**Deep Learning for Sustainable Farming: Multi-Class Disease Detection in Apple and Tomato Leaves**

1. **Abstract:**

**Improving agricultural production and overall food quality requires accurate identification of diseases affecting tomato and apple leaf. Traditional disease detection techniques are time-consuming and require specific knowledge, making them unsuitable for widespread agricultural observation. An automated approach for disease classification is presented in this paper. The comparison research was conducted using a dataset of apple and tomato plant leaf images to compare seven different deep-learning architectures, which are EfficientNet, ResNet, DenseNet, MobileNet, AlexNet, Xception, and GoogleNet. In terms of performance and applicability in limited in resources contexts, GoogleNet outperformed other models with an impressive accuracy rate of 95.84% at the end of the training process. Data augmentation methods were used with a variety of data prior treatment methods, including picture scaling and normalisation, to increase the model's possibility of generalisation. The results of our investigation suggest that the lightweight GoogleNet architecture is especially advantageous for real-world applications in the detection of agricultural diseases, providing a swift, accurate, and mobile-adaptable solution. Subsequent research initiatives will focus on broadening the dataset while simultaneously optimizing the model to attain improved accuracy across a more extensive range of agricultural diseases.**

1. **Introduction :**

To ensure the nourishment of crop health and mitigate production deficits, modern agricultural practices are profoundly reliant on the precise identification of Plant leaf disease afflictions. In particular, species of apple and tomato are extensively cultivated owing to their considerable nutritional benefits and economic importance. However, a maximum of diseases that negatively influence plant health can severely impact these crops, resulting in a decrease in both the quality and yield of the harvest. Prevalent diseases that compromise the plants of Apple cultivation include apple scab, black rot, and cedar apple rust, while bacterial spots, early blight, and late blight are notable pathologies that adversely affect the plants of Tomato. In these agricultural systems, the timely and precise identification of diseases can greatly reduce the spread of infections and boost total agricultural productivity.

Automated methodologies that leverage leaf imagery for the diagnostic assessment of plant leaf disease conditions have emerged, attributable to recent advancements in image processing and computer vision technologies. These algorithms adeptly classify diseases predicated upon the visual attributes of leaves, utilizing either deep learning techniques or manually engineered feature extraction methodologies. Although handcrafted methods have demonstrated efficacy across a wide array of classification tasks, including the identification of plant diseases, deep learning-based approaches have gained heightened favor due to their superior accuracy and robust generalization capabilities in complex classification contexts. The predominant inclination within the realm of study of plant diseases classification favors the utilization of deep learning frameworks, particularly Convolutional Neural Networks (CNNs), which have garnered prominence due to their operational effectiveness and performance optimization. In the present study, we introduce an optimized and efficient GoogleNet model specifically designed for the classification of diseases afflicting tomato and apple plants.

The exceptional computational efficiency inherent to the GoogleNet architecture constitutes one of its principal advantages, rendering it particularly advantageous for mobile and edge devices that face inherent limitations concerning memory capacity and processing power. The primary aim of this academic investigation is to construct a model that achieves improved accuracy while concurrently reducing computational demands, thereby enabling its deployment in resource-constrained, real-time environments, such as compact unmanned aerial vehicles or mobile application frameworks. We performed GoogleNet architecture compared against deep learning frameworks, encompassing EfficientNet, ResNet, DenseNet, MobileNet, AlexNet, Xception employing a substantial dataset of images that depict both healthy and infected leaves of tomato and apple plants

The results shows that GoogleNet model surpasses all the models that we have used, with an accuracy rate of 95.84%.The main contributions of this research project are outlined in the following section:

1. **Literature Review:**

Convolutional neural networks (CNNs) have been employed to establish a methodological framework designed for the detection of pathologies impacting tomato plants, thereby underscoring the paramount importance of timely identification to mitigate economic detriments for agricultural stakeholders. By automating both the feature extraction and classification procedures, this framework—which categorizes diseases into ten distinct classifications—attained a notable accuracy rate of 93%, thereby highlighting the practical implications of the model and its prospective utility for immediate interventions in the management of tomato-associated diseases [1]. A focused investigation was conducted to discern ailments in custard apple plants, thereby emphasizing the critical importance of precise classification to reduce pesticide utilization and improve agricultural productivity. Methods like image segmentation and support vector machine (SVM) classifiers were applied to categorize custard apple diseases, showcasing the benefits of advanced image processing techniques in agricultural applications [2].

