Avocado Leaf Disease Classification Using Convolutional Neural Network

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Abstract: ***Countries agricultural production of plants and crops were affected by pests and pathogens. Avocado is one of the popular subtropics fruit of high economic importance. Avocado plant has so much importance for food consumptions, oil production and financial source of income, however most of the time it is affected by the different diseases that result in the reduction of quality and quantity of the avocado production. Usually avocado disease symptoms were appear on the leaf of the plant and through time it affect the fruit and stem of the tree leading to the death of the plant. Traditionally farmers and specialists or experts detect and identify plant disease by naked eyes. This method was inaccurate and expensive. Detection using image processing technique will be accurate and fast. In this thesis the researcher proposes deep learning based avocado leaf disease detection and classification. Algal leaf spot, leaf burn, perseamite damaged and powdery mildew disease of avocado that appear on leaf of avocado plant were concerned. This research has passed through the following steps, image acquisition, image preprocessing, feature extraction, training the model and detection and classification. The proposed method was classified into three phases, by changing the values of hyper parameters. All phases had passed the above processing steps. Avocado leaves affected by four diseases and healthy leaves were trained and classified into their disease class. To test the model performance, data set was split into training set and validation set in the ratio of 80%, 20% respectively. Convolutional Neural Network (CNN) model is used for the detection and classification purpose. CNN has shown good performance in training, prediction of the disease and classification that result 100% for training accuracy and 98.8% for testing accuracy with the overall accuracy of 99%.***

Keywords: Avocado Disease, Convolutional Neural Network, Deep Learning

1. Introduction

Basis of Ethiopian Economy is agriculture. Ethiopia's key agricultural sector has grown at a yearly rate of about 10% over the past decade; much faster than population growth [1]. Agriculture play a vital role in development of human civilization and economic, it is mother of all cultures [2]. But the Productivity of crops grown for human consumption will get affected with the infection of pests, especially weeds, pathogens and animal pests. Crop losses due to these harmful organisms can be substantial and may be prevented or reduced by crop production measure. A crop disease is a major sources of famine and food insecurity on our planet.

Avocado plant has more importance for food consumptions, oil production and financial source of income for the country. The product quality and quantity reduces due to some diseases. Avocado diseases are fungal, viral, bacterial and others. Traditionally those diseases were detected by observation or applying laboratory tests. It needs some experienced experts and takes long time and it is not easy for producers or farmers [3]. Plant disease identification by visual way is more laborious task and it is less accurate and can be performed in limited areas. Whereas if detection is done by using machine learning techniques it will take less efforts, less time and become more accurate.

It is important to analyze plant accurately with the diseases within specific time. Some diseases are recognizable to human eyes and can be easily detected and cured. Some are so complicated which needs most powerful microscopes or precise electromagnetic spectrum. Digital technology can process all kinds of diseased plant and leaf images very accurately [4]. The main approach is the naked eye observation of experts adopted in practice for identification of plant diseases [5]. However, continuous monitoring of experts is required which might be more expensive in large farms. Traditionally most of the diseases were not diagnosed or suspected by the farmers as they lack knowledge about the crop diseases and definitely they require a support and suggestions from the subject matter specialists. But it is costlier, time consuming and not definite as it is biased based on the decision of the subject matter specialist [3]. In Ethiopia avocado plant is very essential and one source of income. Avocado leaf disease detection is very essential to avoid the huge damage of the whole avocado plants field. Detection and classification of diseases are existing for the other plants like banana, coffee, tomato etc. Very less research is done related to avocado leaf disease detection. However the disease symptoms most of the time appear first at the leaves of the avocado. Most of the research done on plant disease detection were by using ANN algorithm which has unexplained behavior of the network to determine proper network structure and also it leads to overfitting when the image size is large.

2. Data Collection

In this study the researcher collected data in three ways 1. From the avocado plantation area stored on their computers. 2. Manually by capturing avocado leaf images using digital camera 3. From the net image repository. All acquired and captured images are saved as JPG (Joint Photographic Group) and each of same class are grouped in one folder and saved by their disease class name.

