

Deep Learning-Based Disease Detection in Citrus Plants: A Comparative Analysis

A thesis

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Bachelor of Science in Computer Science and Engineering

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CANDIDATES' DECLARATION

We, hereby, declare that the thesis presented in this report is the outcome of the investigation performed by us under the supervision of Mr. Md. Reasad Zaman Chowdhury, Department of Computer Science and Engineering, Ahsanullah University of Science and Technology, Dhaka, Bangladesh. The work was spread over two final year courses, CSE400: Project and Thesis I and CSE450: Project and Thesis II, in accordance with the course curriculum of the Department for the Bachelor of Science in Computer Science and Engineering program.

It is also declared that neither this thesis nor any part thereof has been submitted anywhere else for the award of any degree, diploma or other qualifications.

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CERTIFICATION

This thesis titled, “**Deep Learning-Based Disease Detection in Citrus Plants: A Comparative Analysis**”, submitted by the group as mentioned below has been accepted as satisfactory in partial fulfillment of the requirements for the degree B.Sc. in Computer Science and Engineering in April 2024.

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ABSTRACT

Citrus diseases pose significant threats to fruit trees, impacting both agricultural productivity and the economic livelihood of farmers. Among these diseases, black spot, greening, canker, and melanose stand out as particularly detrimental to citrus orchards, affecting varieties such as lemon, grapefruit, lime, and orange. The manifestation of these diseases leads to reduced fruit yield and compromised fruit quality, thereby diminishing profitability and farmers' livelihoods. To address this challenge, this study focuses on the early detection of citrus diseases using object detection models, namely YOLOv5, YOLOv8, and YOLOv9. By training these models with annotated datasets containing images depicting disease-related lesions, discoloration, and abnormal patterns on citrus plants, we aimed to develop a robust system for disease identification. Our dataset comprised over 5300 images sourced from various online platforms and custom collections. Through rigorous training and validation, YOLOv9 emerged as the most effective model, achieving high accuracy rates in detecting melanose (99.5%), black spot (77.00%), canker (87.30%), greening (58.40%), and healthy citrus plants (98.30%). This research contributes to the development of efficient tools for disease detection in citrus farming, ultimately aiding in the preservation of citrus plants health and farmer livelihoods.

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Chapter 1

Introduction

Citrus, encompassing a diverse array of fruits such as lemons, limes, grapefruits, oranges, and tangerines, holds significant importance in global agriculture and consumption patterns. These acidic fruits find their way into various culinary delights, from refreshing lemonades to tangy orange juices enjoyed by people worldwide. However, despite their popularity and widespread cultivation, citrus trees are susceptible to a range of diseases that pose significant challenges to farmers and consumers alike. Common afflictions include black spot([fig. 2.1](#)) , canker([fig. 2.4](#)) , greening([fig. 2.2](#)) , and melanose([fig. 2.3](#)) , which can devastate citrus crops, leading to financial losses for farmers and diminished quality or availability of produce for consumers and pose significant threats to citrus production, leading to yield losses, reduced fruit quality, and economic hardships for farmers [[10](#)].

The motivation behind addressing the issue of citrus disease detection stems from the dire consequences these diseases impose on both agricultural economies and food security and to employ deep learning techniques for disease detection in citrus plants [[11](#)]. Farmers face substantial financial losses due to reduced crop yields, compromised fruit quality, and even complete loss of harvests when diseases ravage citrus orchards. Moreover, the ripple effects extend to consumers, who may experience limited access to fresh citrus fruits or encounter higher prices due to supply shortages resulting from disease outbreaks. In light of these challenges, early detection and intervention are paramount to mitigate the spread of citrus diseases and safeguard agricultural livelihoods and food supplies and can also save from economic loss as well as save from reduced crop yield and compromise the quality of produce. This scale of food loss and waste harms not only human health and nutrition but also economies and the environment. Wasted food takes a major financial toll, costing the global economy more than \$ 1 trillion every year, according to WORLD RESOURCES INSTITUTE [[12](#)].

One of the primary obstacles in combating citrus diseases lies in the difficulty of early detec-

tion. While visual symptoms such as leaf discoloration, black spots, and lesions can indicate the presence of disease, accurately identifying and diagnosing these symptoms across vast citrus orchards is a labor-intensive and time-consuming task. Moreover, human visual inspection is prone to errors and inconsistencies, leading to delayed or inaccurate diagnoses, which can exacerbate the spread of diseases and amplify economic losses for farmers.

To address the shortcomings of existing disease detection methods, particularly in terms of accuracy, efficiency, and scalability, this work endeavors to harness the power of deep learning algorithms for automated citrus disease detection [13]. Leveraging advancements in computer vision and machine learning, the goal is to find the best model capable of accurately identifying citrus diseases based on visual cues captured in images of citrus trees and leaves. By training a deep learning model on a comprehensive dataset comprising thousands of annotated images representing various citrus diseases and their symptoms, it is envisaged that the resulting system will offer a reliable and efficient means of disease detection.

Prior to embarking on the development of the detection system, an extensive review of existing literature and research on citrus diseases was conducted to gain insights into the underlying causes, symptoms, and detection methodologies. By synthesizing knowledge from diverse sources, including academic papers, agricultural studies, and industry reports, a comprehensive understanding of the challenges and opportunities in citrus disease detection was acquired. This foundational knowledge served as the bedrock for designing and implementing an effective detection solution grounded in empirical evidence and best practices.

Central to the development of the citrus disease detection system is the creation and curation of a high-quality dataset comprising thousands of annotated images. Drawing upon both publicly available datasets and proprietary sources, over 5300 images were collected, encompassing a wide range of citrus diseases and their visual manifestations. To ensure the accuracy and diversity of the dataset, rigorous manual sampling and annotation processes were employed, resulting in a representative collection of images that capture the variability and complexity of citrus diseases in real-world settings. The dataset was then partitioned into training, validation, and testing sets for evaluating the model's accuracy and generalization capabilities. This systematic approach to dataset partitioning ensures robust model training and evaluation, minimizing the risk of overfitting while maximizing the model's ability to generalize to unseen data and real-world scenarios.

Several state-of-the-art deep learning models, including YOLOv5, YOLOv8m, and YOLOv9m, were evaluated for their suitability and performance in citrus disease detection. By benchmarking these models against the annotated dataset, key metrics such as accuracy, precision, recall, and computational efficiency were assessed to identify the most effective model for

deployment in the detection system. Through iterative experimentation and fine-tuning, the optimal model architecture and parameters were determined, culminating in a robust and reliable solution for automated citrus disease detection.

In summary, this work represents a concerted effort to address the pressing challenge of citrus disease detection through the application of deep learning techniques. By leveraging advances in computer vision and machine learning, coupled with a comprehensive dataset and rigorous evaluation framework, the developed system offers a scalable and accurate solution for early detection and mitigation of citrus diseases. Through collaboration with farmers, it is envisioned that this technology will not only empower agricultural communities to safeguard their livelihoods but also contribute to global efforts to ensure food security and sustainability in the face of emerging agricultural challenges. This paper is organized

as follows: The introduction (Chapter 1) provides an overview of the motivation behind the research and outlines the common problems associated with existing citrus disease detection methods. In Chapter 2, a comprehensive literature review is presented, including discussions on citrus diseases such as canker, melanose, greening, and blackspot, along with an examination of related works in the field of agricultural technology and disease management. Chapter 3 serves as a background study, covering essential concepts such as Convolutional Neural Networks (CNN), pooling, general object detection models, and specific models like YOLO (You Only Look Once), including its architecture and variants such as YOLOv5, YOLOv8, and YOLOv9. Methodology details are provided in Chapter 4, including image pre-processing techniques, dataset acquisition methods, annotation processes, dataset distribution, model training steps, and performance measurement criteria. The results and analysis are presented in Chapter 5, where the performance of each model (YOLOv5, YOLOv8, and YOLOv9) is evaluated, and comparative analyses are conducted to determine the most effective approach for citrus disease detection. Validation batch predictions and final analyses are also included in this chapter. Chapter 6 concludes the paper by summarizing key findings and discussing implications for future research and practical applications. Finally, Chapter 7 outlines potential avenues for future work, while the References section provides a comprehensive list of cited sources for further reading and reference.

Chapter 2

Literature Review

2.1 Citrus Diseases

- **Citrus Black Spot:**

Citrus black spot, caused by the fungus *Phyllosticta citricarpa* [14], is a significant fungal disease affecting citrus plants worldwide. The disease manifests as dark, sunken lesions on fruit, leaves, and twigs, leading to reduced fruit quality and yield. Infection occurs through spore penetration into the plant's tissues, facilitated by rain or overhead irrigation. Warm and humid conditions favor disease development. Citrus varieties such as sweet orange (*Citrus sinensis*) and mandarin (*Citrus reticulata*) are particularly susceptible. Cultural practices such as pruning and removal of infected plant material, along with fungicide applications, are commonly employed to manage the disease [15].



Figure 2.1: Black Spot

- **Citrus Greening:** Citrus greening, also known as Huanglongbing (HLB), is a devastating bacterial disease caused by *Candidatus Liberibacter* species. It affects various citrus species, including oranges, grapefruits, and lemons, leading to asymmetrical

yellowing of leaves, stunted growth, and bitter, malformed fruits. The disease is primarily spread by the Asian citrus psyllid (*Diaphorina citri*) vector. Once infected, there is currently no cure for citrus greening, and affected trees typically decline rapidly, necessitating their removal to prevent further spread. Management strategies involve vector control, removal of infected trees, and planting of disease-free citrus varieties [16].



Figure 2.2: Greening

- **Citrus Melanose:**

Citrus melanose, caused by the fungus *Diaporthe citri*, is a common disease affecting citrus trees in subtropical regions. It appears as small, dark, sunken lesions on leaves, stems, and fruit, reducing aesthetic appeal and market value. Melanose infection occurs through wounds or natural openings in the plant tissue, facilitated by rain or wind-driven rain. Warm and humid conditions favor disease development. Citrus cultivars such as grapefruit (*Citrus paradisi*) and lemon (*Citrus limon*) are particularly susceptible. Management strategies include cultural practices like pruning, removal of infected plant parts, and fungicide applications during the growing season [17].



Figure 2.3: Melanose

- **Citrus Canker:**

Citrus canker, caused by the bacterium *Xanthomonas citri* subsp. *citri* [18], is a highly contagious disease affecting citrus plants, resulting in characteristic raised, corky lesions on leaves, fruit, and stems. The disease causes defoliation, premature fruit drop, and bark cracking, leading to reduced fruit yield and quality. Citrus canker is primarily spread through wind-driven rain, insects, and contaminated tools. Various citrus species, including lime (*Citrus aurantiifolia*) and grapefruit, are susceptible to the disease. Control measures involve prompt removal and destruction of infected plants, strict quarantine measures, and copper-based bactericides



Figure 2.4: Canker

2.2 Related Works

The strategies that are relevant to this project approaches are classified into three major categories. They are RT-PCR ASSAY, CNN and YOLO. The publications that are relevant to this work was also mentioned. The following sections go through the specifics of these projects.

2.2.1 RT-PCR ASSAY

RT-PCR (Reverse Transcription Polymerase Chain Reaction) is pivotal in citrus disease detection, providing crucial accuracy and sensitivity. It swiftly identifies pathogens like *Candidatus Liberibacter asiaticus*, aiding prompt intervention to prevent crop loss. RNA from plant samples is converted to cDNA, then amplified through PCR cycles targeting pathogen genetic material. Fluorescent probes monitor amplification in real-time, indicating pathogen presence. RT-PCR quantifies pathogen abundance, aiding diagnosis and management decisions. It's a rapid, sensitive, and specific method empowering growers to protect crops and

mitigate losses.

Reverse Transcription Polymerase Chain Reaction assay plays a crucial role in the detection of diseases in citrus plants, offering a sensitive and rapid method for identifying pathogens [19]. This technique is of paramount importance in citrus agriculture due to the susceptibility of citrus plants to various pathogens, including bacteria, fungi, and viruses, which can cause devastating crop losses if not promptly identified and managed [20]. RT-PCR is particularly valuable because it can detect low levels of pathogen nucleic acids, even in cases of latent infections where symptoms may not be readily apparent [15]. The process of RT-PCR involves several steps: first, nucleic acids are extracted from citrus plant samples suspected of harboring pathogens. Then, reverse transcription is performed to convert RNA into complementary DNA (cDNA) using reverse transcriptase enzyme [21]. Subsequently, PCR amplification is carried out using primers specific to the target sequences of interest, facilitated by DNA polymerase enzyme [22]. The amplified DNA is then detected using fluorescent dyes or probes, enabling real-time monitoring of the amplification process [23]. RT-PCR's ability to provide rapid and accurate detection of citrus plant pathogens allows for timely implementation of disease management strategies, ultimately safeguarding citrus crops and ensuring agricultural sustainability [24].