In light of the significant economic implications for apple cultivators, a considerable number of scholarly research endeavours concentrate on the detection of plants diseases in Apple employing advanced deep learning methodologies. One investigation examined the progress of Convolutional Neural Networks (CNNs) alongside the limitations inherent in widely utilized datasets such as PlantVillage, which is commonly deployed for the assessment of agricultural ailments. This investigation highlights the imperative for the advancement of methodologies proficient in the prompt identification of plant leaf diseases to protect Apple plantations and augment the financial sustainability of agricultural producers [3]. In an alternative investigation, the afflictions of apple and grapevine plants were classified utilizing Convolutional Neural Networks (CNNs) in conjunction with Multi-Layer Perceptron (MLP) architectures. The results indicated that CNNs exhibited superior performance relative to MLPs with respect to both precision and effectiveness. Employing the PlantVillage dataset, this research substantiated that CNNs are exceedingly suitable for applications in real-time agriculture [4].

Through a comparative analysis of Support Vector Machine (SVM), Random Forest, Naive Bayes, K-Nearest Neighbor, and VGG-16 models, the research demonstrated the efficacy of machine learning and deep learning methodologies in the identification of diseases affecting apple crops. The VGG-16 model attained the apex of validation accuracy at 97.23%, thus asserting its position as a reliable tool for the categorization of apple leaf diseases. The investigation also highlights the importance of carefully selecting appropriate models in accordance with specific project requirements, thereby clarifying the complex nature of automated disease detection across various agricultural paradigms [5]. In the context of tomato disease identification, a well-balanced dataset was constructed employing data augmentation techniques, which enabled Convolutional Neural Network (CNN) models such as MobileNetV2 in achieving accuracy rate of 98.01% in disease classification. This study highlights the critical role of balanced datasets and deep learning methodologies in the management of heterogeneous agricultural data, thereby positioning MobileNetV2 as a superior option for real-time applications due to its proficiency in the detection of tomato diseases [6].

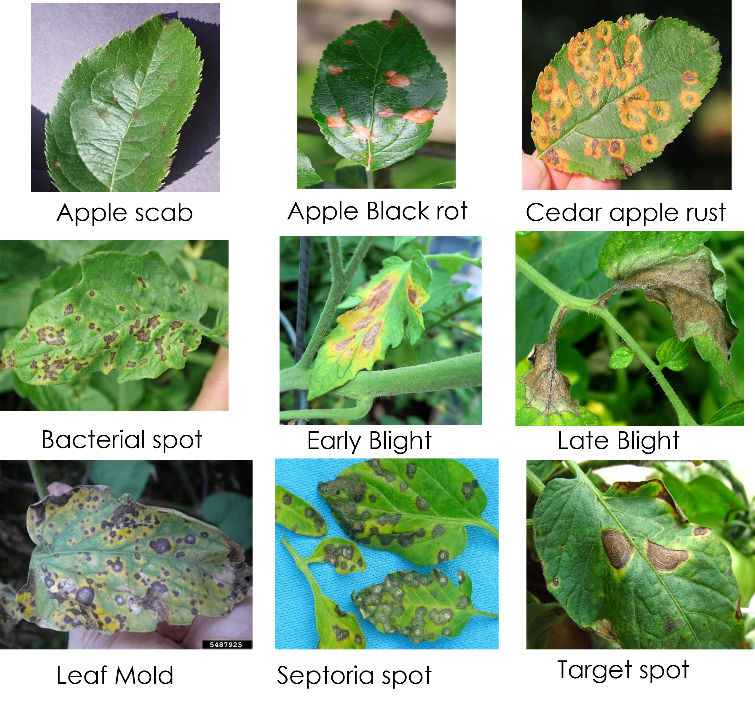
A subsequent investigation concentrated on the detection of diseases affecting tomato leaves through the application of the YOLOv8 framework, attaining an impressive classification accuracy of 99% and a mean Average Precision (mAP) of 98.9%. Assessed against a dataset consisting of 1,650 images, this model proficiently distinguished between healthy and diseased tomato plants, thereby highlighting the efficacy of real-time computer vision in the enhancement of agricultural health management [7]. For the classification of diseases affecting tomatoes, hybrid models that integrate Convolutional Neural Networks (CNN) with Long Short-Term Memory (LSTM) architectures were also explored; these models attained a remarkable accuracy rate of 99.8%. Evaluated on an extensive dataset, this methodology exemplified the efficacy of hybrid deep learning models in reliably discerning various pathological conditions, thus offering a robust approach for timely agricultural interventions [8].