3. Literature Review

3.1 Avocado Disease

The Roots, trunk, branches, leaves, and fruits of the avocado tree get affected by number of diseases. The diseases are caused primarily by fungi, virus, etc.. Causes may be the result of deficiencies or excesses of certain elements used by the trees [6]. In this study the researcher consider only leaf diseases of avocado plant. Most of the avocado plant diseases express their symptoms on the leaf of avocado. Algal leaf spot: Algal leaf spot also known as green scurf. It is a viral disease of avocado and its symptoms are raised, orange-red spots on both upper and lower surface of the leaves. Spots may coalesce to form irregularly shaped patches; spots may also be present on twigs and branches [7]. CercosporaSpot or Blotch: This disease can able to infect previously uninjured leaves, young stems and fruits. The disease appears on the leaves with symptoms of individual spots which are angular in shape with less than 2mm in diameter and with color of brown to chocolate brown. Groups of spots frequently may coalesce to form patches of irregular shapes. Spots on the fruits are light to dark brown, with 3-6 mm in diameter, slightly sunken with a fissured or cracked surface with irregular shape. Leaf infection occasionally may results to severe or partial defoliation of the tree. Cercospora spot is caused by the fungus CercosporapurpureaCke. During moist periods on either leaf or fruit surfaces with grayish spore bearing tufts are produced throughout the year. The disease is carried over on old leaf infections from season to season. Without proper disease control, the disease tends to become more serious in an orchard [8]. Powdery mildew: powdery mildew of avocado is caused by fungus Oidiumspp. Powdery mildew frequently occurs on the foliage of nursery and field-grown trees; it may become serious enough in the nursery to warrant an application of fungicide. On the upper surface greenish areas appear for the young, expanding leaves and on the lower surface the powdery, white, spore-bearing growth characteristics appear. Mature leaves will get infected generally with purplish-brown appearance at first which may or may not be covered with the powdery white growth. The white, powdery covering of mycelia and spores is entirely superficial [8]. Leaf Burn (physiological): At the tips and edges the leaves will be brown. Affected leaves may drop prematurely. Accumulation of salts in the soil, wind desiccation, inadequate soil moisture, and frost results in these symptoms. Avoidance of light irrigation is required since this fails to leach accumulated salts out of the root zone. The soil should have good drainage [9]. Perseamite damaged leaf**:** the leaves of the avocado are damaged by the pests called Perseamite, they sock the leaf of the avocado and it results in damaging of premature leaves. The pests appear on the leaf and feed them by socking and the leaf became damaged and changes its color and shape [6].

3.2 Related Work

The paper [10] conducted experiment on two types of avocado species to identify their class using Deep Learning with total of 1,234 avocado images data set of 960 unique plants of the avocado. The data set were trained using Deep Convolutional Neural Network. They used three color channels those were RGB and Gray Scale for the experimentation. They obtained accuracy of 99.8% of test set

The study [11] described the Detection of Plant Leaf Disease using image segmentation and soft computing techniques. In this study Genetic Algorithm for image segmentation technique is used for automatic detection and classification of plant leaf diseases on the grayscale image of the leaf taken using texture feature, contrast, local homogeneity and cluster shade. The leaf disease samples were classified into five leaf disease classes using proposed algorithm. The researcher performs classification in two phases. The first classification is done using the Minimum Distance Criterion with K-Mean Clustering and shows its efficiency with accuracy of 86.54%. The proposed genetic algorithm improves the detection accuracy to 93.63%. In the second phase, classification is done using SVM classifier and shows its efficiency with an improved accuracy of 95.71%.