In a recent work by Yao, Wu and Hung (2023) [25], multiplex RT-PCR assay method is introduced for the simultaneous detection of four diseases that commonly affect citrus crops. These diseases are Citrus Tristeza Virus (CTV), Citrus Psorosis Virus (CPsV), Citrus Tatter Leaf Virus (CTLV) and Citrus Variegated Chlorosis (CVC). All of the diseases are big concerns for citrus farming. The potential implications of the multiplex RT-PCR assay in the citrus industry includes disease management, cost and time savings. The paper highlights on molecular diagnostic techniques, offering an alternative to deep learning models for disease detection in citrus. The study did not employ YOLO (You Only Look Once) as it's designed for image/video object detection, while the focus was on developing a multiplex RT-PCR assay for molecular pathogen detection in citrus plants, rendering YOLO unsuitable for this purpose.

2.2.2 CNN

Convolutional Neural Networks (CNNs) have emerged as a pivotal technology in the realm of citrus plant disease detection, driven by their capacity to automate and enhance the accuracy of diagnosis [26]. These neural networks operate by learning hierarchical representations of input data through a series fig. 3.3 of convolutional layers, pooling layers, and fully connected layers [27]. Trained on extensive datasets comprising images depicting both healthy and diseased citrus plants, CNNs are adept at discerning subtle visual cues indicative of various diseases affecting citrus crops [28]. Once trained, they analyze new images

and classify them as healthy or diseased based on learned features, thereby streamlining diagnostic processes [29]. This automated analysis replaces subjective human inspection, leading to more efficient and objective disease identification [30]. CNNs also offer real-time insights into disease prevalence and distribution, allowing for timely interventions to prevent crop losses [31]. Moreover, their potential to facilitate smartphone-based applications or portable diagnostic devices for field use further enhances their importance in citrus plant disease detection (Patel et al., 2018). In summary, CNNs represent a transformative technology in this domain, empowering growers and agricultural authorities to combat diseases effectively and safeguard citrus crops [32].

Recent advancements in deep learning have sparked interest in leveraging this technology for the detection and management of citrus plant diseases. Traditional methods of disease diagnosis in citrus, such as visual inspection by experts, are often subjective and time-consuming [33]. Deep learning techniques, particularly Convolutional Neural Networks (CNNs), have shown promise in automating disease detection tasks by analyzing large datasets of citrus plant images [34]. By training CNN models on diverse sets of annotated images, researchers have successfully identified various citrus diseases, including citrus canker, citrus greening, and citrus black spot, based on visual symptoms such as leaf discoloration and lesions [35] [36]. This approach offers a potential solution for early disease detection and management in citrus orchards, paving the way for more efficient disease control strategies in agriculture.

The researchers [37] utilized Convolutional Neural Networks (CNNs) to address the challenge of plant disease detection in agriculture. CNNs are ideal for this task due to their ability to automatically learn complex patterns from image data. In their proposed Channel–Spatial segmentation network, CNNs are employed in two main stages: channel attention and spatial attention. Channel attention discriminates between healthy and diseased parts of leaves by focusing on channel-specific features, while spatial attention refines the detection by considering spatial relationships within the image. This sequential approach effectively highlights diseased regions in leaf images. The overall result of using CNNs in this network is highly accurate disease prediction, with a remarkable accuracy rate of 99.76%. This demonstrates the efficacy of CNNs in automated plant disease detection, providing farmers with a reliable tool for early disease diagnosis and management in agriculture.

In their 2022 study, Saebom Lee and her team proposed an automated classification system using deep learning for the recognition of pests that affect citrus crops. [38]. The system used Convolutional Neural Networks (CNNs) to detect common citrus pests. The paper contributes to the field of pest management in citrus agriculture. This is essential for the early detection and control of diseases such as canker, scab, black spot, greening, and melanose which minimize the loss and ensure maximum benefit for the farmers.

In a study in 2023 by B. V. Apacionado and T. Ahamed, Authors focused on the alarming issue of sooty mold in citrus farming. Their research focused on using deep learning algorithms for the early detection and monitoring of fungal disease on citrus trees. Sooty mold easily identifiable by black fungal growth on leaves and branches, poses a significant threat to citrus crop health and production. The research aims to swiftly and accurately identify sooty mold at the initial stages. This will enable farmers to take prompt action and mitigate damage quickly. This research contributes valuable insights into the utilization of deep learning techniques in the context of citrus plant disease detection and maintaining healthy plant life and harvesting the maximum amount of healthy fruit [39].

In a study conducted by Lin, Wu, Shen, Yeh and Hung in 2015, authors used multiplex detection and genetic diversity analysis of Hop Stunt Viroid and Citrus Exocortis Viroid in citrus crops. The study mainly focuses on the Taiwan region. The research focuses on the detection and genetic diversity of viroids that infect citrus trees using viroid detection techniques rather than deep learning models. It provides insight to relevant citrus plant diseases and disease detection. In further research, the authors plan to incorporate a deep learning counting mechanism to calculate the canopy area with the highest number of infections for implementing a spot spraying system that can apply the right amount of control on sooty mold infections at the right time. [40]

2.2.3 YOLO

- **YOLOv5:**

YOLOv5 is an iteration within the YOLO (You Only Look Once) family of object detection models, has emerged as a promising tool for citrus plant disease detection. This model is significant in agricultural contexts due to its ability to automate the identification and monitoring of diseases in citrus plants, which is crucial for effective disease management. Through its deep learning architecture, YOLOv5 can analyze images of citrus plants and accurately detect signs of diseases such as citrus greening or citrus canker [41]. This capability facilitates early detection and intervention, enabling farmers to implement timely measures to prevent the spread of diseases and minimize crop losses. YOLOv5 operates by dividing the input image into a grid and simultaneously predicting bounding boxes and class probabilities for each grid cell [42]. By doing so, it achieves real-time inference speeds while maintaining high detection accuracy, making it an indispensable tool for citrus plant disease detection in agricultural settings.

This paper [43] proposed an optimised lightweight YOLOv5 model for plant disease detection and classification using the Plant Village and a self-made peanut diseases dataset. To improve the model's precision and effectiveness, an improved attention

sub-module (IASM) mechanism was used. Weighted boxes fusion (WBF) structures and Ghostnet were employed to reduce model weight as well as combining bidirectional feature pyramid network (BiFPN) and rapid normalisation fusion for weighted feature fusion to hasten the learning rate of each feature layer. The optimised YOLOv5 model for disease classification had accuracy, recall, and F1 scores of 93.73%, 92.94%, and 92.97%, correspondingly. In a research paper published by H. Wang, S. Shang, D. Wang, X. He, K. Feng and H. Zhu, Apple flower was detected using YOLO v5 model with CSP Darknet53 and Pruning of model using channel pruning .The performance Metrics of the model was mAP - 97.31%. [44]

- **YOLOv8**

YOLOv8 represents an advancement from YOLOv5 in the domain of citrus plant disease detection, addressing specific challenges and enhancing performance. The update from YOLOv5 to YOLOv8 typically involves improvements in the model architecture, training techniques, or dataset augmentation strategies [45]. This update is important as it aims to refine the accuracy and efficiency of disease detection in citrus plants, offering farmers more reliable tools for crop management. YOLOv8, like its predecessors, operates on the principle of object detection through deep learning, dividing input images into a grid and predicting bounding boxes and class probabilities for each grid cell [42]. By continuously refining and optimizing the underlying algorithms and methodologies, YOLOv8 strives to achieve better performance in citrus plant disease detection, ultimately contributing to improved agricultural productivity and sustainability.

This paper aims to observe the performance of the YOLOv8 model [46]. Use a small-scale plant disease dataset Here results demonstrate that the combination of YOLOv8s with CA mechanism and transfer learning obtained the best result, yielding mAP0.5 score of 72.2% which surpassed the studies that utilised the same dataset. best result is demonstrated by YOLOv8s with GhostNet and CA mechanism yielding a mAP0.5 score of 69.3%.

The latest YOLOv8 model was just released in the latter half of 2022. For these reasons, this research undertakes the study and development of both a traditional YOLOv8 model and an optimized lightweight deep learning object detection model. [47] These models aim to effectively and accurately detect and classify plant diseases by using a neural network approach by implementing the YOLOv8 model with Ghost module and CA mechanism that overcomes the drawbacks of the traditional systems, warning farmers before any significant losses are incurred. This research will compare and analyze the performance of the proposed model and the conventional YOLOv8 model in the field of plant condition assessment to find out the difference in performance, [48] the detection accuracy of Yolo v5s is 83.36% mAP (mean Average

Precision), the detection speed is 28.57 FPS (Frames Per Second), and the detection accuracy of Yolo v5 Ghost is 80.76% mAP.

- **YOLOv9**

YOLOv9 is the latest iteration in the YOLO (You Only Look Once) series, specifically tailored for citrus plant disease detection. This update from YOLOv5 and v8 signifies ongoing advancements in the field of deep learning and object detection, aiming to further improve accuracy and efficiency in identifying diseases affecting citrus plants [45]. YOLOv9 was developed in response to evolving challenges and demands within agricultural management, where precise and timely disease detection is crucial for preserving crop health. The importance of YOLOv9 lies in its ability to provide farmers with more reliable tools for early disease detection, enabling proactive measures to mitigate crop losses and ensure sustainable agriculture practices. Similar to its predecessors, YOLOv9 operates on the principle of dividing input images into a grid and predicting bounding boxes and class probabilities for each grid cell, leveraging deep learning techniques for efficient object detection [42]. The researchers [4] introduces YOLOv9 for fracture detection in X-ray images, enhancing performance compared to the previous state-of-the-art model by 3.7%. YOLOv9 preserves more information during model training, addressing challenges in low-featured X-ray images. It employs Programmable Gradient Information (PGI) and Generalized Efficient Layer Aggregation Network (GELAN) to improve feature extraction and integration. Experimental results demonstrate YOLOv9's superior performance in real-time object detection and medical image recognition, achieving state-of-the-art results on the GRAZPEDWRI-DX dataset.

Chapter 3

Background study

3.1 Convolutional Neural Network (CNN)

Convolutional neural networks, or CNNs, initially appeared in 1998, but the Large Scale Visual Recognition Challenge in 2012 demonstrated that CNNs could be an effective tool for classifying images. CNN is a deep learning algorithm that can distinguish one object from another in an input image by giving different aspects or objects in the image different weights and biases that can be learned. When compared to other classification algorithms, CNNs require a lot less pre-processing. While filters are manually designed in earlier techniques, CNN is capable of learning these characteristics and filters with sufficient training.

3.2 Pooling

A pooling operation is performed to further simplify the information after each complex operation. Condensed feature maps are created through the pooling process by merely compressing earlier feature maps. The two most popular pooling techniques are max-pooling and average-pooling. Max-pooling is the process of choosing the maximum value, whereas average pooling outputs the average value across the pooling fields. A 2×2 pooling filter is used in a max pooling operation, as seen in Figure 8. The feature map's dimensions have been shrunk from 24 by 24 to 12 by 12.

