitor the model

After defining the problem, which is to predict the category of an image from the three mentioned categories, namely ”Potato__healthy,” ”Potato__early_blight,” and ”Potato__late_blight” using images, the next step is collecting and preparing the data. Data visualization is a valuable technique for data preparation and data analysis, enabling the study of data to create an appropriate model based on image pixel quality for image classification in such cases.To select the optimal parameters for configuring the prediction model, data visualization plays a crucial role.

In this case we could see the histogram created to compare the pixel intensity to number of pixels in common and also 3 different histograms reflecting pixel intensity in the green channels for Training, Testing and valid dataset respectively. After studying the graph properly which reveal valuable information about the distribution of intensity value in the images. The green channel represents the intensity of green light reflected from the object image which plays crucial role in capturing the natural color variation of plants and leaves. Common interpretation of image characteristics can be used to select appropriate model for image classification.

After data is processed and data visualization is performed the next step is to choose a machine learning algorithm such as Logistic regression, Support Vector Machine (SVMs), K-nearest neighbors (KNN), Decision trees, Random forests, Convolutional neural networks (CNNs). The best algorithm for image classification with three classes will depend on the specific task and the dataset. However, CNN are typically the most accurate algorithm for this type of task in general there are several layers of CNN model that can be implemented

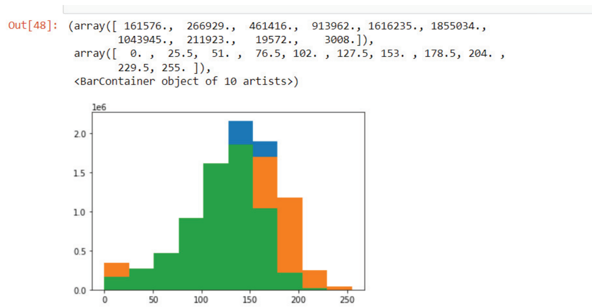

Fig. 2. Histogram of the pixel intensities in the green channel of the images for Training dataset.

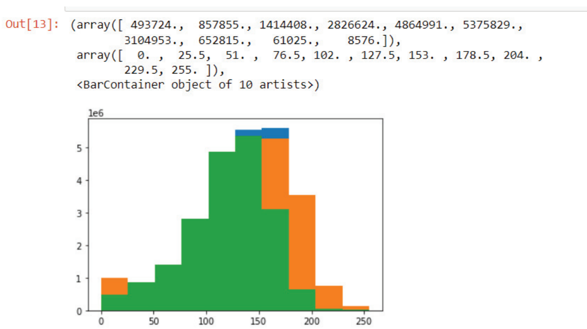

Fig. 3. Histogram of the pixel intensities in the green channel of the images for Testing dataset.

to perform image classification some of them are pre trained and few are untrained model which need to be trained from the start. Below table summarizes the strengths and weaknesses of each algorithm.

This paper includes study made by implementing VGG16 architecture based model with few of the customized classification layers. It uses pre-trained VGG16 weights from ImageNet, as the dataset that model is to be implemented on is image dataset with 3 classification of images namely Potato___healthy, Potato___late_blight, and Potato___early_blight which shows the importance of implementing such a model which is suitable for image classification and also keeping in mind the number of images pre trained models fit best as we don't have enough of the dataset to implement any model from scratch. Global average pooling is applied to the output, followed by a dense layer with 1024 neurons and ReLU activation. The model also implements final dense layer which has 3 neurons with softmax activation for multi-class classification. Pre-trained layers are frozen to retain their weights. Adom optimizer is used to compile the model, categorical crossentropy loss, and accuracy as the metric.

IV. Limitation

Despite the promising result, our model has few limitations that can be overcome and which create a scope for future work on this same model for classification. Model's validation accuracy of 77.78% is still lower than the training accuracy of 85.83%. Suggesting that the model may not be

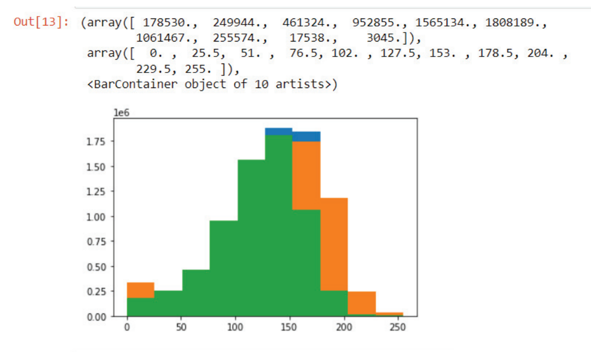

Fig. 4. Histogram of the pixel intensities in the green channel of the images for Valid dataset.