To achieve an accuracy rate of 96%, an alternative system specifically targeting Black rot and Cedar apple rust in apple plants employed preprocessing and image segmentation techniques prior to the application of Multiclass Support Vector Machine (SVM) for classification purposes. This investigation illustrates the effective synergy of image processing and SVM methodologies in addressing specific diseases afflicting apple crops [9]. In conclusion, a specialized online platform has been developed to detect tomato illnesses, making it easier for agronomists to quickly evaluate the health of tomato leaves by uploading images. The model's remarkable 93% accuracy rate highlights the fascinating potential of easily available internet tools for smallholder farmers in areas like Zimbabwe, where economic stability is largely determined by agricultural productivity [10].

In conclusion, our research methodologies employing Convolutional Neural Networks (CNNs) for the detection of pathologies in tomato and apple agriculture demonstrated that automated feature extraction and classification can achieve a significant degree of precision, which prompted us to explore analogous architectural paradigms. Our objectives were centered on both precision and computational efficacy, leading us to select and optimize our model based on academic literature that underscored the necessity of dataset equilibrium to improve the feasibility of real-time implementations, utilizing robust architectures such as ResNet, DenseNet, EfficientNet, and GoogLeNet. Our decision to investigate a spectrum of architectures with the objective of identifying the most suitable model for our investigation was informed by studies that similarly emphasized the significance of specific algorithms designed for a diverse range of agricultural crops.

1. **Dataset/Data Preparation:**

In pursuit of our academic research, we incorporated a dataset that contains 14 distinct classifications of plant diseases affecting both Apple (apples) and Tomato (tomatoes), thereby facilitating an extensive examination of numerous common plant leaf diseases. This dataset encompasses categories such as Apple Scab, Apple Black Rot, Apple Cedar Apple Rust, and Apple Healthy, all of which are pertinent to the diseases afflicting apples. In relation to tomatoes, the categories consist of Bacterial Spot, Early Blight, Late Blight, Leaf Mold, Septoria Leaf Spot, Spider Mites, Two-Spotted Spider Mite, Target Spot, Mosaic Virus, and Yellow Leaf Curl Virus. Inclusively, our dataset consists a total of 11,101 images, with 8,878 images allocated for the purpose of training and 2,223 images for the purpose for validation.

 Fig. 1: Leaves with Different diseases

To enhance model performance and ensure generalization, we applied various data preprocessing techniques using TensorFlow's *ImageDataGenerator.* These include:

1. Rescaling: The pixel intensity values contained within each image were adjusted from the interval [0,255] to the interval [0,1] by means of multiplication with the coefficient of 1/255. This normalization procedure is critically significant for neural networks, as it improves stability and expedites the training process.
2. Image Augmentation: A variety of data augmentation methodologies were implemented to alleviate the potential for overfitting.
3. Shear Transformation: This technique applies a particular degree of distortion to the image, thereby bolstering the model's resilience against fluctuations in the positioning of leaves.
4. Zooming: The application of random zooming was employed to ascertain the model's invariance to variations in scale and to augment its capability to identify the disease in images acquired from diverse distances.
5. Horizontal Flipping: The random horizontal flipping of images contributes to the introduction of variability, which is especially advantageous for scenarios that do not possess a clearly defined orientation.

The process of augmented data generation enables the model to "perceive" a diverse range of image transformations, thereby assisting it in the acquisition of invariant features and enhancing its robustness. Our dataset was systematically partitioned into training and validation subsets, employing an 80-20 ratio. The training subset comprised 8,878 images, whereas the validation subset encompassed 2,223 images, thereby facilitating comprehensive model evaluation throughout the training process.