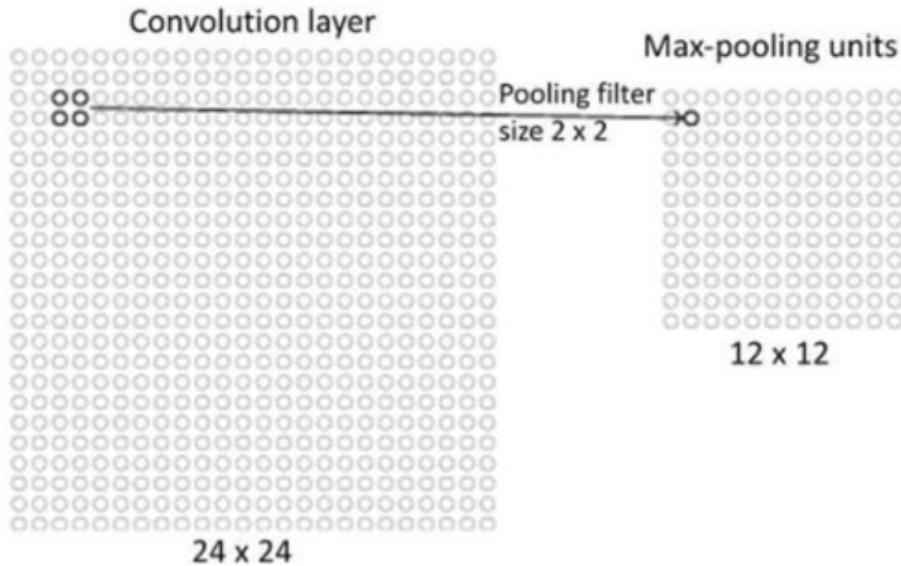


Figure 3.1: Max-pooling. Pooling from 24×24 to 12×12 [1]

Max-pooling will be employed in this experiment for its simplicity and effectiveness, enabling efficient extraction of key features while reducing computational complexity.

3.3 General Object Detection Model

A CNN classifier comes after a region proposal component in Figure 3.2 object detection structure. Several candidate regions are generated by researchers using region proposal techniques; each candidate region may contain a single type of object. The CNN classification algorithm is then applied to each region. A multiple object detection problem is to be transformed into a single object classification problem using the model.

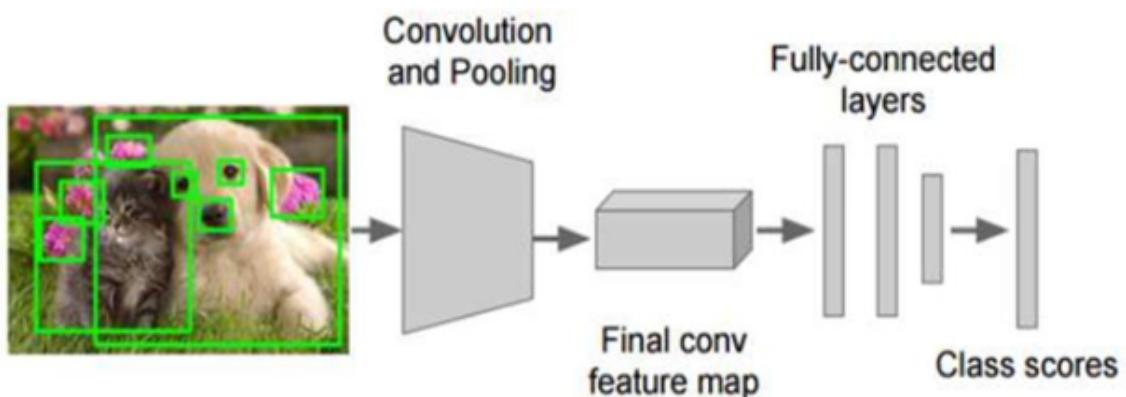


Figure 3.2: Structure of a CNN Based Object Detection Model [2]

Nevertheless, the classification portion of the system is much faster than these region proposal techniques, which causes a bottleneck throughout the entire system. This structure's disadvantage is that, in time-sensitive applications, we are unable to compromise between accuracy and detection speed.

3.4 YOLO

Popular object detection algorithm YOLO (You Only Look Once) is renowned for its accuracy and speed. YOLO splits the image into a grid and predicts bounding boxes and class probabilities for each grid cell simultaneously, in contrast to traditional object detection algorithms that run an image through multiple passes. YOLO is incredibly quick and appropriate for real-time applications.

- **Single Unified Model:**

YOLO approaches object detection as a single regression problem, predicting bounding boxes and class probabilities directly from the full image.

- **Grid Division:**

YOLO divides the input image into a grid, with each grid cell responsible for predicting bounding boxes and class probabilities if an object's center falls within it.

- **Bounding Box Prediction:**

Each grid cell predicts a fixed number of bounding boxes, including bounding box coordinates (x , y , width, height), confidence score, and class probabilities.

- **Feature Extraction Backbone:**

YOLO employs a CNN as a feature extractor, using models like Darknet or ResNet to extract features from the input image.

- **Predictions Across Multiple Scales:**

YOLO makes predictions at multiple scales by applying convolutional layers at different stages of the network.

- **Loss Function:**

YOLO uses a specific loss function that combines localization loss, confidence loss, and classification loss to train the model.

- Non-max Suppression:

YOLO applies non-maximum suppression (NMS) to remove redundant and overlapping bounding boxes after prediction.

- Post-processing:

After NMS, YOLO outputs the final detections with class labels and confidence scores.

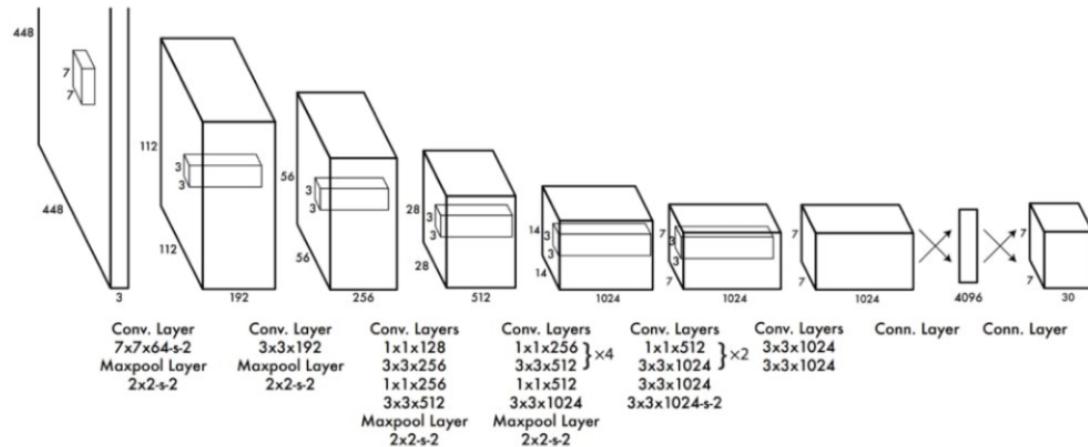


Figure 3.3: Yolo Architecture [3]

In Figure 3.3 the Yolo architecture's initial step in the preprocessing pipeline involves resizing the input image to dimensions of 448x448 before it traverses through the convolutional network. To streamline the channel information, a 1x1 convolutional layer is employed, reducing the channel dimensions. Following this reduction, a subsequent 3x3 convolutional layer is applied to generate a cuboidal output. Throughout the network, the activation function employed is Rectified Linear Unit (ReLU), imparting non-linearity to the model's transformations. However, in the ultimate layer, a linear activation function is utilized. To enhance model regularization and prevent overfitting, batch normalization is integrated into the architecture. Additionally, dropout is strategically implemented to further safeguard against overfitting by randomly deactivating neurons during training. These techniques collectively contribute to the robustness and generalization capabilities of the convolutional network.

The YOLO model uses a methodical approach to object detection in Figure 3.4. First, an input image is first processed and arranged into a $s \times s$ grid. In every grid cell, the model makes two crucial predictions at once. First, it accurately predicts the class labels and bounding box coordinates (x , y , width, and height), which effectively outline the spatial information of possible objects. It also calculates the likelihood that each class will be present in the grid cell. This two-pronged strategy yields a comprehensive detection output by fusing class

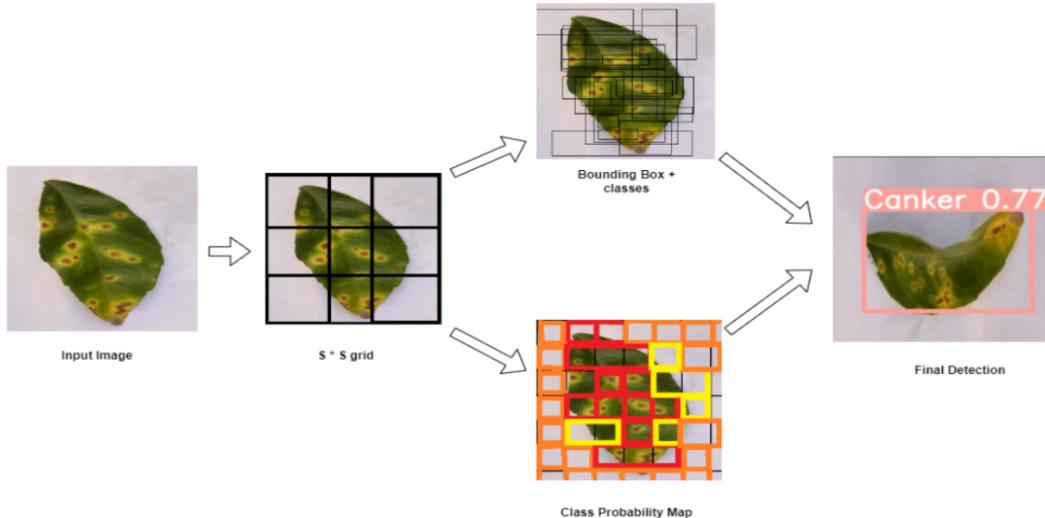


Figure 3.4: How YOLO Works

probabilities with accurate bounding box data. As a result, the final detection output is produced, offering a comprehensive comprehension of item positions and the corresponding class likelihoods.

3.5 Network Structure

The two main, multi-scale components of the entire system are the Feature Extractor and Detector. In order to obtain feature embeddings at three or more different scales, a new image is first passed through the feature extractor. The bounding boxes and class information are then obtained by feeding these features into three or more of the detector's branches.



Figure 3.5: YOLO Network Architecture [2]

3.6 Intersection over Union (IoU)

Intersection over union (IoU) is the default metric used by YOLO to calculate the overlap between two bounding boxes or masks. The Intersection over Union (IoU) evaluation metric, which ranges from 0 to 1, quantifies the overlap between an annotation's predicted boundary and its ground truth boundaries. IoU determines if a forecast is "good enough." The prediction is nearer to perfection the closer it is to 1. The graphical representation of the equation below is shown in Figure 3.6.

$$IoU = \frac{\text{Area of Intersection}/\text{Overlap}}{\text{Area of Union}} \quad (3.1)$$

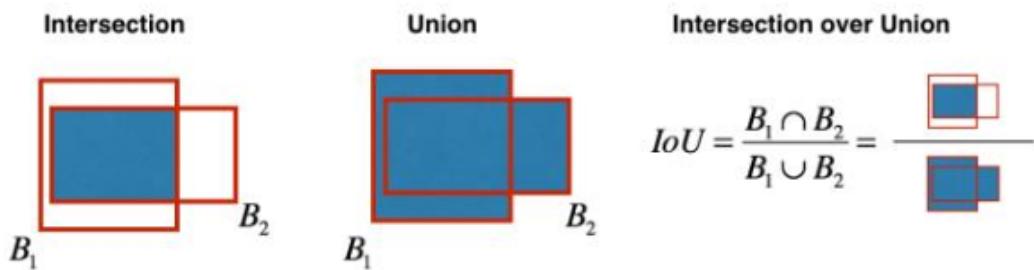


Figure 3.6: Graphical View of the IoU equation [4]

3.7 YOLOv5

Our research has successfully used the YOLOv5 model for citrus disease diagnosis, demonstrating its efficacy in handling complex agricultural problems. In order to train the network, we had to customize a dataset with scenarios related to citrus diseases. This dataset ensures that the model may be used to actual agricultural settings by including a wide variety of photos that depict four disease symptoms and environmental factors.

YOLOv5's architecture consists of three main parts:

- **Backbone:** This is the main body of the network. For YOLOv5, the backbone is designed using the New CSP-Darknet53 structure, a modification of the Darknet architecture used in previous versions.