fully generalizable to new data. Model was trained on small dataset of potato leaf images. This could limit its ability to generalized to new data and could also make it more susceptible to overfitting. The histogram shows the pixel intensity which shows quality of image that can affect the model's performance. Images that have low pixel intensity which are blurry, noisy, or poorly lit may be more difficult for the model to classify accurately. For future study to increase the model validation and accuracy recommendations parameters that one could work on are-

- Collect a larger dataset of potato leaf images to improve the model's generalizability.
- Data argumentation plays important role in increasing model efficiency, argumentation techniques to increase the size of the training dataset and reduce the risk of overfitting.
- Preprocess the input images to improve their quality and make them more consistent.
- Different layers which are implemented and classification layers can be modified to increase the efficiency of working model parameters of VGG16 model can be manipulated accordingly.

V. Result

This machine learning model is designed for the detection of Potato leaf diseases, focusing on classifying leaves into three categories: healthy, late blight, and early blight. Our decision to employ a pre-trained model stems from observations during data visualization and pixel graph plotting, suggesting that a pre-trained model would be more suitable. Traditional models like CNN might risk underfitting, and, therefore, we have opted for the VGG16 model. The versatility of VGG16's layers allows for effective augmentation and adaptation to our specific classification needs.

The model after the 5 epochs for training it according to the VGG16 model implementation we get the accuracy of 85.83%. As the model is pre Trained initially the loss was quite great but it steadily decreases throughout the training, indicates the correct image classification this is the result that we got for training performance for our model. For validation performance accuracy reaches to 77.78% on the validation dataset which suggests that the model has generalized well to unseen data. The model appears to be well performing on bases of both training and validation. It is likely that the model will be able to classify potato leaf disease accurately on new images. . After performing the evaluation of trained model on the test dataset we get test accuracy of 0.87999 (87.99 %) and test loss of 0.28396. After running plotting training and validation loss and training and validation accuracy we could easily see variation of accuracy and loss with each epoch.

```
In [15]: import matplotlib.pyplot as plt

         # Plot training and validation loss

         plt.plot(history.history['loss'], label='Training Loss')
         plt.plot(history.history['val_loss'], label='Validation Loss')
         plt.title('Loss across Epochs')
         plt.xlabel('Epoch')
         plt.ylabel('Loss')
         plt.legend()
         plt.show()
```

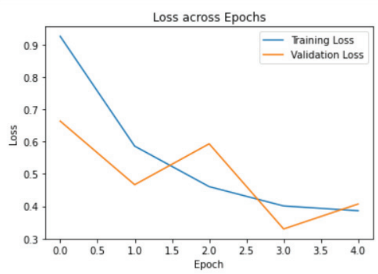

Fig. 5. Plot showing training and validation loss

```
In [16]: # Plot training and validation accuracy
         plt.plot(history.history['accuracy'], label='Training Accuracy')
         plt.plot(history.history['val_accuracy'], label='Validation Accuracy')
         plt.title('Accuracy across Epochs')
         plt.xlabel('Epoch')
         plt.ylabel('Accuracy')
         plt.legend()
         plt.show()
```

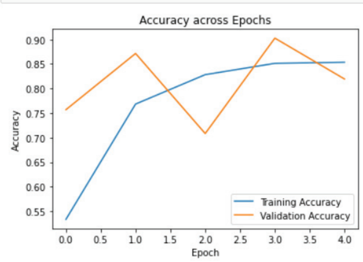

Fig. 6. Plot showing training and validation accuracy

TABLE I
COMPARISON OF DIFFERENT MODELS

Ref.	model	Accuracy	loss	val_accuracy	val_loss
1	VGG16	0.853	0.385	0.819	0.406
2	DenseNet	0.799	0.355	0.822	0.291
3	ResNet	0.785	0.302	0.619	0.496
4	CNN	0.533	0.602	0.407	0.662

VI. CONCLUSION

Overall, the classification model shows promising result, the model starts with accuracy of around 53%, and over the course of five epochs it improved significantly also the validation accuracy follows the similar trends, reaching around 82%. The training loss decreases from 0.93 to 0.39, which clearly concludes that the model is successfully minimizing the difference between predicted and actual values. While looking at the plots for accuracy and loss we can also conclude that though training accuracy is improving, it does not show sign of overfitting but still there could be sign of overfitting due to significant gap between training and validation performance. It's advisable to further analyze the model's performance on additional unseen data to assess its generalization capabilities. Techniques such as data argumentation, regularization, or adjusting the learning rate to potentially enhance model performace.

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