The researcher in [12] used Deep Learning-based Approach for Banana Leaf Diseases Classification. They used deep learning based approach to classify banana disease. LeNet architecture was used to classify the image data set. The researcher conducted experiments using data set of banana disease which is obtained from plant village project which contains thousand of images of healthy and diseased crop plants that are open and available on the web. The images in the dataset are annotated to three different categories which are healthy (1643 images), black sigatoka (240 images) and black speckle (1817 images), to evaluate the predictive performance on unseen data of banana diseases of the proposed model. In their experiments the researcher decided to test all the different range of train and test set splits to evaluate the robustness of proposed algorithm and its ability to avoid overfitting. This means that a percentage of the whole dataset is used for training and the rest is used for testing. The training dataset varies from 80%, 60%, 50%, 40 % to 20 % with the use of the some hyper parameters described below thus are optimization algorithm with value SGD, 0.001 learning rate, momentum 0.9, weight decay 0.005, batch size 10 and iterations 30.These parameters are determined empirically according to a series of experiments carried on the whole dataset that give the best results of classification. To measure the effectiveness of the proposed model, the researcher used accuracy, precision and F-measure. They obtained good results using deep learning model for identifying three banana images classes (healthy, black sigatoka and black speckle) and the result of the model was compared by using color image and gray image, based on the result they obtained the model was able to find good results when applied to classify the diseases of banana from its leaves. The obtained results confirm the importance of the color information in plant disease detection.

Author [13] proposed classification of types of Mulberry leaf disease detection using deep learning algorithm which is CNN. In the data preprocessing the researcher aimed to satisfy the constraints in CNN model when the data was trained (i) no missing values in their dataset, (ii)The dataset must be divided into training and testing sets,(ii) Either the training or the testing set shouldn't contain any irrelevant data out of the model domain in case of an image dataset, all the images they used were same size, (ii) The images converted into black and white format before feeding it into the convolution layer because reading images in RGB would involve a 3-D numPy matrix which will reduce the execution time of the model by a considerable amount. Any kind of corrupted or blurred images were trimmed from the database before feeding it into the neural network. The affected area of the mulberry leaves is identified using CNN algorithm effectively.

Garima Tripathil [14] proposed Image Processing and Neural Network based approach for detection and classification of plant leaf diseases. In the study four types of diseases namely early blight, late blight, powdery-mildew and septoria that affect the plant leaf has been considered for the study and evaluation of the proposed method feasibility. K- means clustering algorithm was used to divide images into clusters for separation of infected area of the leaves. The color co-occurrence method has been applied for extracting set of color and texture features specific to the type of leaf diseases. The researcher got an efficient, simple, fully automatic, cheap, fast and reliable system for detection and classification of plant diseases.

Modified Mobile Net model to enhance the recognition accuracy of avocado fruit disease was proposed [15]. The model was developed using a python programming language with deep learning frameworks such as Keras and TensorFlow. The researcher collected real time images of avocado fruit diseases from trusted online sources. They used image augmentation techniques such as rotating, flipping, resizing, and color augmentation such as brightness, contrast are used to enhance the size of the dataset. The dataset contains 9000 images of avocado fruits belonging to eight different classes from those 80% of the entire data were utilized for training the model and 20% is used for testing. The training and testing images are resized into 224 x 224 pixels to satisfy the dimensional requirement of the model. The learning rate, batch size, and a number of epochs were the hyper parameters used to train the model. And Adaptive Moment Estimation (Adam) optimizer is employed in model training. The proposed transfer learning based on CNN model can identify the eight common diseases of avocado fruit through image recognition. The experiment result shows that the proposed model achieves coherent improvement in the accuracy with an increase in the number of epochs, irrespective of performance degradation, and model over fitting. The modified MobileNet model employs less number of parameters to accomplish classification exhibitions. The modified model achieved a top 1 accuracy of 96.82% and top 5 accuracies of 98.24% on the test dataset of avocado fruit.

4. Research Methodology

In this proposed model, the model passes through a series of steps starting from image acquisition, image preprocessing, feature extraction, detection and classification. Generally, there are two components (image processing and deep learning) and two phases (training and testing). Diseased plant shows unusual physical characteristics on the leaves, such as changes in shapes and colors due to similar patterns of those changes. An earlier detection and treatment can avoid several losses in the whole plant. For this reason in this work the researcher's attention is to deliver the identification of avocado leaf disease using a Deep Convolutional Neural Network. After the data collected the image processing techniques are applied and then processed image is provided for the model for training and the performance of the model is evaluated using accuracy, precision, recall and F1 score.