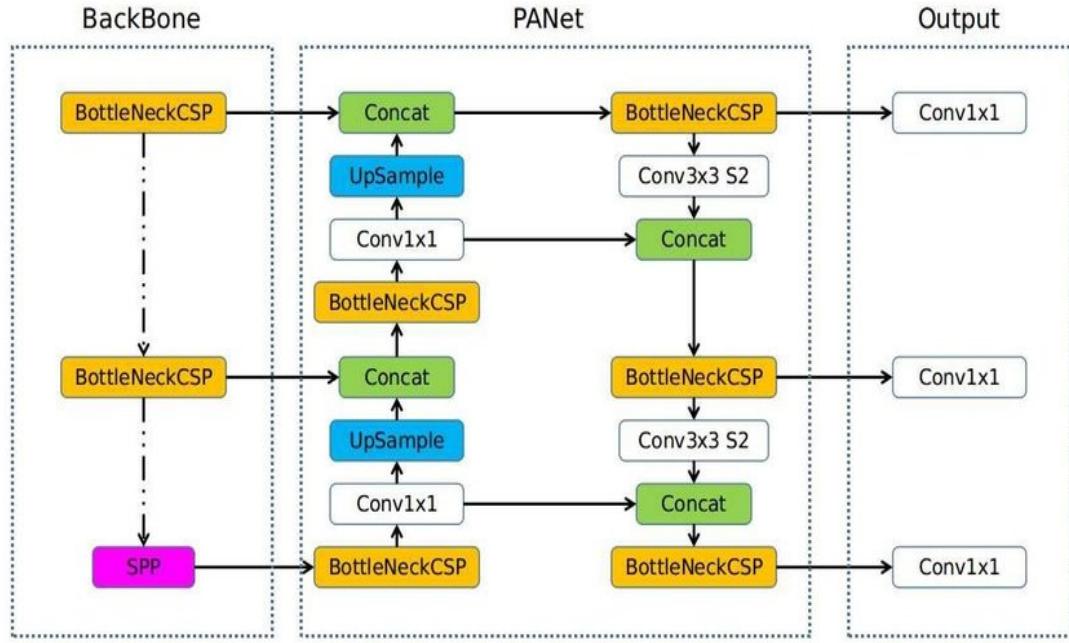


Figure 3.7: YOLOv5 Architecture [5]

- **Neck:** This part connects the backbone and the head. In YOLOv5, SPPF and New CSP-PAN structures are utilized.
- **Head:** This part is responsible for generating the final output.

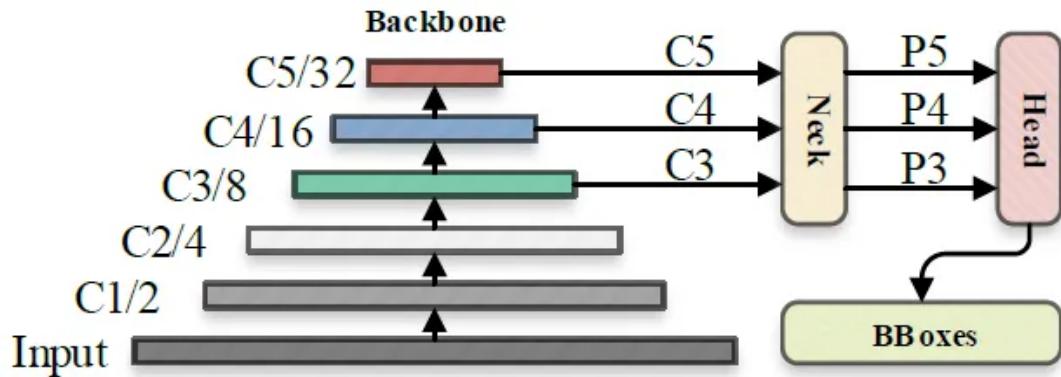


Figure 3.8: YOLOv5 Overall Architecture [6]

After processing by an input layer (input), the dataset was sent to the backbone so that features could be extracted. In order to create three feature maps—P3, P4, and P5 (in the YOLOv5, the dimensions are expressed with the size of 80×80 , 40×40 , and 20×20)—the backbone first obtains feature maps of various sizes. These feature maps are then fused through the feature fusion network (neck) to detect small, medium, and large objects in the picture, respectively. Following the delivery of the three feature maps to the prediction head

(head), bounding-box regression and the confidence calculation were carried out for every pixel in the feature map using the pre-established prior anchor. This resulted in the creation of a multi-dimensional array (BBoxes) that included data on object class, class confidence, box coordinates, width, and height. The final detection information can be output by applying a non-maximum suppression (NMS) process and setting the corresponding thresholds (confthreshold, objthreshold) to filter out the unnecessary data in the array. Models of YOLOv5's are YOLOv5n , YOLOv5s, YOLOv5m, YOLOv5l, YOLOv5x, YOLOv5n6, YOLOv5s6, YOLOv5m6, YOLOv5l6, YOLOv5x6 +TTA . We tried the YOLOv5s with our custom dataset.

3.8 YOLOv8

We used the state-of-the-art YOLOv8 model, the apex of YOLO algorithm advancements in our research work. This most recent version demonstrates unmatched performance in a wide range of vision AI tasks, such as object detection, image categorization, and instance segmentation. The core of our approach was a painstaking training procedure that involves fine-tuning the YOLOv8 model on a custom dataset that was carefully selected to match the subtleties of our particular application domain. This collection of photos encompasses a wide range of situations and circumstances. This thorough training process guarantees the model's durability and dependability in real-world scenarios while also highlighting its adaptability.

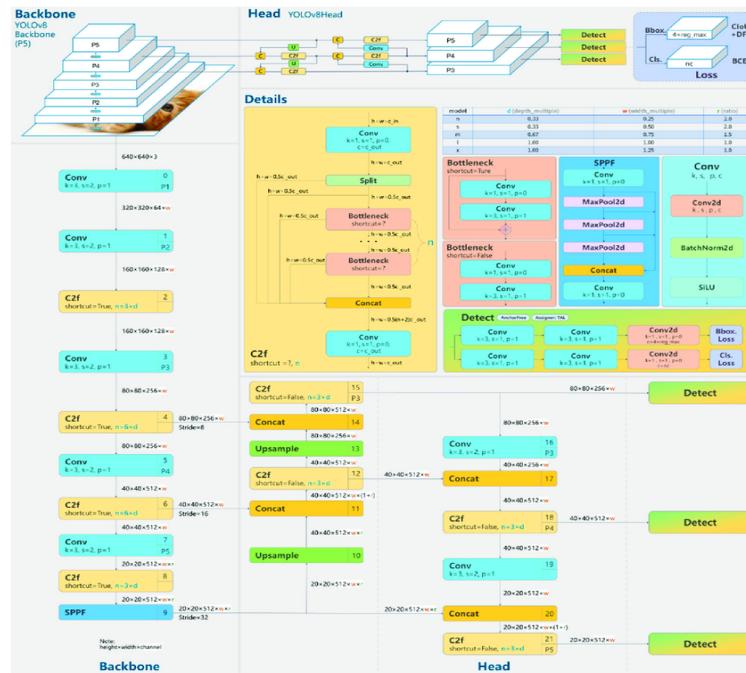


Figure 3.9: YOLOv8 Architecture [7]

The architecture of YOLOv8, which uses a convolutional neural network with two main

components—the head and the backbone—is an evolution of earlier YOLO models. 53 convolutional layers that have been improved with cross-stage partial connections make up the backbone, which is based on a modified version of the CSPDarknet53 architecture. Multiple convolutional layers make up the head, which is followed by fully connected layers that forecast class probabilities, bounding boxes, and objectness scores. Notably, YOLOv8 combines a feature pyramid network for multi-scaled object detection with a self-attention mechanism at the network’s head, allowing it to focus on different areas of an image and identify objects of varying sizes and scales. The main features of YOLOv8 include mosaic data augmentation, anchor-free detection, a C2f module, a decoupled head, and a modified loss function.

Model of YOLOV8's are YOLOv8n, YOLOv8s, YOLOv8m, YOLOv8l, YOLOv8x. In this paper we used YOLOv8m.

3.9 YOLOv9

We also used the most recent YOLOv9 model known for its speed and accuracy, which marks a significant advancement in real-time object detection, introducing groundbreaking techniques such as Programmable Gradient Information (PGI) and the Generalized Efficient Layer Aggregation Network (GELAN).

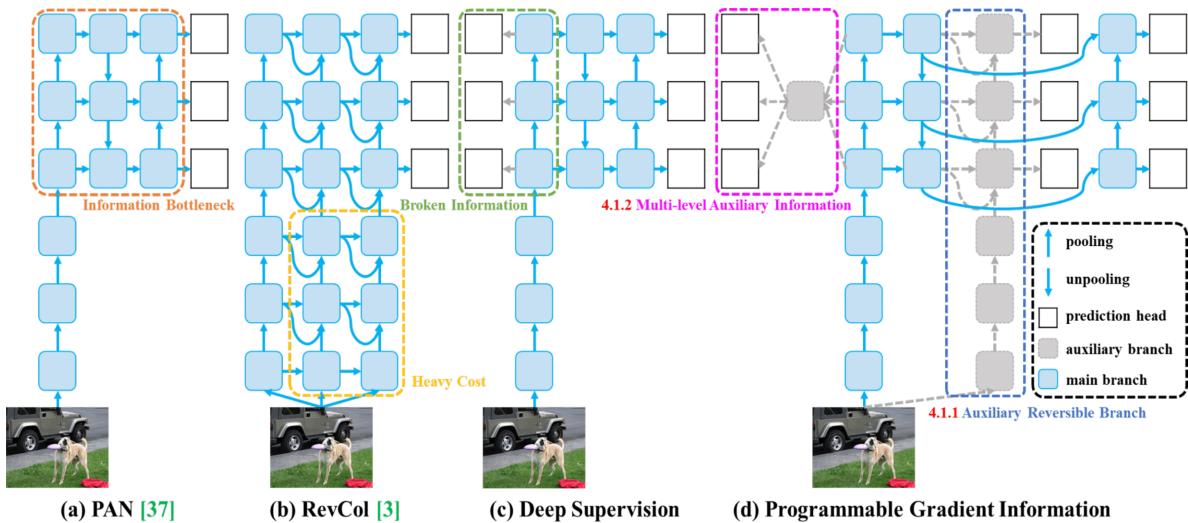


Figure 3.10: YOLOv9 Architecture [8]

In YOLOv9 architecture, firstly, Information Bottleneck Principle strategically compresses data while keeping key object detection details. Secondly, Reversible Functions ensures information isn't lost during processing for accurate updates. And then , Programmable Gradient Information (PGI) improves how the model learns from complex data. Lastly, Gen-

eralized Efficient Layer Aggregation Network (GELAN) optimizes efficiency by strategically combining information within the network. By combining these features, YOLOv9 achieves significant improvements in disease detection accuracy and efficiency.

- **Main Branch Integration:** The YOLOv9 architecture can be easily integrated with the main branch of PGI, which serves as the network's main pathway during inference.
- **Auxiliary Reversible Branch:** Utilizing the auxiliary reversible branch of PGI, it adds more gradient flow channels and more dependable gradients for the loss function.
- **Multi-level Auxiliary Information:** To identify objects of various sizes, YOLOv9 usually uses feature pyramids. YOLOv9 can effectively handle error accumulation problems related to deep supervision by integrating multi-level auxiliary information from PGI, particularly in architectures with multiple prediction branches.

