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Tomato Leaf Diseases Classification using Deep Learning

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Abstract: *Tomatoes are among the most popular vegetables in the world due to their frequent use in many dishes, which fall into many varieties in common and traditional foods, and due to their rich ingredients such as vitamins and minerals, so they are frequently used on a daily basis, When we focus our attention on this vegetable, we must also focus and take into consideration the diseases that affect this vegetable, a deep learning model that classifies tomato diseases has been proposed. The aim of this paper is to diagnose tomato diseases based on a dataset containing 11000 picture and 11 classes. The model gave the final accuracy test with Accuracy (99.87%), F1-score (99.87%), Recall (99.87%), and Precision (99.88%) in an estimated time 1.36 second, as with these results it proved its effectiveness and good ability in the classification of the testing data.*

Keyword: Tomato, Deep Learning, Classification, EfficientNetV2B0, CNN.

1. Introduction

Tomato is a popular fruit that is widely used in cooking. They are native to South America and are members of the nightshade family. Tomatoes are usually round or oblong in shape and red in colour, although there are other varieties coloured yellow and green. The fruit is juicy and has a sweet and acidic flavour [1]. Tomatoes are considered one of the good sources of minerals and vitamins, including potassium and vitamin C. It is often used in salads, sandwiches, sauces, and other dishes and is a key ingredient in many different cuisines around the world. In addition to eating fresh tomatoes, tomatoes can also be canned, dried, or made into juice or paste. As for the diseases that affect this fruit, the common diseases are many and varied.

To prevent tomato diseases, it is important to grow disease-resistant varieties, rotate crops, and practice good hygiene. By removing and destroying infected plants. [2], common tomato diseases are “bacterial spot, early light, late light, leaf, downy mildew, two-spotted spider, target, blight, tomato, virus, tomato, virus, health virus [3], To name a few. They have diseases such as powdery mildew.” Early blight: It is caused by a fungus called Alternaria solani and is characterized by circular dark spots on the leaves and stems of the plant. Late blight: It is caused by a fungus called Phytophthora infestans and is characterized by large, dark, water-soaked spots on the leaves, stems and fruits of the plant. Tomato mosaic virus: caused by a virus and characterized by mottled or deformed leaves and stunted growth. Fusarium wilt: This is caused by a fungus called Fusarium oxysporum and is characterized by yellowing of the lower leaves and wilting of the plant. Verticillium wilt: This is caused by a fungus called Verticillium dahliae and is characterized by yellowing leaves and wilting of the plant [3].

When it comes to technology in general and deep learning in particular in disease diagnosis, we will turn to neural network technology, which is a subset of Machine Learning (ML) [4]-[10], and it is at the basis of deep Learning Algorithms (DL) [11]-[14] that consist of layers of nodes, which contain one input layer and one or more hidden layers and one output layer. In a network, nodes are connected to one another and have assigned weights and thresholds [15]-[16]. If the output from a node exceeds its specified threshold, the node is triggered and sends information to the subsequent layer. However, if the output remains below the threshold, no information will be transmitted to the next layer [17]-[19].

We find that the classification of these diseases based on the deep learning model, specifically Convolutional Neural Networks (CNN), is much easier than human forces, while saving time, effort, and even accuracy in classification, especially since our model classifies eleven diseases [20]-[23]. It is common for the tomato fruit to give an accuracy test of up to 99.87% with an almost non-existent error rate, so we tried as much as possible to bring a modern, comprehensive and accurate data set in order to provide good information and reliable results, so we find that deep learning is a strong future trend that can be relied upon strongly, considering the machine learning approach that emulates the human capability of learning through examples is called deep learning [24]-[29]. This technology powers self-driving cars to identify traffic signs such as stop signs, and to differentiate between a pedestrian and a lamppost [30]. Which is exactly what we mean in diagnosing tomato diseases. To explain more about our model, a dataset containing approximately 11,000 images in 11 categories, with an accuracy of 99.87%.

2. RELATED WORK

There are many studies that were used in the classification of tomato leaf diseases that employed a number of deep learning and machine learning methods. Different datasets were used for the problem of classification. Some studies used mainly the accuracy for the evaluation metrics and others utilized different metrics like F1-score, Precision, and Recall. The accuracies attained the previous studies vary from 83.06% to 99.64%.

In the study [1] they used MobileNet, VGG16, ResNet101 and ResNet50 for the classification of tomato leaf disease. The dataset they used was collected from the internet images and the best accuracy achieved was 99.64%.