Furthermore, the images were modified to dimensions of 227x227 pixels, in accordance with the input requirements of GoogleNet model. This specific dimensionality establishes an essential equilibrium between computational efficiency and the preservation of critical features, which is vital for the precise identification of subtle diseases. The data generators were systematically configured to load images in batches of 32, thereby facilitating optimal memory utilization throughout the model's training process.

1. **Methodology:**

In this study, we employed GoogleNet (also known as Inception V1) as the final model for identifying pathologies in the leaves of Apple and Tomato plants. GoogleNet was selected based on its excellent performance in categorizing leaf images into one of fourteen distinct disease classes. The model achieved impressive results during the evaluation phase, yielding the following validation metrics.

GoogleNet epitomizes an advanced deep convolutional neural network (CNN) architecture that has been rigorously designed to improve both precision and computational efficacy It introduces an innovative architectural component known as the Inception module, which empowers the network to assimilate diverse levels of abstraction by concurrently applying multiple convolutional filters with varying kernel dimensions. This architectural framework exhibits exceptional efficacy in capturing intricate features within images while concurrently preserving a compact model size GoogleNet, commonly designated as Inception v1, represents a convolutional neural network (CNN) architecture that initiated the deployment of the Inception module to improve both computational efficacy and model precision. This network utilizes a multi-branch arrangement within the Inception module, amalgamating 1x1, 3x3, and 5x5 convolutional filters, alongside max-pooling, all executed concurrently. The amalgamation of these outputs enables the extraction of multi-scale spatial features, thereby augmenting the model's capability to discern intricate patterns.

GoogleNet implements dimensionality reduction via 1x1 convolutions to diminish computational burden. The architecture is deeper than its predecessors, consisting of 22 layers, yet achieves efficiency with a reduced number of parameters owing to the Inception modules. Furthermore, auxiliary classifiers are incorporated at intermediate stages of the network to facilitate gradient propagation during the training phase and to enhance overall model performance. The design of GoogleNet underscores a critical equilibrium between computational expense and accuracy, marking it as a seminal advancement in the realm of deep learning. For this work, we have taken a pre-trained GoogleNet architecture, which had undergone prior training utilizing the ImageNet dataset.

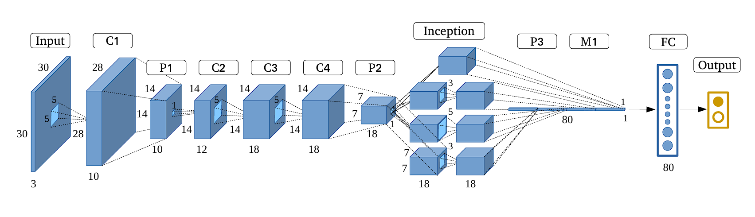


Fig. 2: GoogleNet Structure

This methodology of transfer learning enabled us to capitalize on the pre-trained model's capacity to discern general visual patterns, thereby significantly curtailing training duration and enhancing accuracy. Subsequently, the pre-trained model underwent fine-tuning through the incorporation of custom output layers specifically designed for the 14 disease categories pertinent to our dataset We implemented the Adam optimization algorithm during the training phase, commencing with a learning rate of 0.0001 for the first 20 epochs. The Adam optimization algorithm amalgamates the beneficial attributes of the Adaptive Gradient Algorithm (AdaGrad) and Root Mean Square Propagation (RMSProp) to dynamically adjust the learning rate for individual parameters, thus rendering it especially beneficial for datasets that demonstrate traits of noisy or sparse gradients.

During this phase, only the custom output layers were subjected to training, while the pre-trained base layers were retained in a frozen state to safeguard the acquired features. Subsequent to the preliminary training phase, we unblocked the terminal layers of the GoogleNet architecture and conducted fine-tuning for an extended duration of 10 epochs, simultaneously diminishing the learning rate to 0.0001 to facilitate stable convergence. The model was trained utilizing a batch size of 32 images, which optimized memory utilization and processing efficiency. Throughout the training regimen, both training and validation accuracy and loss metrics were meticulously monitored. The model exhibited a consistent enhancement in accuracy, ultimately attaining a peak validation accuracy of 95.84%. This improvement was concomitant with a steady reduction in loss, signifying that the model was effectively acquiring the capability to classify the leaf images. The accuracy plots for both training and validation illustrated a stable training trajectory with negligible indications of overfitting.