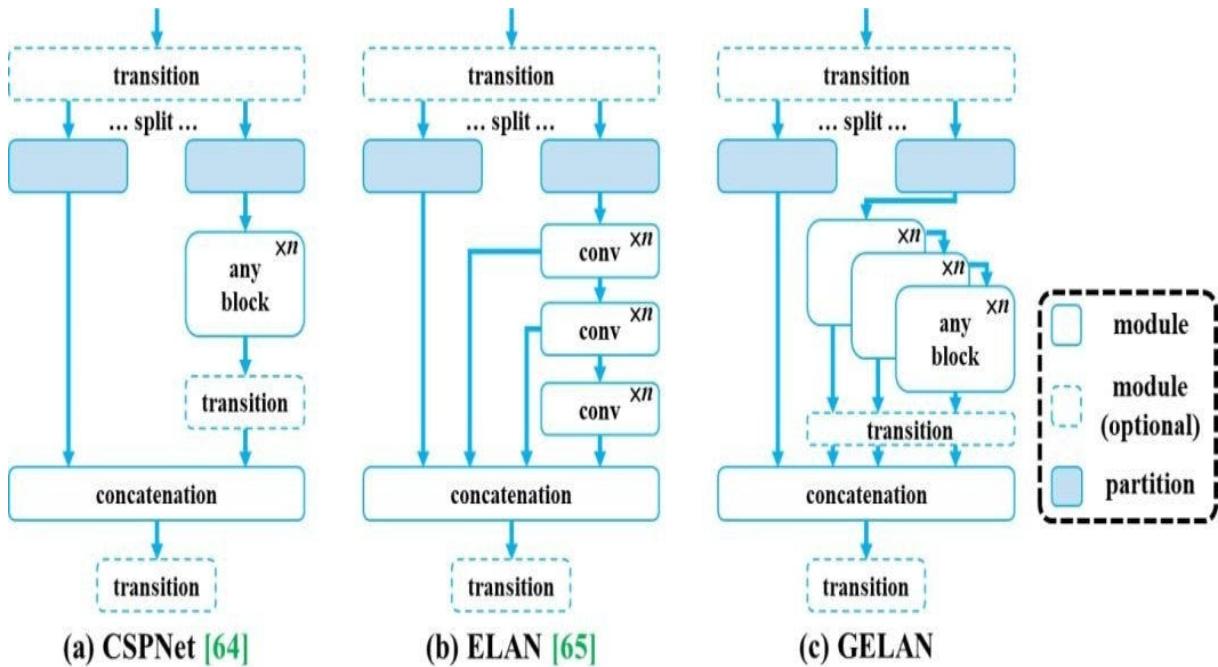


Figure 3.11: GELAN Architecture [9]

For gradient path planning, the Generalized Efficient Layer Aggregation Network, or GELAN, is a cutting-edge architecture that combines CSPNet and ELAN concepts. Accuracy, speedy inference, and lightweight design are given top priority. GELAN ensures flexibility by extending ELAN's layer aggregation and allowing any computational block.

The YOLOv9 architecture leverages a combination of splitting, transitioning (convolution), and concatenation to efficiently extract features from an image and ultimately detect objects within it using CSPNet(Cross Stage Partial Network), ELAN(Efficient Layer Aggregation Network), Generalized Efficient Layer Aggregation Network (GELAN) . Models of YOLOv9's are YOLOv9S, YOLOv9M, YOLOv9C, YOLOv9E. In this paper we used YOLOv9M.

Chapter 4

Methodology

You Only Look Once (YOLO) is a state-of-the-art, real-time object detection algorithm introduced in 2015 by Joseph Redmon, Santosh Divvala, Ross Girshick, and Ali Farhadi in their famous research paper “You Only Look Once: Unified, Real-Time Object Detection”.

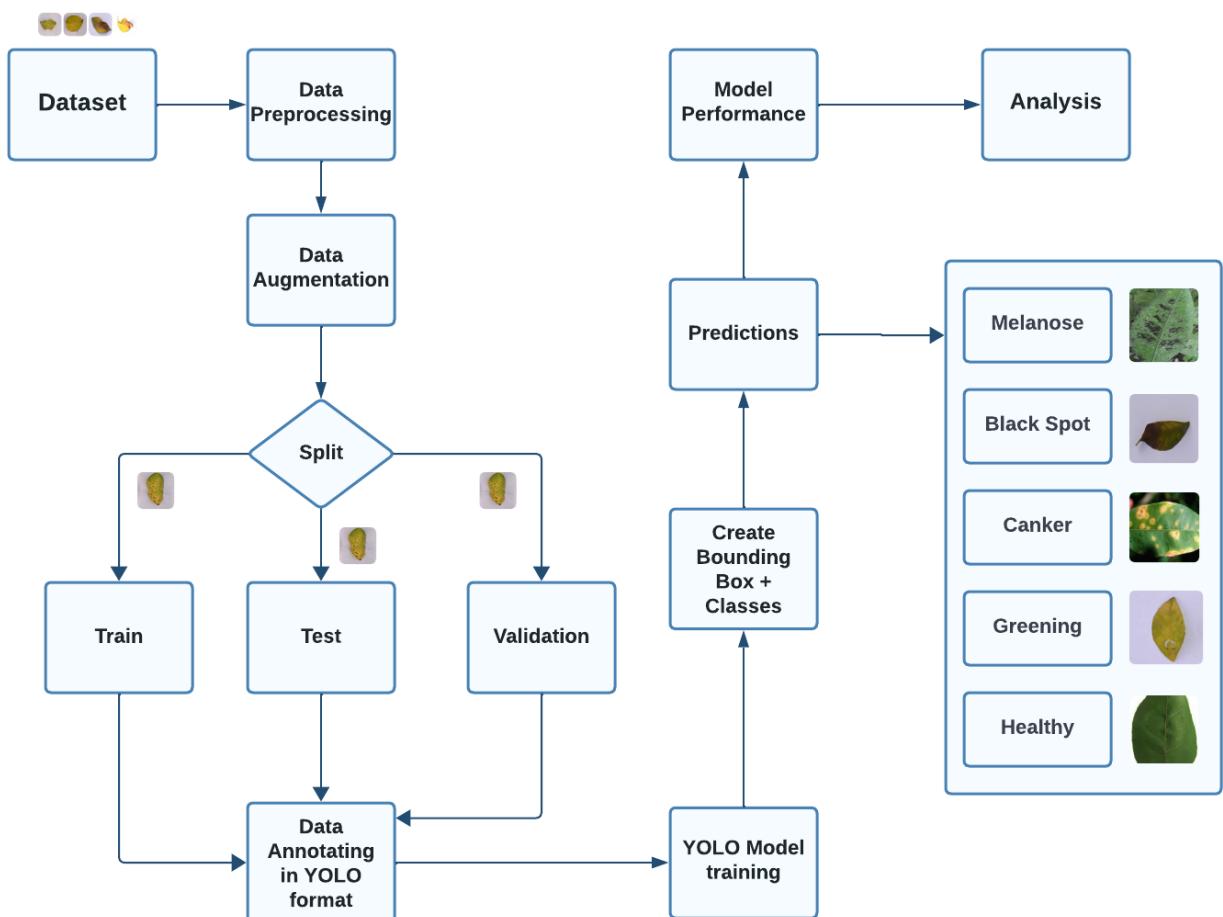


Figure 4.1: Methodology for YOLO models

In the methodology of our research, we initiate the citrus disease detection process using images of citrus plants as the primary input. Employing prepossessing techniques such as resizing, normalization, and noise reduction optimizes image quality for subsequent analysis. The YOLOv5, YOLOv8 and YOLOv9 models, recognized for its object detection capabilities, is loaded and applied to identify potential diseases within the prepossessed images. Post-model inference, diseases are classified into specific categories, such as citrus canker or citrus greening. A critical decision point determines the presence of diseases, leading to further analysis if confirmed or concluding the process if no diseases are detected, indicating the health of the citrus plants. The localization step extracts precise bounding boxes, revealing the spatial coordinates of disease-affected regions. To aid in result interpretation, the image is annotated with labelled bounding boxes, providing a visual representation of disease locations. This streamlined approach facilitates the completion of the citrus disease detection process for subsequent agricultural decision-making or research analysis.

4.1 Image Pre-Processing

Images have to be preprocessed before running the model using them. It is used so that our model can extract the features more easily from the image. It helps to improve the data and give better results. To ensure that parameters such as image size meet the needs of model training and reduce noise during image, it is necessary to preprocess images and unify features, such as image size and color, which, in turn, can expand the number of datasets. The more commonly used Roboflow image preprocessing [4.1](#).

In the case of preprocessing, we used ImageDataGenerator which helps to rotate, zoom, and rescale the images. We used an image size of (224, 224) pixels.

Class Label	Disease Common Name	Scientific Name	Image no	Source% Public	Source% Field
0	Black Spot		226	80	20
1	Canker	Xanthomonas axonopodis pv. citri	2008	70	30
2	Greening		406	60	40
3	Healthy		639	60	40
4	Melanose	Diaporthe citri	9	100	

Table 4.1: Information of Classes

4.2 Dataset Acquisition

This study used a total of 3288 images, taken from the citrus dataset [49] [50]. The infected images were divided into five (one healthy) groups, each representing a different disease of citrus leaves. Black spot, canker, Greening, Melanose and healthy were the diseases we studied in the datasets .and we also added 1000 image and video .Picture were collected and videos were from a near by nursery [51] [52] [53] [54]. The collection device was an Redmi Pro Max, the shooting distance was 15–30 cm, the picture resolution was 3472×4640 pixels ,the picture storage format was JPG the picture dates were Tuesday, October 31, The shooting scene was in natural light conditions. The dataset is diverse, encompassing various environments, lighting conditions, and object classes, thus ensuring robustness and generalization of the trained model. Also, the brightness were labeled to -30% to +30% .

4.3 Annotation Process

For object detection tasks, ground truth labels were added to every image in the dataset through annotation. Bounding boxes with information about the class and location of objects in the photos are included in the annotations.Careful manual verification through Roboflow was used to guarantee annotation accuracy, reducing mistakes and discrepancies in the dataset.

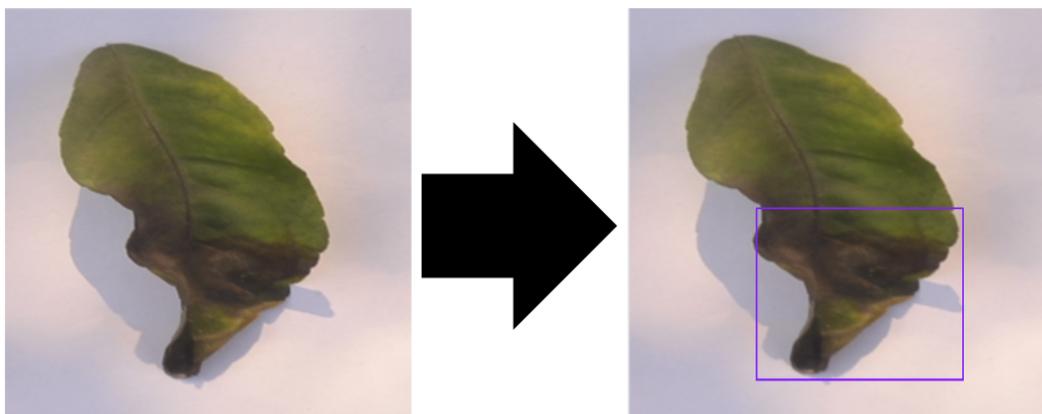


Figure 4.2: Data Annotating in YOLO format

4.4 Dataset Distribution

To facilitate model training, validation, and evaluation, the dataset was split into three subsets:

- **Train:** 70% of the samples were allocated for training purposes, providing a large volume of data to train the model effectively.
- **Validation:** 20% of the samples were reserved for validation, allowing for fine-tuning of model hyperparameters and monitoring training progress.
- **Test:** The remaining 10% of samples were set aside for testing, enabling unbiased evaluation of model performance on unseen data.

4.5 Model Training

It first feeds the image into a special neural network that excels at recognizing patterns. This network extracts clues about potential objects within the image. Next, the image is sliced into a grid, and each grid cell makes predictions. These predictions include where an object might be located (bounding box) and how confident the model is about that prediction (confidence score). Since the same object might be spotted by multiple grid cells, a final step ensures only the most confident prediction for each object remains. This refined list of objects, complete with bounding boxes and confidence scores, is the final output from the YOLO model.

4.6 Performance Measurement

To evaluate the accuracy of the trained model, three different object detection architectures, YOLOv5, YOLOv8m, and YOLOv9m, were employed for comparison. Model performance will be assessed using standard evaluation metrics such as precision, recall, and mean average precision (mAP), calculated based on the predicted bounding boxes and ground truth annotations. Additionally, qualitative assessments of model outputs will be conducted to evaluate the visual quality and correctness of detected objects in sample images. The testing subset of the dataset will be utilized to evaluate the generalization capability of the model and its ability to accurately detect objects in unseen data. Metrics Used for Evaluation:

- **Mean Average Precision (mAP):** This is the primary metric used to evaluate YOLO's performance. It takes into account both precision and recall for all object classes present in the dataset.

$$mAP = \frac{1}{N} \sum_{i=1}^N AP_i \quad (4.1)$$

Where N is the number of classes and AP_i is the Average Precision for class i .