In the study [2], they used Deep Neural Network (DNN) to classify the tomato leaf disease using the plant village dataset. The accuracy they attained was 86.00%.

In the study [3] they employed RsNet50 for the classification of the tomato leaf diseases using plant village dataset and the accuracy attained was 86%.

In the study [31], the authors employed three CNN models: AlexNet, SqueezeNet, and InceptionV3. The dataset was Plant Village and the best accuracy achieved was AlexNet (93.40%), SqueezeNet (90.76%), and InceptionV3 (90.43%).

Most of the previous studies like [1]-[3], [31]-[37] used Convolutional Neural Networks (CNN) methods and study [38] used machine learning techniques.

A complete summary of the previous studies in terms of Year of publication, methods used, performance metrics, dataset, and accuracy attained (Table 1).

Table 1. Summarizes the previous studies in term of method, performance metric, dataset and accuracy used

Reference	Year	Method used	Performance metrics	Dataset	Accuracy (%)
[1]	2019	ResNet101, VGG16, and MobileNet, ResNet50	Average precision	Internet images	99.64%
[2]	2021	DNN	Accuracy and loss rate	Plant Village	86.00%
[3]	2020	ResNet50	Accuracy	Plant Village	97.00%
[31]	2020	Inception V3, SqueezeNet, AlexNet,	Accuracy, recall, F1-score	Plant Village	InceptionV3: 90.43%, SqueezeNet: 90.76%, AlexNet: 93.40%
[32]	2020	ResNet and U-Net	Accuracy	Plant Village	94.00%
[33]	2020	Inception V3	F1-score, recall, precision	Private	InceptionV3: 99.60%
[34]	2020	CNN	F1-score, recall, precision	Plant Village	91.20%
[35]	2020	CNN	F1-score, recall, precision	Private	98.46%
[36]	2017	R-CNN	F1-score, recall, precision	Private	83.06%
[37]	2020	Extreme Learning Machine (ELM)	Accuracy, AUC	Tomato powdery mildew dataset	89.19%
[38]	2020	LR, SVM	Accuracy, F1- score, AUC	Tomato powdery mildew dataset	92.73%

3. Study Objective

The objective of classifying tomato leaf diseases is to accurately identify and diagnose the specific disease affecting the plant. This helps in:

- Selecting appropriate treatment and control measures: Accurate diagnosis of a disease is essential in order to choose the most effective control and treatment measures.
- Improving crop yield and quality: Proper diagnosis and control of diseases can help in improving crop yield and quality.
- Preventing spread of diseases: Classifying tomato leaf diseases can help to prevent the spread of diseases from infected to healthy plants.
- Increasing farmer's profitability: Effective disease management through accurate diagnosis and control can help increase farmer's profitability.

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- Improving understanding of plant pathology: Classification of tomato leaf diseases can also contribute to a better understanding of plant pathology, which can be useful in developing more effective control measures in the future.

Overall, the classification of tomato leaf diseases plays an important role in the sustainable production of tomato crops and helps in protecting the interests of farmers, consumers and the environment.

4. Methodology

4.1 Dataset

A balanced data set was collected from Kaggel [40] containing approximately 11,000 images divided between training, testing and validation sets, in 11 classes: Target Spot, Late blight, Leaf Mold, Spider mites Two-spotted spider mite, leaf spot, Septoria, Tomato mosaic virus, Tomato Yellow Leaf Curl Virus, powdery mildew, Early blight, healthy and Bacterial spot. Figure 1 illustrates the different classes of the tomato leaf diseases.