4.1 Image Acquisition

In image processing the first step is data acquisition or image acquisition. The images of avocado leaves that are affected by four types of disease such as algal leaf spot, perseamite damaged, leaf burned, powdery mildew and healthy leaves were obtained in three ways such as i. Captured using digital camera, ii. Existing image taken from the plantation area and iii. From internet. As it was taken from different sources, it is mandatory to prepare images. The images were captured and the existing images are taken from Butajira center of excellence for Horticulture which is established by MOARD-ETHIOPIA,USAID-USA and MASHAV-ISREAL in September 2009 G.c and from the private avocado plantation site which is owned by a farmer named NuriAwal resident of Butajira zone, Mesikanworeda, Yetabor kebele. The captured and acquired images were in the format of JPG (joint photography). The images were captured as RGB(red ,green and blue) by using Techno Kc8 with android version 9.0 which has resolution of 13Mpixel(4160x3120 pixel). The total images collected were 4000, from those 1000 are removed from the data set because of similarity. Removing of the images is done manually by guidance of the experts before the experimentation and during experimentation its removed by using python duplicate removal command. The size of the data set used is 3000. Since large data set is required by the CNN, different image pre-processing and data augmentation techniques were applied on the images. Figure 1(a) is avocado leaf affected by algal leaf spots Figure 1 (b) avocado leaf affected by powdery mildew. Figure 1(c) avocado leaf affected by perseamite avocado leaf burned. Figure 1(d) healthy avocado leaf Figure 1(e) avocado leaf burned

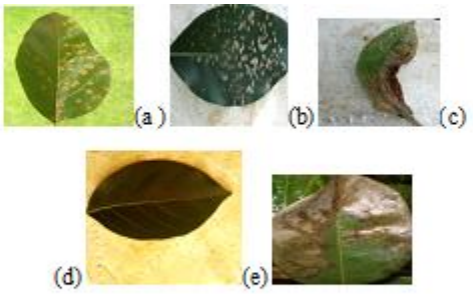

Figure 1: Leaves Affected with Diseases

4.2 PreProcessing

Each image was resized into a unified dimension and scaled to have identical widths and heights before fed to the learning algorithm. All images were annotated using tensor flow object detection format. The following preprocessing was applied to each image. The image was resized into 224x224, Auto-contrast via histogram equalization.

Augmentation such as, Horizontal and vertical flip, 90 – degree rotation of the clock wise, anticlockwise, up and **down, cropping** image between 0.1 and 0.5 manually by making square around the leaf, to position **the region** of interest as the image has different regions of interest, rotation between -45 and 45 degree, sheer of between -45 to 45 **degree horizontal** and vertical, brightness adjusted between 0.1 to 0.3 (this means minimum of 0.1 and maximum of 0.3). These were done to increase the size our dataset and expose the neural network to a wide variety of variations of our images. This makes it more likely that our model recognizes objects when they appear in any form and shape. Also it was very important to improve model performance and to reduce overfitting [16]. Unlike traditional machine learning, deep learning algorithms require minimum data preprocessing because, neural networks do most of the heavy lifting in processing an image and extracting features. This means the network learns the filter that in traditional algorithm were hand engineered. This independence from previous knowledge and human effort in feature design are the major advantages [10].

4.3 Feature Extraction

The first layer is a convolutional layer in CNN. The RGB image is an input to the first convolutional layer whereas the feature map is the input to the other convolutional layer. To get a feature map the input image is convolved by the kernel filter to extract important features in a given region. During convolution the researcher considered important parameters such as padding, stride and filter size. Convolutional output denoted as three convolution layers with threeReLU layers which introduces more nonlinearity. The number of convolution filters has been increased by double. After convolution operation, if the feature map result has negative value inside the matrix, the rectified nonlinear activation function (ReLU) is applied after every convolutional operation. The dimension after the activation function is similar to the convolution operation (input shape)

4.4 Detection and Classification

After extraction of learnable features and development of the model the next step is detection and classification of avocado leaf disease using 5 classes. During data collection process the experts detect each disease type and explained about their symptoms and their effects on the avocado plant. This helped the researcher to have little knowledge about the avocado plant leaf diseases.