- **Precision:** Precision refers to the proportion of detections that are actually correct. In simpler terms, it represents how many of the objects the model identified as a specific class were truly that class.

$$P = \frac{\text{TruePositives}}{\text{TruePositives} + \text{FalsePositives}} \quad (4.2)$$

- **Recall:** Recall refers to the proportion of actual objects that the model detected. It represents how many of the actual objects present in the image were identified by the model.

$$R = \frac{\text{TruePositives}}{\text{TruePositives} + \text{FalseNegatives}} \quad (4.3)$$

- **F1-score:** The F1-score is a metric commonly used in binary classification tasks, which combines both precision and recall into a single value. It provides a balance between precision and recall and is calculated as the harmonic mean of precision and recall.

$$F1 = 2 \times \frac{\text{precision} \times \text{recall}}{\text{precision} + \text{recall}} \quad (4.4)$$

- **Mean IoU (Intersection over Union):** This metric measures the average overlap between predicted bounding boxes and ground truth bounding boxes across all classes. Higher IoU values indicate better localization accuracy of the detected objects.

$$IoU = \frac{\text{Area_of_Overlap}}{\text{Area_of_Union}}, \quad mIoU = \frac{1}{N} \sum_{i=1}^N IoU_i \quad (4.5)$$

Where N is the number of detections and IoU_i is the IoU for detection i .

Chapter 5

Result Analysis

Below is a list of several indicators that were used to assess the model. These are typical indicators that are used to assess the outcomes intuitively. During the training process, the loss function used in YOLO creates three different types of broken lines. Every training session will produce a node, and for every boundary box, confidence level, and target class, there will be a corresponding broken line. A reduction in the broken line indicates a progressive convergence of the outcome, leading to increased accuracy for the neural network. Every broken line is further separated into two categories, train and val, which stand for various loss function values in the training and verification sets. The broken lines in the training set will typically decrease fairly steadily as the number of training times increases, whereas the broken lines in the verification set are more prone to fluctuations. Additionally, this confusion matrix and broken lines show the precision, recall, and map of a neural network. A node will also be produced by each training. The accuracy of neural network results can be intuitively displayed by these indicators. In general, the accuracy increases with the broken line's height.

5.1 YOLOv5

We first verify the convergence of the model, whose loss can be seen shown in Figure 5.1. For the training procedure, the box loss, obj loss and cls loss decrease with the increase of epochs and tend to be stable finally. We also can observe that the change of loss of verification broken lines are similar to those of training broken lines. The trend of the broken lines shows that the model has basically converged.

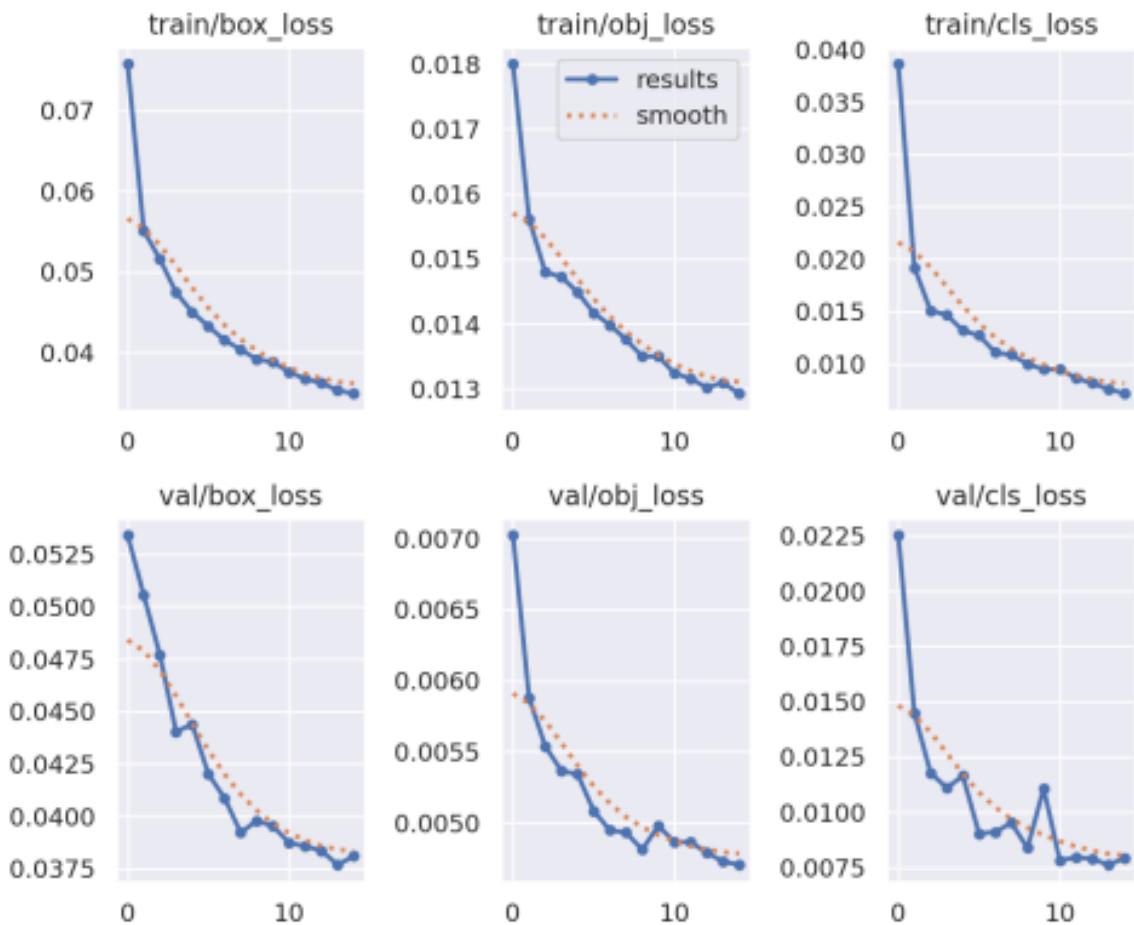


Figure 5.1: Box, Object, Class losses for YOLOv5s

We further analyzed the running results of the model to prove the practicality of it, which are reported in Figure 5.2. We can achieve a precision and recall more than 80%, and a mAP of 86% and mAP of 55% when the threshold are 0.5 and 0.5, 0.95 respectively.

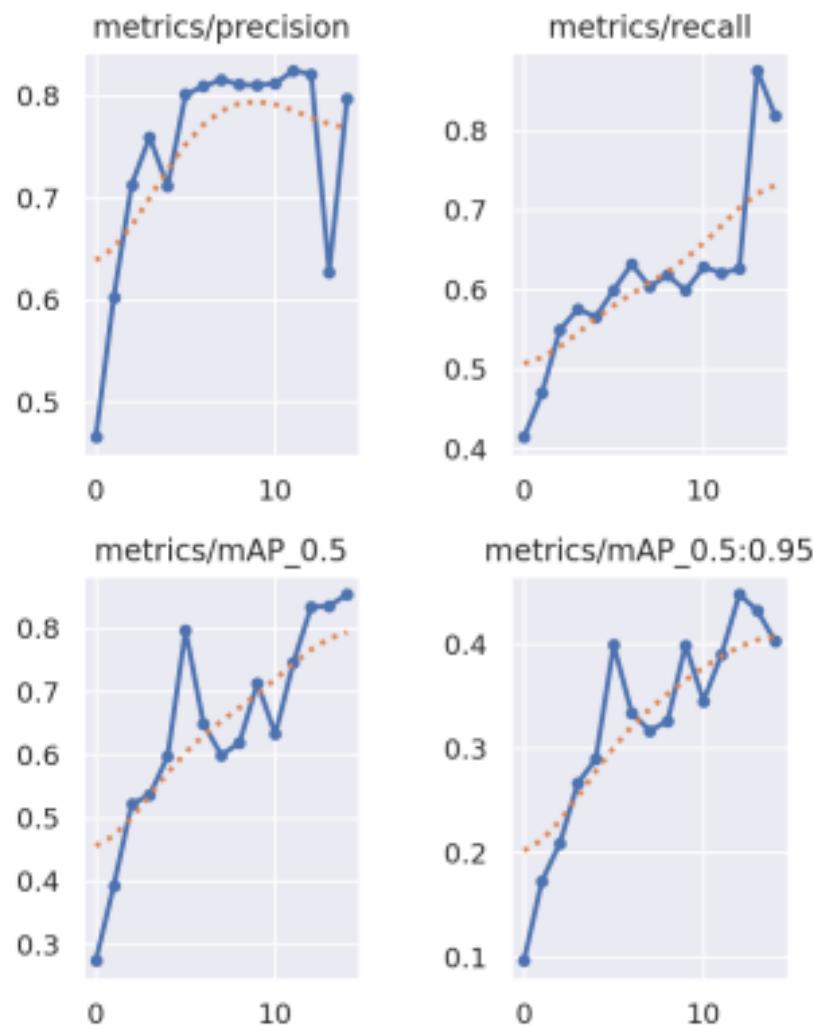


Figure 5.2: Precision, Recall and mAP Evaluation for YOLOv5s

To analyze the detection performance of various categories, we also give the confusion matrix of our method in Figure 5.3 . The results show that we can achieve a precision of 90% for Melanose, precision of 82% for black spot , precision of 84% for canker , precision of 72% for greeninga precision of 95% for healthy. All the results show the effectiveness of our Deep Learning-Based Disease Detection in Citrus Plants: A Comparative Analysis.

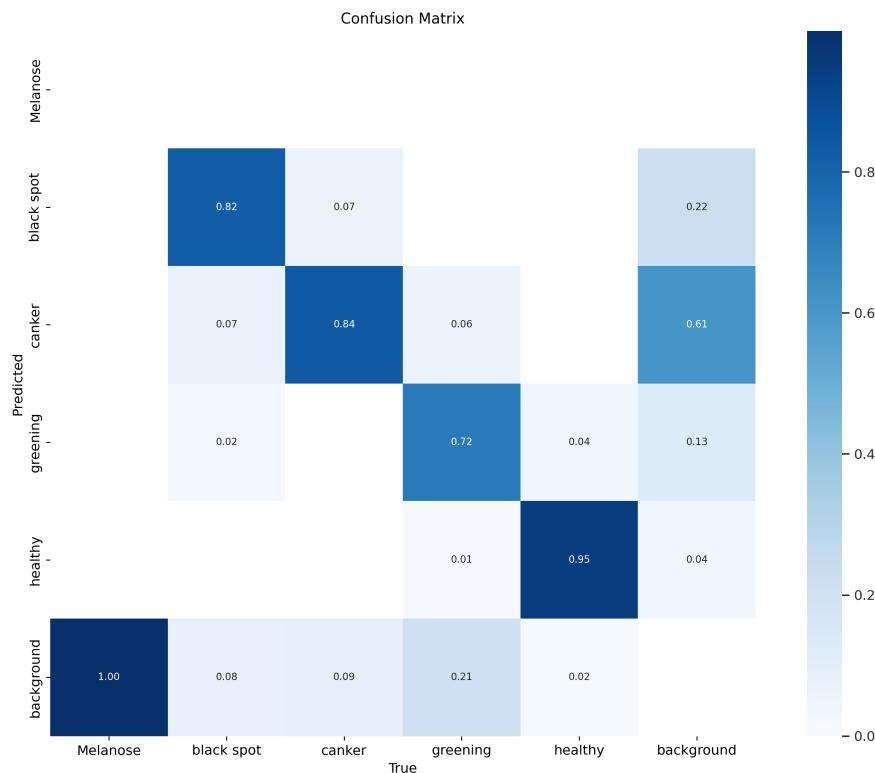


Figure 5.3: Confusion Matrix for YOLOv5s

Model	Variants	Diseases Accuracy					Total Accuracy
		Melanose	Black Spot	Canker	Greening	Healthy	
YOLOv5	B16E10	99.50	73.60	82.80	59.00	95.00	81.80
	B16E15	99.50	74.80	86.40	58.10	98.00	83.40

Table 5.1: Various hyper-parameter analyses of YOLOv5

The table 5.1 compares disease accuracy of YOLOv5 variants B16E10 and B16E15 for various plant diseases: Melanose, Canker, Black Spot, Greening, and Healthy. Both variants excel in Melanose (99.50%), but differ in other diseases. B16E10 performs better in Green-

ing (59.00%), while B16E15 excels in Canker (86.40%) and Black Spot (74.80%). Choosing between variants depends on the target plant disease.

5.2 YOLOv8

We then confirm that the model, whose loss is depicted in Figure 5.4, is converging. In the training process, the box loss and box very up and down, as well as the object loss and class loss, decrease as the number of epochs increases and eventually tend to be stable. Furthermore, we can see that the pattern of lost verification broken lines is similar to that of training broken lines. The broken line trend indicates that the model has essentially converged.