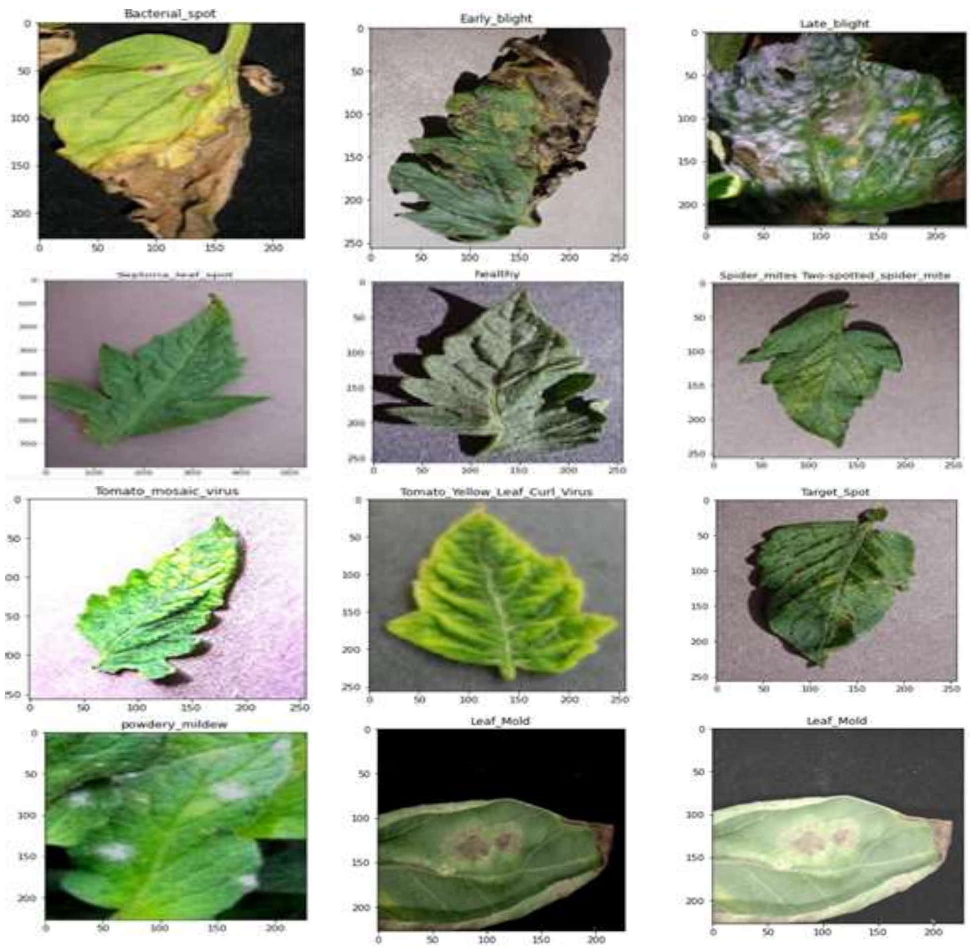

Figure 1. Samples of the dataset

4.2 Proposed Model

The proposed model is the fine-tuned model EfficientNetV2B0. EfficientNetV2B0 is a type of deep learning model for image classification. It is a variant of the EfficientNet architecture, which was introduced by Google in 2019. The "V2" in the name indicates that it is a version 2 of the original EfficientNet architecture, while the "B0" indicates that it is the baseline version of the model [40].

The EfficientNetV2B0 model is designed to be both accurate and efficient, making it suitable for deployment in real-world applications. The model uses a combination of depthwise separable convolutions, squeeze-and-excitation (SE) blocks, and a novel scaling method to achieve improved accuracy and efficiency compared to other architectures.

EfficientNetV2B0 has been trained on a large image dataset and can be fine-tuned for specific tasks, such as image classification, object detection, and semantic segmentation. The model has shown excellent performance on a variety of

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benchmark datasets and is widely used in a range of computer vision tasks.

Overall, the EfficientNetV2B0 model is a powerful tool for image classification and is well-suited for deployment in real-world applications due to its combination of accuracy and efficiency.

4.3 Proposed model Architecture

EfficientNetV2B0 consists of several components that work together to perform image classification tasks. The key components of EfficientNetV2B0 are [40]:

1. Convolutional Layers: These layers perform feature extraction by applying filters to the input image to learn its local features.
2. Pooling Layers: These layers down-sample the feature maps produced by the convolutional layers to reduce the spatial dimensions while maintaining the most important information.
3. Squeeze-and-Excitation (SE) Blocks: SE blocks are used to increase the network's ability to model complex relationships between the channels of the feature maps.
4. Depthwise Separable Convolutions: The model uses depthwise separable convolutions, which can reduce the number of parameters and computational cost compared to traditional convolutions.
5. Residual Connections: The model uses residual connections, which can help to alleviate the vanishing gradients problem and improve the model's ability to learn.
6. Skip Connections: The model uses skip connections, which can help to improve the model's accuracy and reduce the risk of overfitting.
7. Fully Connected Layers: The model includes one or more fully connected layers at the end of the network, which perform the final classification tasks based on the features extracted by the convolutional layers.

These components work together to learn and extract features from the input image and make predictions about the class of the image. The specific design and configuration of these components in EfficientNetV2B0 have been optimized to achieve high accuracy and computational efficiency. The architecture of the EfficientNetV2B0 is represented in the table 2 and illustrated in Figure 2 [40].