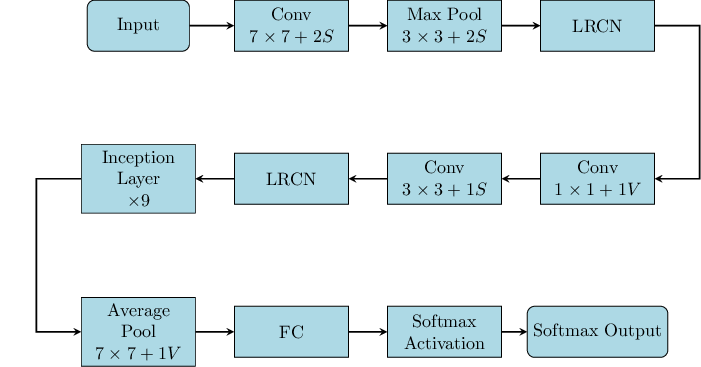


Fig. 3: GoogleNet Workflow

In summary, GoogleNet was chosen as the final model because of its outstanding results, which included a computationally efficient solution for real-time disease detection in plant leaves and an accuracy of 95.84%. The model is a great option for real-world applications where accuracy and efficiency are remarkable due to its capacity to capture a variety of image data and the advantages of transfer learning.

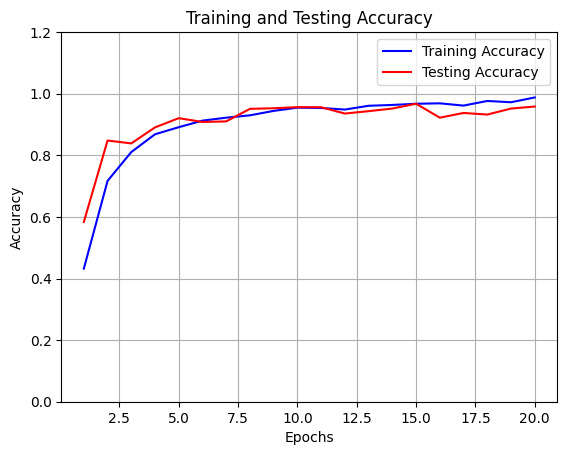


Fig. 4: GoogleNet Accuracy plot

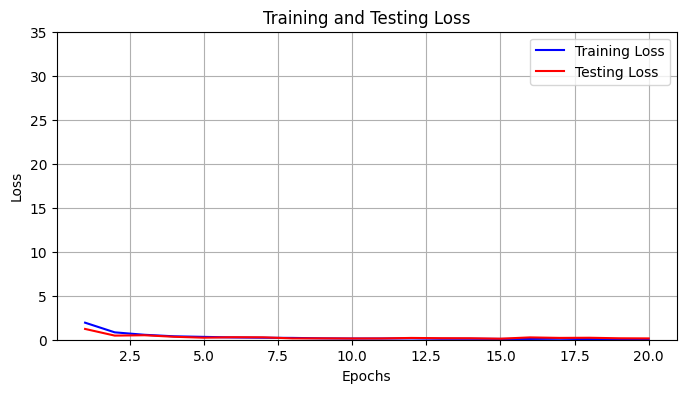


Fig. 5: GoogleNet Accuracy plot

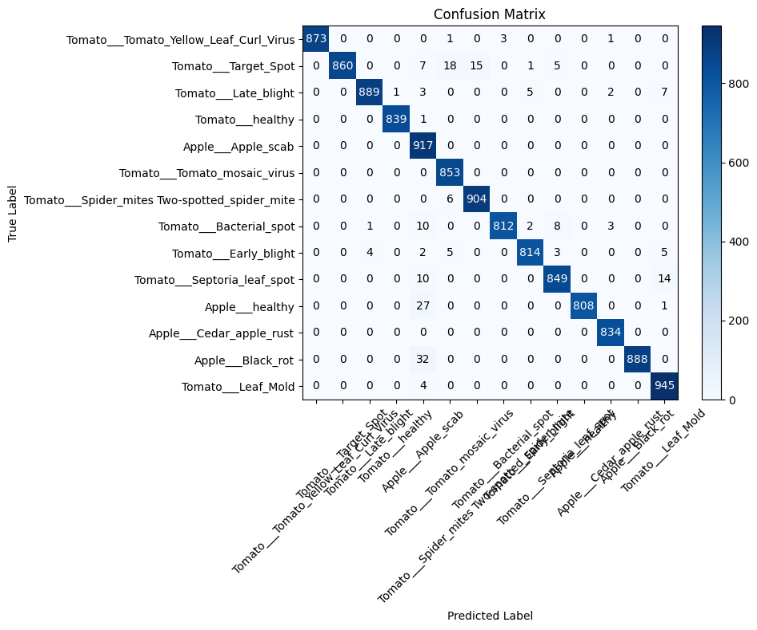


Fig. 6: GoogleNet Confusion matrix

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Class** | **Precision** | **Recall** | **F1-Score** | **Support** |
| Tomato Yellow Leaf Curl Virus | 1.00 | 0.96 | 0.98 | 224 |
| Tomato Target Spot | 0.98 | 0.91 | 0.95 | 217 |
| Tomato Late blight | 0.99 | 0.93 | 0.96 | 225 |
| Tomato healthy | 1.00 | 0.99 | 1.00 | 233 |
| Apple scab | 0.87 | 0.99 | 0.93 | 225 |
| Tomato mosaic virus | 0.95 | 1.00 | 0.97 | 204 |
| Tomato Spider mites Two-spotted spider mite | 0.96 | 0.97 | 0.97 | 207 |
| Tomato Bacterial spot | 0.98 | 0.93 | 0.95 | 233 |
| Tomato Early blight | 0.94 | 0.92 | 0.93 | 223 |
| Tomato Septoria leaf spot | 0.93 | 0.93 | 0.93 | 229 |
| Apple healthy | 0.99 | 0.94 | 0.97 | 198 |
| Apple Cedar rust | 0.96 | 1.00 | 0.97 | 215 |
| Apple Black rot | 0.99 | 0.95 | 0.97 | 213 |
| Tomato Leaf Mold | 0.91 | 1.00 | 0.95 | 228 |

Table. 1: Classification Report

1. **Experiments and Results**