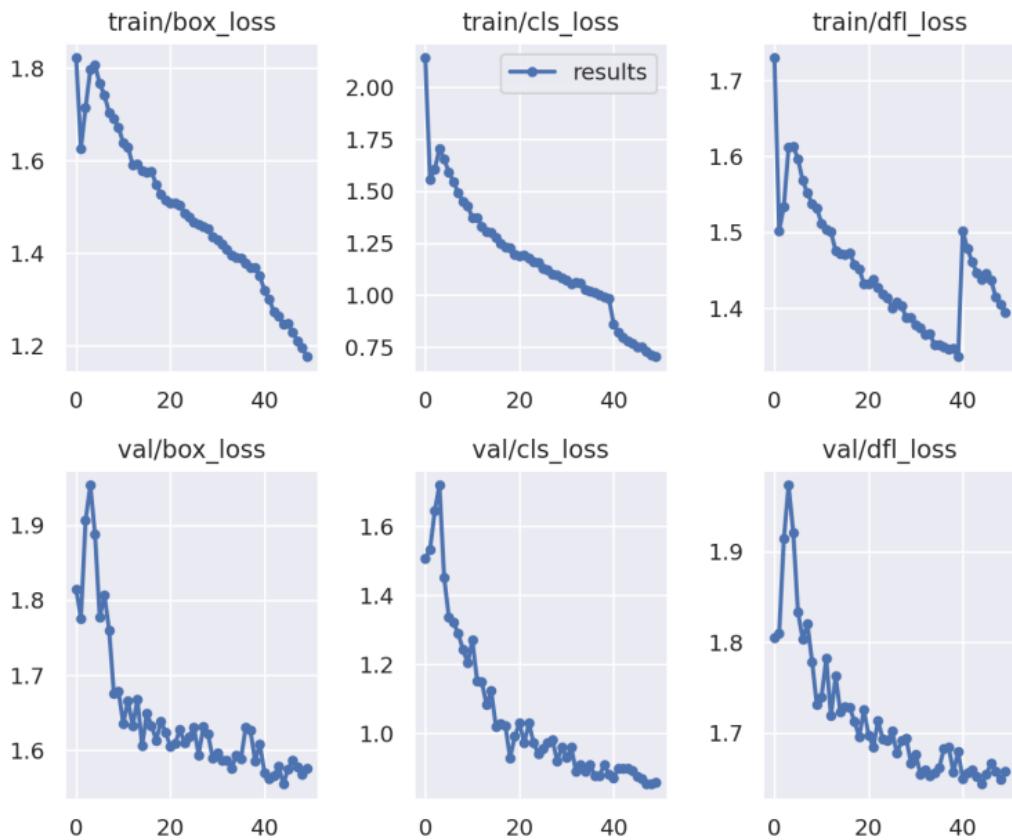


Figure 5.4: Box, Object, Class losses for YOLOv8m

To demonstrate the model's applicability, we examined its running results in more detail; these are shown in Figure 5.5. When the thresholds are set at 0.5 and 0.5 - 0.95, respectively,

we can attain a precision and recall of more than 70%, as well as a mAP of 80% and mAP of 55%.

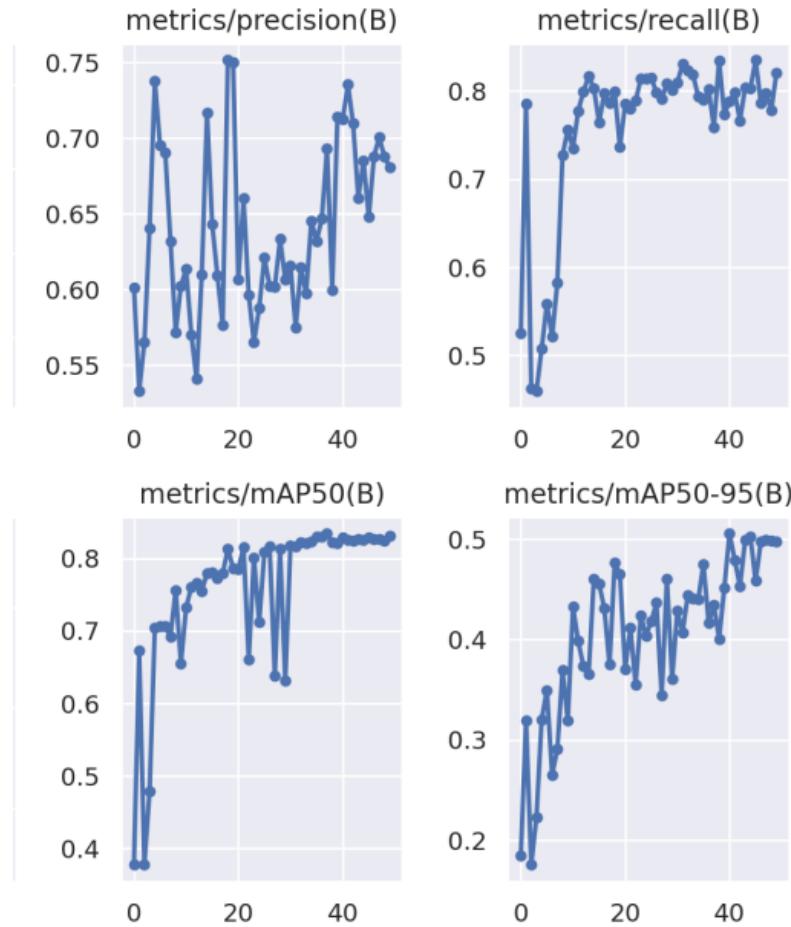


Figure 5.5: Precision, Recall and mAP Evaluation for YOLOv8m

We also provide the confusion matrix of our method in Figure 5.6 for analysis of the detection performance of different categories. Our ability to achieve a precision of 100% for Melanose, 66% for Black Spot, 82% for Canker, 54% for Greening, and 96% for Healthy is demonstrated by the results. Our Deep Learning-Based Disease Detection in Citrus Plants: A Comparative Analysis has been proven effective based on all the results.

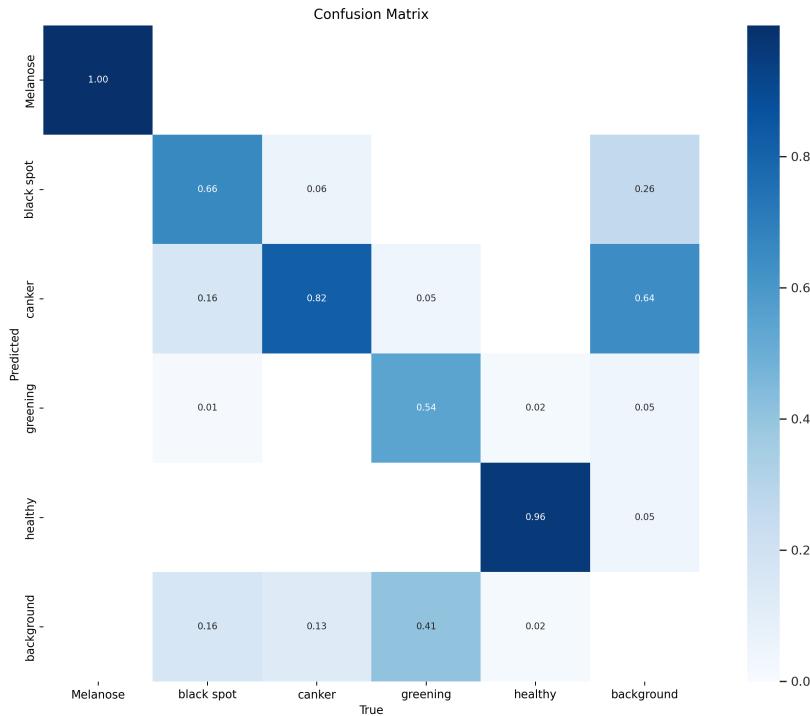


Figure 5.6: Confusion Matrix for YOLOv8m

Model	Variants	Diseases Accuracy					Total Accuracy
		Melanose	Black Spot	Canker	Greening	Healthy	
YOLOv8	B16E30	99.50	72.70	84.80	54.10	95.00	81.22
	B16E40	99.50	74.90	83.70	55.40	97.60	82.20
	B16E50	99.50	75.50	84.40	56.60	98.10	82.90

Table 5.2: Various hyper-parameter analysis of Yolov8

The YOLOv8 variants B16E30, B16E40, and B16E50 exhibit varying accuracies across different plant diseases. While all variants from table 5.2 achieve high accuracy in Melanose detection (99.50%), their performance differs for other diseases. B16E30 generally shows lower accuracy compared to B16E40 and B16E50, with B16E40 and B16E50 performing better overall. Specifically, for Canker, Black Spot, Greening, and Healthy categories, B16E40 and B16E50 consistently outperform B16E30. These findings emphasize the importance of selecting the appropriate YOLOv8 variant based on the specific plant disease of interest.

5.3 YOLOv9

Third, we confirm the model's convergence, the loss of which is depicted in Figure 5.7. In the training process, as the number of epochs increases, the box loss, object loss, and CLS loss decrease and eventually tend to stabilize. Furthermore, we can see that the pattern of lost verification broken lines is similar to that of training broken lines. The broken line trend indicates that the model has essentially converged.

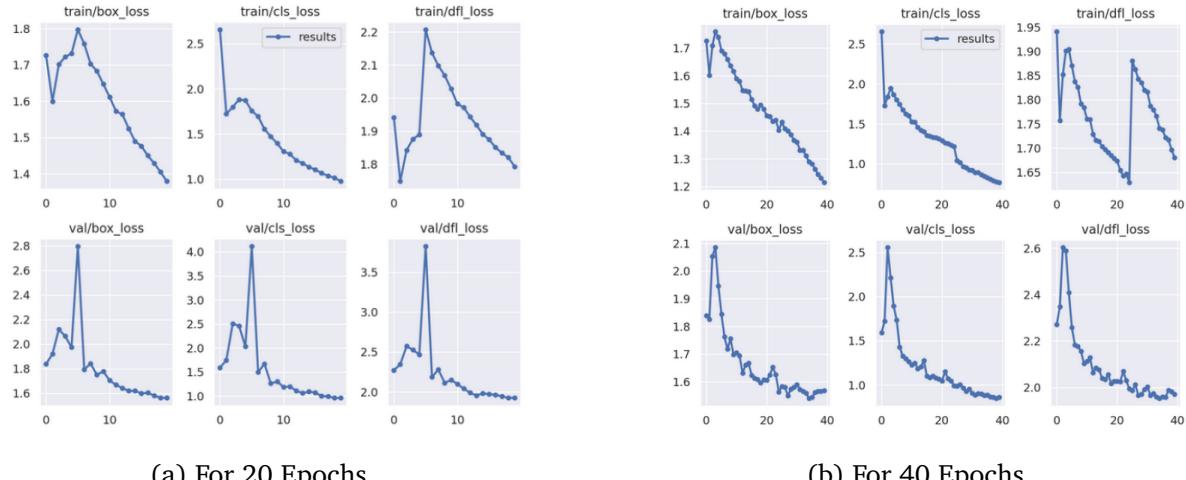


Figure 5.7: Box, Object, Class losses for YOLOv9m

To further demonstrate the model's viability, we examined its running results, which are shown in Figure Figure 5.8. For both epochs 20 and 40, we can attain precision and recall of greater than 80%, as well as mAP of 85% and mAP of 50%, when the thresholds are set at 0.5 and 0.5-0.95, respectively.