Table 2. EfficientNetV2B0 Deign Summary

Step	Operator	Stride	Channels Num.	Layers Num.
0	Conv3x3	2	24	1
1	Fused-MB-Conv_1; k3x3	1	24	2
2	Fused-MB-Conv_4; k3x3	2	48	4
3	Fused-MB-Conv_4; k3x3	2	64	4
4	MB-Conv_4, k3x3; SE0.25	2	128	6
5	MB-Conv_6, k3x3; SE0.25	1	160	9
6	MB-Conv_6, k3x3; SE0.25	2	256	15
7	Conv1x1 + Pooling + FC	-	1280	1

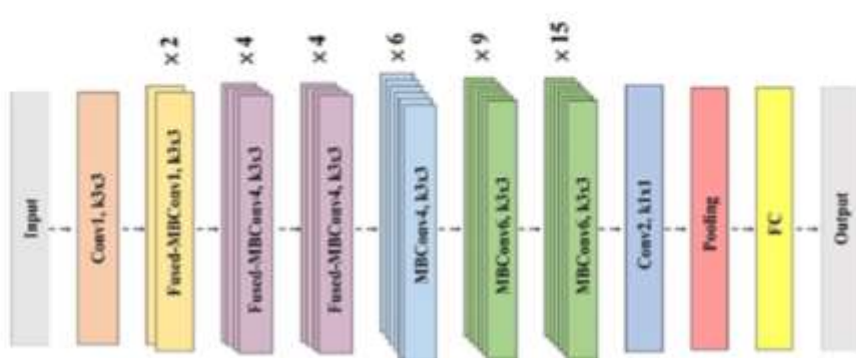

Figure 2. Architecture of EfficientNetV2B0

7.1 Evaluation Metrics

For the assessment of the suggested EfficientNetV2B0 model using the tomato leaf diseases dataset, we used Accuracy as in Eq. 4, Precision (Eq. 1), Recall (Eq. 2) and F1-Score (Eq. 3) [30].

$$\text{Precision} = \frac{\text{TP}}{\text{TP + FP}} \quad (1)$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP + FN}} \quad (2)$$

$$F1 - score = 2 * \frac{\text{Precision x Recall}}{\text{Precision + Recall}} \quad (3)$$

$$\text{Accuracy} = \frac{\text{TN + TP}}{\text{TN+FP+ TP + FN}} \quad (4)$$

Where: TP =True Positive, FP=False Positive, TN=True Negative, FN=False Negative

5. Results and Discussion

We have trained the proposed model using the training and validation sets for 60 epochs. The results of the training accuracy was 99.88%, Training Loss: 0.0032 the Validating Accuracy: 0.96.61%, Validating Loss: 0.138 after 60 Epochs. As shown in Figure 3. The history of the training and validation of the proposed model for the last 20 epochs are shown in Figure 4 and Figure 5.

```
Training Accuracy: 0.9988, Training Loss: 0.0032
Validating Accuracy: 0.9661, Validating Loss: 0.1384
```

Figure 3. Accuracies and losses of the training and validation of the proposed model

Figure 4. History of training and validation accuracy

Figure 5. History of training and validation Loss

The accurcy and loss of tesing the proposed model came out: testing accurcy (99.87%) and testing loss (0.0039) as in Figure 6.

```
50/50 [==============================] - 1s 15ms/step - loss: 0.0039 - accuracy: 0.9987
Testing final accuracy: 0.9987, Testing Final loss: 0.0039
Time elapsed inb seconds: 1.3644986152648926
```

Figure 6. Accuracy and loss of the testing of the proposed model

The classification report of the proposed model is shown in Figure 7. Form the Figure we can see that the proposed model achieved: Accuracy (99.87%), F1-score (99.87%), Recall (99.87%), and Precision (99.88%).

Figure 8 show the ROC curve of each class in the tomato leaf diseases of the proposed model; while Figure 9 show the confusion matrix of the proposed model. Form Figure 8 and Figure 9, we can see that the proposed model learned the training data and thus it can generalize and not memorize the images.

	precision	recall	f1-score	support
Bacterial_spot	1.0000	1.0000	1.0000	131
Early_blight	1.0000	1.0000	1.0000	128
Late_blight	1.0000	1.0000	1.0000	152
Leaf_Mold	1.0000	0.9858	0.9929	141
Septoria_leaf_spot	0.9868	1.0000	0.9933	149
Spider_mites Two-spotted_spider_mite	1.0000	1.0000	1.0000	145
Tomato_Yellow_Leaf_Curl_Virus	1.0000	1.0000	1.0000	161
Tomato_mosaic_virus	1.0000	1.0000	1.0000	150
healthy	1.0000	1.0000	1.0000	153
powdery_mildew	1.0000	1.0000	1.0000	148
Target_Spot	1.0000	1.0000	1.0000	132
accuracy			0.9987	1590
macro avg	0.9988	0.9987	0.9987	1590
weighted avg	0.9988	0.9987	0.9987	1590