The empirical findings substantiate that GoogleNet (Inception v1) exhibits exceptional efficacy in the identification of diseases affecting tomato and apple plants, attaining an impressive validation accuracy of 95.84%. This establishes GoogleNet as one of the foremost models within the analytical framework, illustrating its capability to harmonize accuracy with computational efficiency. The variance in performance among different architectures is pronounced, as evidenced by models such as Xception, which registered a significantly lower accuracy of 56.41%, while alternative configurations like DenseNet secured a commendable 93.14%. In comparison, MobileNet, characterized as a lightweight architecture, achieved a marginally lower accuracy of 89.07%, reflecting the heterogeneity in performance across various models.

The Inception module-based architecture of GoogleNet, meticulously designed to adeptly process multi-scale features, is a significant factor contributing to its outstanding performance. The neural network demonstrated exceptional performance on critical evaluative indicators, encompassing precision (96.02%), recall (95.84%), and F1-score (95.85%), thus substantiating its resilience in classification endeavors. These outcomes underscore the dependability of GoogleNet in real-world scenarios pertaining to disease identification.

Furthermore, a comparative assessment was undertaken to scrutinize model parameters, inference duration, and memory prerequisites. GoogleNet achieves a commendable equilibrium between accuracy and computational requisites, surpassing resource-demanding models such as DenseNet in terms of efficiency while attaining comparable or superior accuracy. Its performance regarding computational expense and inference velocity renders it particularly advantageous for real-time applications, especially in contexts necessitating on-the-go disease detection.