Confusion matrix is used to classify images into their class by using the test set image (unseen or untrained images). Categorizing the images into five classes such as algal leaf spot, leaf burned, perseamite damaged, powdery mildew and healthy is done. During data collection process the experts grouped each image into their disease class. Based on this data the researcher tries to classify the disease class using CNN model.

5. Experiments and Results

In this work 90%, 80% data set is used for training, 10%, 20% data is used for validation.

Table 1: Dataset size of each class

No	Class	Total number of images
1	Healthy leaf	600
2	Algal leaf spot	600
3	Powdery mildew	600
4	Perseamite damaged	600
5	Leaf burned	600

All the training and testing images pass all preprocessing steps, After pre-processing the data was feed in to CNN model, and the model was trained. The experiment was performed to detect and classify avocado leaf disease. Table 2 shows hyper parameters used for training the CNN model.

Table 2: Hyper Parameters

Hyper parameters	First phase	Second phase	Third Phase
Batch size	32	32	32
Learning rate	0.001	0.001	0.001
Number of epochs	10	15	15
Optimizer	Adam	Adam	Adam

5.1 Training and Testing

5.1.1 Phase One

Using 10 epochs, 2 convolution layers, by splitting the data set into 0.8, 0.2 for training and testing set respectively without dropout. In this phase training accuracy increase from epoch one up to ten and validation accuracy increase from epoch 1 to 5 and decrease at epoch 6 and seven and again increase from epoch 8 to 10. Training and validation loss decrease from 0.87 to 0.0385 and 4.0 to 0.485 respectively from epoch 1 to 10. The training and validation accuracy and validation loss and training loss is shown below in Figure 2 and 3.

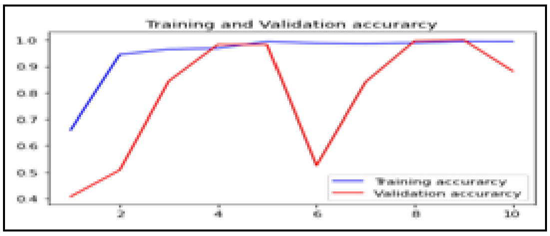

Figure 2: Training and Validation Accuracy of Phase One

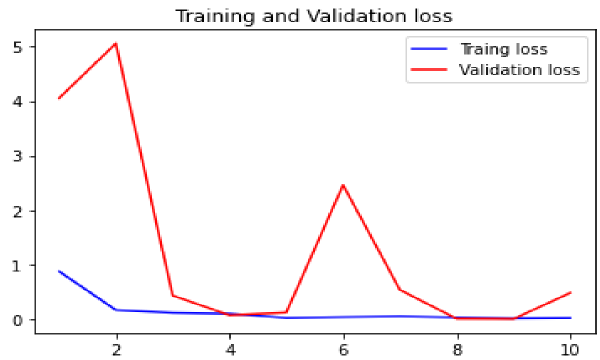

Figure 3: Training and Validation Loss of Phase One

5.1.2 Phase Two

Using 15 epochs, splitting data into 0.9 and 0.1 for training and testing respectively, using Adam optimizer with 0.001 Learning Rate (LR), dropout of 0.25 and Batch Normalization (BN) and batch size of 32. In the second phase training increase and decrease interchangeably up to epoch 13 and from epoch 14 to 15 it increase and validation accuracy also does the same. The training and validation accuracy is 99% and 96% respectively.