Figure 7. Classification Report of the proposed model

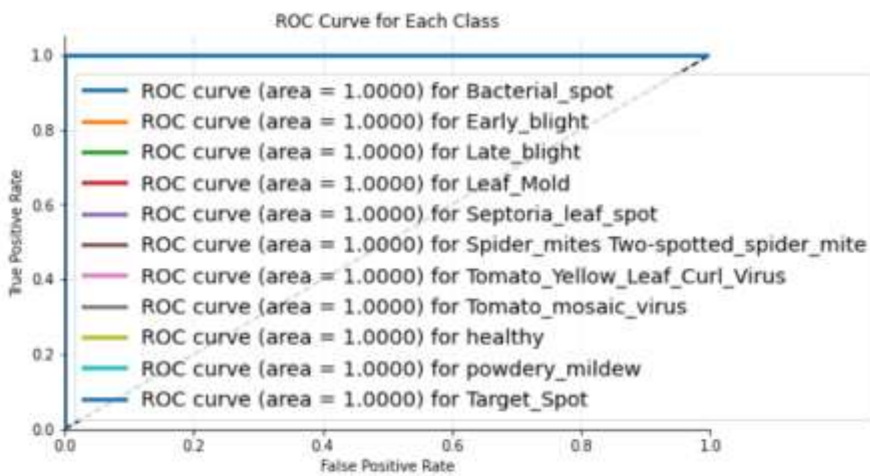

Figure 8. ROC curve for each class of the dataset

131	0	0	0	0	0	0	0	0	0	0
0	128	0	0	0	0	0	0	0	0	0
0	0	152	0	0	0	0	0	0	0	0
0	0	0	139	2	0	0	0	0	0	0
0	0	0	0	149	0	0	0	0	0	0
0	0	0	0	0	145	0	0	0	0	0
0	0	0	0	0	0	161	0	0	0	0
0	0	0	0	0	0	0	150	0	0	0
0	0	0	0	0	0	0	0	153	0	0
0	0	0	0	0	0	0	0	0	148	0
0	0	0	0	0	0	0	0	0	0	132

Figure 9. Confusion Matrix of the proposed model

Table 2 show a comparison between the previous studies and the current study. From Table 2, we can conclude that our proposed model EfficientNetV2B0 outperformed the models in the previous studies where the beast accuracy in the previous studies was 99.64% while purposed model achieved Accuracy (99.87%), F1-score (99.87%), Recall (99.87%), and Precision (99.88%).

Table 1. Summarizes the previous studies in term of method, performance metric, dataset and accuracy used

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[32]	2020	ResNet and U-Net	Accuracy	Plant Village	94.00%
[33]	2020	Inception V3	F1-score, recall, precision	Private	InceptionV3: 99.60%
[34]	2020	CNN	F1-score, recall, precision	Plant Village	91.20%
[35]	2020	CNN	F1-score, recall, precision	Private	98.46%
[36]	2017	R-CNN	F1-score, recall, precision	Private	83.06%
[37]	2020	Extreme Learning Machine (ELM)	Accuracy, AUC	Tomato powdery mildew dataset	89.19%
[38]	2020	LR, SVM	Accuracy, F1- score, AUC	Tomato powdery mildew dataset	92.73%
Current Study	**2023**	**EfficientNetV2B0**	**F1-score, recall, precision**	**Kaggle Tomato leaf Diseases Dataset**	**99.87%**

6. CONCLUSION

A deep learning model that classifies tomato diseases has been completed. The aim of this paper was to diagnose tomato diseases based on a dataset containing 11,000 images and 11 categories of common tomato diseases, through deep learning and EfficientNetV2B0 architecture and to discuss relevant design options and implementation aspects. The model gave a final test Accuracy (99.87%), F1-score (99.87%), Recall (99.87%), and Precision (99.88%) in an estimated time of 1.36 seconds, as it proved with these results its effectiveness and good ability in the classification test. Convolutional neural networks have proven their quality in classifying diseases related not only to tomato leaves, but also have proven their worth in classifying diseases in general.

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