The proficiency of GoogleNet in accurately identifying leaf diseases with high precision and reliability accentuates its potential as a viable solution for agricultural diagnostics. Its equilibrium of performance and efficiency designates it as an optimal candidate for deployment in settings with constrained computational resources, such as mobile or edge devices utilized in the field. These findings validate the model's appropriateness for assisting farmers and agricultural specialists in acquiring immediate and precise assessments of plant health, providing a robust instrument for contemporary precision agriculture.

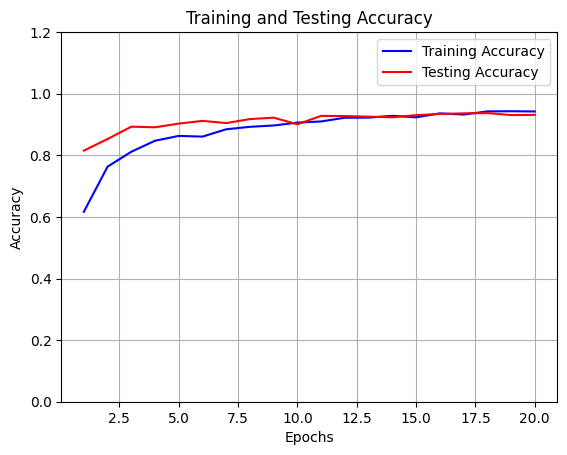


Fig. 7: DenseNet Accuracy plot

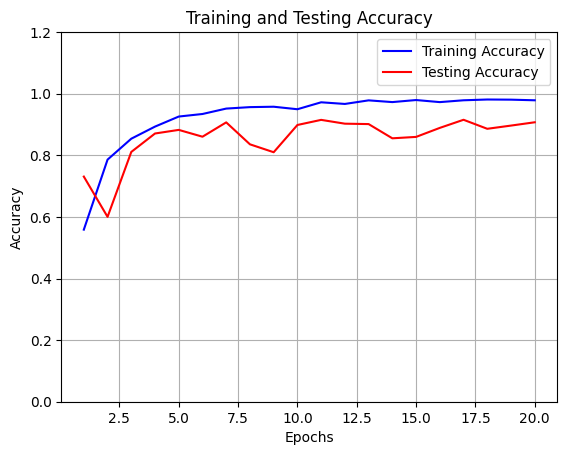


Fig. 8: AlexNet Accuracy Plot

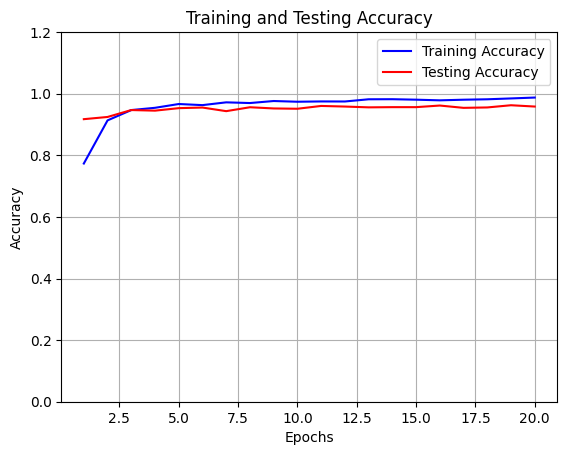


Fig. 9: ResNet Accuracy Plot

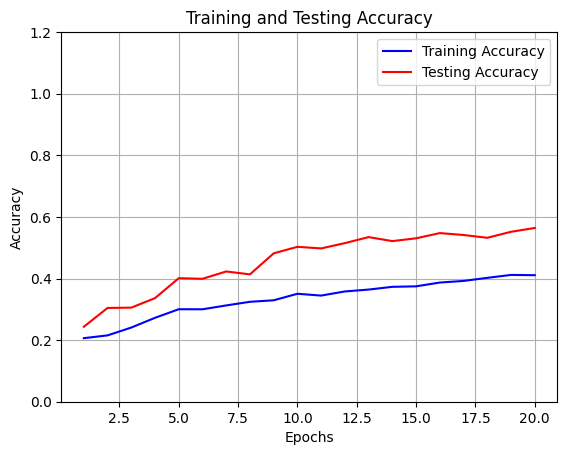


Fig. 10: Xception Accuracy Plot

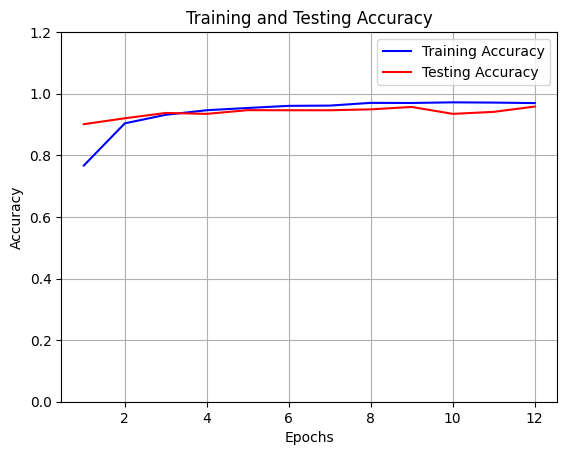


Fig. 11: EfficientNet Accuracy Plot

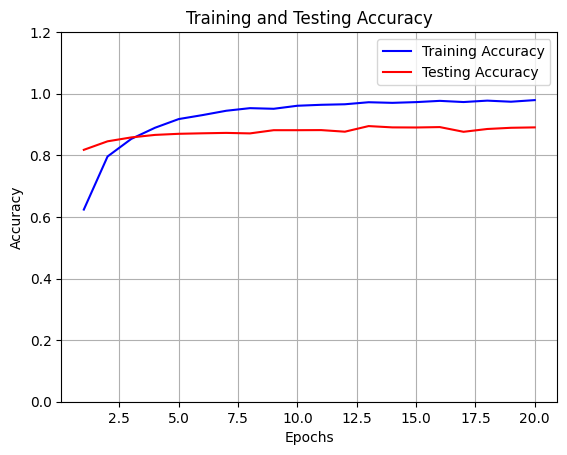


Fig. 12: MobileNet Accuracy Plot

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Model** | **Validation Accuracy** | **Validation Precision** | **Validation Recall** | **Validation F1 Score** |
| EfficientNet | 95.84% | 95.88% | 95.84% | 95.83% |
| DenseNet | 93.14% | 93.36% | 93.14% | 93.17% |
| GoogleNet | 95.84% | 96.02% | 95.84% | 95.85% |
| Xception | 56.41% | 57.33% | 56.41% | 54.94% |
| ResNet | 95.84% | 95.91% | 95.84% | 95.83% |
| AlexNet | 90.73% | 90.85% | 90.73% | 90.70% |
| MobileNet | 89.07% | 89.25% | 89.07% | 89.00% |

Table. 2: Accuracy Table

1. **Conclusion:**