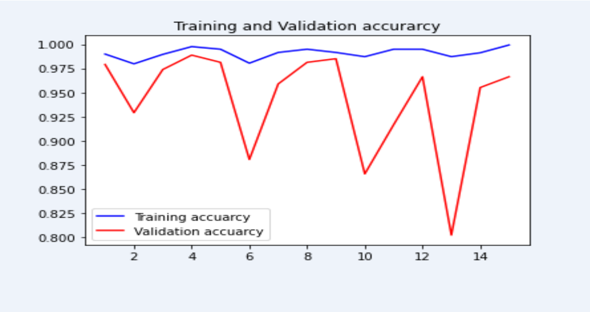

Figure 4: Training and Validation Accuracy of Phase Two

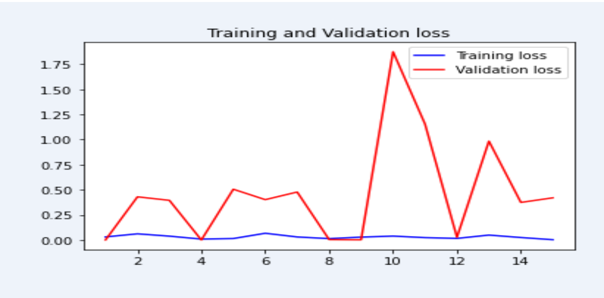

Figure 5: Training and Validation Loss of Phase Two

5.1.3 Phase Three

In third phase of the training 15 epoch, LR 0.001, by using convolution, pooling, fully connected and BN layer and dropout with 0.2 in this phase dropout is decreased by 0.05 since dropout help to reduce overfitting and BN used to stabilize the training process. In this phase the data set is split into 80% for training and 20% for validation. Training and validation accuracy increases when the number of epochs increased and training and validation loss decreases when the number of epochs increased. In the first phase by using ten epochs 98% and 88% of training and validation accuracy is obtained. In the second phase by using BN, dropout and increase the number of epochs by five and with the same LR we had obtained training accuracy of 99% and validation accuracy of 96% which is better than accuracy achieved in first phase. In third phase 100% and 98.8% of training and validation accuracy is obtained. The result shows us by increasing the number of hidden layers and the use of BN increase the training and validation accuracy of the network. By using Batch Normalization, Dropout layer and increasing the number of layers the proposed model has result in good training and validation accuracy which were 100% and 98% respectively. Classifying the testing data into their corresponding class was done using confusion matrix as follow.

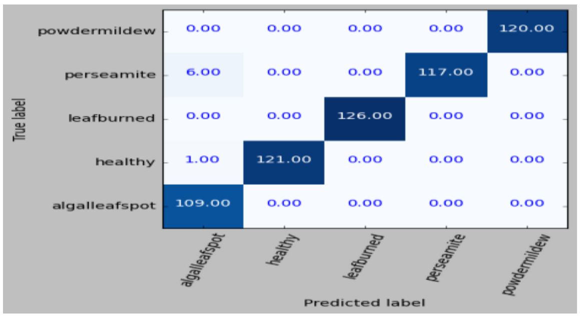

Figure 6: The Result of Confusion Matrix

The confusion matrix is calculated using testing data set which has total of 600 images.

Table 3: The Classification Report

	Precision	Recall	F1 score	Support
Algal leaf spot	0.94	1.00	0.97	109
Healthy	1.00	0.99	1.00	122
Leaf burned	1.00	1.00	1.00	126
Perseamite	1.00	0.95	0.97	123
Powdery mildew	1.00	1.00	1.00	120