In order to discern pathologies within the plant structures of Tomato and Apple, the current research initiative elucidates a highly efficacious model based on GoogleNet, which achieves an exceptional validation accuracy of 95.84% while demanding minimal computational resources. In comparison to other sophisticated deep learning architectures, such as EfficientNet, ResNet, DenseNet, MobileNet, AlexNet, and Xception, GoogleNet exhibits the great balance between augmented accuracy and operational efficiency The optimized and computationally frugal architecture of GoogleNet enables real-time disease detection, thus providing a pragmatic solution for agricultural practitioners and specialists who necessitate rapid, on-site identification of plant leaf diseases.

The findings accentuate the efficacy of GoogleNet as a cost-effective and scalable tool for the identification of disease, which holds the potential to transform disease management strategies within the agricultural domain by providing accessible and precise diagnostic tools. This study constitutes a substantial contribution to the realm of agricultural technology through the development of a model that facilitates efficient, instantaneous monitoring of plant health, thereby augmenting the capabilities for timely intervention.

1. **Future work:**

Future research will be on how GoogleNet may be integrated with Internet of Things (IoT) sensors to enable automated and ongoing plant health monitoring in agricultural settings. Furthermore, using bigger and more varied datasets could improve our model's development and increase its flexibility in response to changing environmental circumstances. To optimize performance on computing systems with increasingly reduced resources, alternative model changes such as pruning and quantization will be systematically explored. In remote locations with limited resources, these advancements could significantly increase the precision and efficacy of plant disease monitoring systems.

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