6. Conclusion

The CNN model has achieved good result in the classification and detection of avocado leaf disease. The avocado leaf image affected by the disease is collected, preprocessed and important features were extracted and then classification of disease is done. In this research CNN algorithm is used which is the most known deep learning algorithm. It was used for the feature extraction or for the extraction of learnable parameters and requires less image preprocessing method. CNN is designed in a manner that is appropriate for the detection and classification of avocado leaf disease, the network is created by using five inputs which means four disease classes and one healthy class and has four hidden layers which includes convolution layer, maxpooling layer, fully connected layer and normalization layer. In order to achieve better results and minimize the chance of overfitting, batch normalization is performed. Data set is divided into training set for training the model and testing set for evaluating the model performance and classifying the disease detected. To stabilize the training process Batch Normalization is done. Within the three phases we obtained the performance of 0.88 in phase one by using 0.001LR, without BN and drop out. 0.9664 in phase two by using 0.001 LR, BN, drop out and 15 number of epochs and 0.9883 in phase three by using 0.001LR, BN, decreased drop out by 0.05 and 15 number of epochs, 32 batch size for each phase is used. Increasing the number of hidden layers and the use of BN can increase the training and validation accuracy of the network. Avocado plant in Ethiopia is at initial stage that means it is not used so much for the commercial purpose for the large market. In this research the researcher worked only on detection and classification of avocado leaf disease. This provided a scope for the further research. In this work the researcher uses the data set for detecting and classifying only four types of avocado leaf diseases found in Butajira plantation site. There are many other diseases which affect avocado plant which can be considered as a scope for future research. Recommendation for treatment of the disease can be done as a future work. Estimate the level of severity of the disease is also possible as a future work.

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References

[1] Martin. T et al, "Agriculture-in-Ethiopia," 01 Aug 2016. [Online]. Available: https://infomineo.com/agriculture-in-ethiopia-3/. [Accessed 01 Oct 2020].
[2] K. Muthukannan et al, "CLASSIFICATION OF DISEASED PLANT LEAVES USING NEURAL," *ARPN Journal of Engineering and Applied Sciences*, vol. 10, no. 4, pp. 1913- 1920, 2015.
[3] M. A. Singh V, "Detection of plant leaf disease using image segmentation and soft computing," *Info Pro Agr*, 2016.
[4] N. Petrellis, "A Review of Image Processing Techniques Common in Human and Plant Disease Diagnosis," Computer Science and Engineering Department, Technological Educational Institute of Thessaly, 41110 Larissa, Greece, pp. 3-34, 2018
[5] V. Ramya, M. Anthuvan Lydia, "Leaf Disease Detection and Classification using Neural Networks,"*International Journal of Advanced Research in Computer and Communication Engineering*, pp. 1-2, 2016.
[6] S. Y. W. Z. C. a. Weizheng, "Garding method for leaf spot disease based image processing," in *International coference for computer science and software engineering* , Washington, DC, 2008.
[7] A. A. Mohammed N, "Classification of Avocado Using Deep Learning,"*International Journal of Academic Engineering Research*, vol. 3, no. 12, pp. 30-34, 2019.
[8] George A. Zentmyer, Diseases of the Avocado, Washington D.C: United States Department of Agriculture, 1953.
[9] V. K. Shrivastava, M. K. Pradhan, S. Minz and M. P. Thakur, "RICE PLANT DISEASE CLASSIFICATION USING TRANSFER LEARNING OF DEEP," *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science*, Vols. XLII-3/W6, pp. 631-638, 2019.
[10] Ch. Usha Kumari, S. Jeevan Prasad, G. Mounika, "Identification of Leaf Spot Disease in cotton and tomato using image processing techniques," *Third International Conference on Computing Methodologies and Communication*, pp. 1095-1098, 2019.
[11] Jihen Amara, Bassem Bouaziz and Alsayed Algergawy, "Adeep learning -based approach for Banana Leaf Disease classification," *Digital Research Center of Sfax*, pp. 79-87, 2017.
[12] M. Akila ,P. Deepan, "Detection and Classification of Plant Leaf Diseases," *International Journal of Engineering Research & Technology (IJERT)*, pp. 1-5, 2018.
[13] D. Deva H, et al, "Mulberry Leaf Disease Detection using Deep Learning," *International Journal of Engineering and Advanced Technology (IJEAT)*, pp. 3366-3370, 2019.
[14] J. S. Garima Tripathi1, "An image processing and neural network based approach for detection and classification of plant leaf disease," *International journal of comuter engineering and technlogy*, pp. 14-20, 2015.
[15] Rajasekaran Thangaraj et al, "Automatic Recognition of Avocado Fruit Diseases using Modified Deep," *nternational Journal of Grid and Distributed Computing*, pp. 1550-1560, 2020.

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