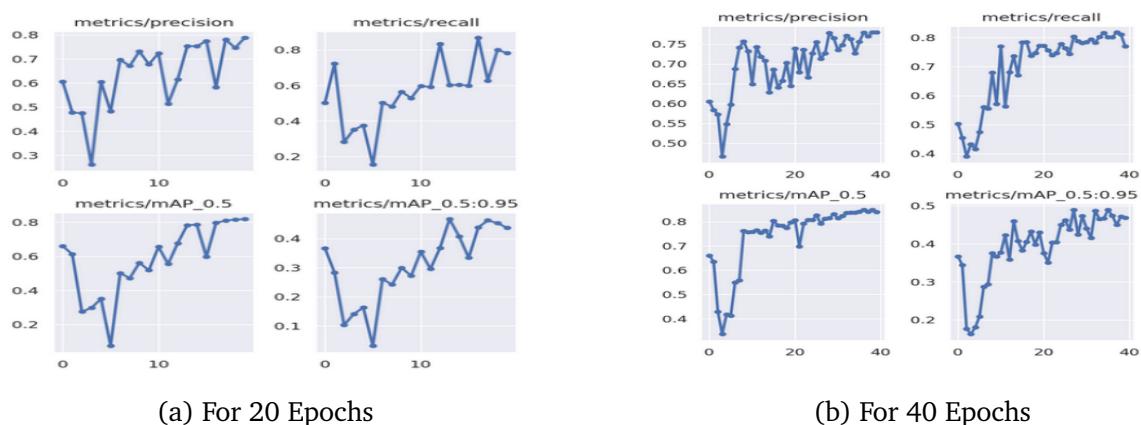


Figure 5.8: Precision, Recall and mAP Evaluation for YOLOv9m

We also provide the confusion matrix of our method in Figure 5.9, which can be used to analyze the detection performance of different categories. The results for Batch16 Epoch20 indicate that we can attain precision levels of 99% for Melanose, 79% for Black Spot, 81% for Canker, 46% for Greening, and 90% for Healthy. Results for Batch16 Epoch40 indicate that we can attain precision levels of 99% for Melanose, 72% for Black Spot, 88% for Canker, 60% for Greening, and 96% for Healthy.

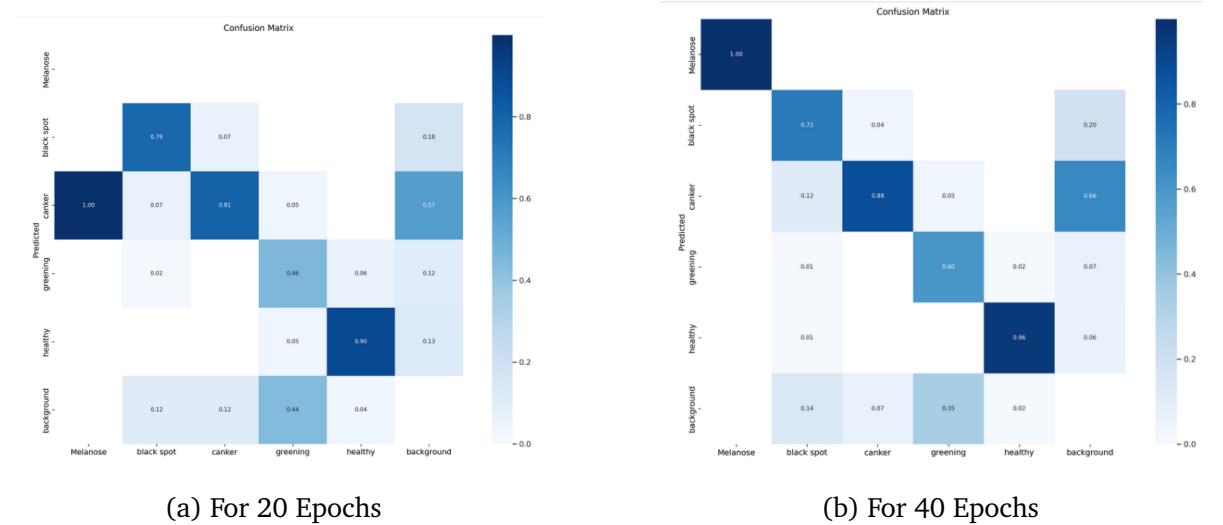


Figure 5.9: Confusion Matrix for YOLOv9m

Model	Variants	Diseases Accuracy					Total Accuracy
		Melanose	Black Spot	Canker	Greening	Healthy	
YOLOv9	B8E10	99.50	67.60	82.40	46.70	96.90	78.60
	B8E15	99.50	65.80	78.80	39.90	97.40	76.30
	B16E15	99.50	71.80	84.60	46.30	98.10	80.00
	B16E20	99.50	71.20	84.30	40.30	96.40	78.30
	B16E40	99.50	77.00	87.30	58.40	98.30	84.10

Table 5.3: Various hyper-parameter analysis of Yolov9

The table 5.3 presents a comparative analysis of plant disease detection models, specifically the B8E10 and B8E15 variants of YOLOv9. While both variants excel in Melanose detection (99.50%), their accuracies differ for other diseases. B8E10 outperforms B8E15 in Greening (46.70% vs. 39.90%), whereas B8E15 shows higher accuracy for Canker (65.80%) and Black Spot (78.80%) compared to B8E10 (67.60% and 82.40%, respectively). Overall, the choice between model variants hinges on the specific plant disease being targeted.

5.4 Model Evaluations

The table 5.4 summarizes the performance metrics of two variants of the YOLOv5 model on disease detection, showcasing higher precision, recall, and F1-score for the B16E15 variant, leading to a slightly higher overall accuracy (83.40) compared to B16E10 (81.80).

Model	Variants	Diseases Accuracy			Total Accuracy
		Precision	Recall	F1-Score	
YOLOv5	B16E10	73.80	69.60	71.63	81.80
	B16E15	76.70	71.80	74.17	83.40

Table 5.4: Model Evaluations of YOLOv5

The YOLOv8 model exhibits increasing precision, recall, and F1-score across its variants, with the B16E50 variant achieving the highest overall accuracy (82.90) in table 5.5, showcasing improvements in disease detection performance compared to B16E30 and B16E40 variants.

Model	Variants	Diseases Accuracy			Total Accuracy
		Precision	Recall	F1-Score	
YOLOv8	B16E30	69.55	61.30	65.16	81.22
	B16E40	71.25	59.40	64.78	82.20
	B16E50	71.76	65.80	68.65	82.90

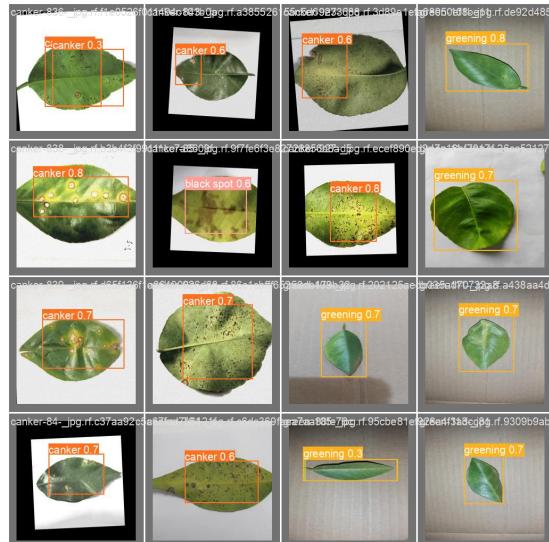
Table 5.5: Model Evaluations of YOLOv8

The YOLOv9 model demonstrates varying performance across its variants, with the B16E40 variant exhibiting the highest precision, recall, and F1-score, resulting in the highest overall accuracy (84.10) in table 5.6 , indicating improved disease detection capabilities compared to other variants.

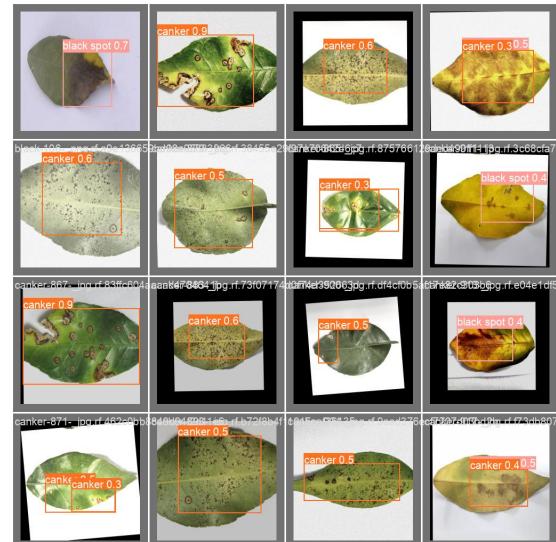
Model	Variants	Diseases Accuracy			Total Accuracy
		Precision	Recall	F1-Score	
YOLOv9	B8E10	62.80	58.70	60.68	78.60
	B8E15	61.30	57.50	59.33	76.30
	B16E15	65.45	62.50	63.94	80.00
	B16E20	62.50	59.80	61.62	78.30
	B16E40	75.80	71.20	73.42	84.10

Table 5.6: Model Evaluations of YOLOv9

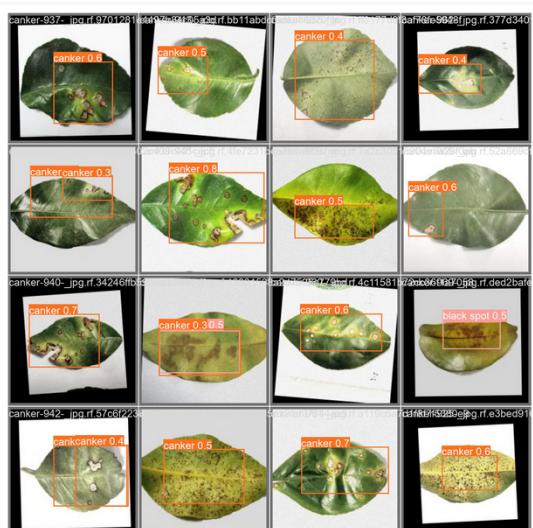
5.5 Validation Batch Predictions



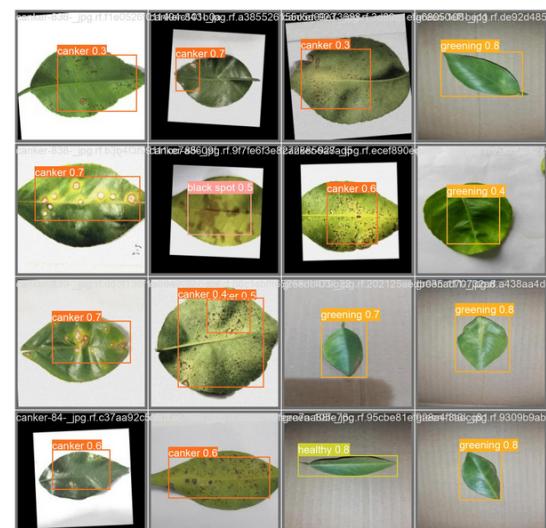
(a) Validation batch prediction for YOLOv5



(b) Validation batch prediction for YOLOv8



(c) Validation batch prediction for YOLOv9 for 20 Epochs



(d) Validation batch prediction for YOLOv9 for 40 Epochs

Figure 5.10: Validation Predictions

YOLOv9 surpasses YOLOv8 and YOLOv5 in prediction accuracy and ease of use. YOLOv8 shows improvements over YOLOv5 but lags behind YOLOv9. YOLOv5 exhibits the least accuracy among the three algorithms. Overall, YOLOv9 emerges as the superior choice for object detection tasks, offering enhanced performance and ease of implementation.

5.6 COMPARATIVE ANALYSIS

Model	Variant	Diseases Accuracy					Total Accuracy
		Melanose	Black Spot	Canker	Greening	Healthy	
YOLOv5	B16E10	99.50	73.60	82.80	59.00	95.00	81.80
	B16E15	99.50	74.80	86.40	58.10	98.00	83.40
YOLOv8	B16E30	99.50	72.70	84.80	54.10	95.00	81.22
	B16E40	99.50	74.90	83.70	55.40	97.60	82.20
	B16E50	99.50	75.50	84.40	56.60	98.10	82.90
YOLOv9	B8E10	99.50	67.60	82.40	46.70	96.90	78.60
	B8E15	99.50	65.80	78.80	39.90	97.40	76.30
	B16E15	99.50	71.80	84.60	46.30	98.10	80.00
	B16E20	99.50	71.20	84.30	40.30	96.40	78.30
	B16E40	99.50	77.00	87.30	58.40	98.30	84.10

Table 5.7: Comparative Analysis of YOLO MODELS

The table 5.7 summarizes the accuracy of different YOLO models for detecting four diseases: Melanose, Black Spot, Canker, Greening, and Healthy. Overall, the models perform well with Melanose, achieving an accuracy of 99.5% across all variations. However, they exhibit more difficulty in accurately detecting Black Spot and Greening, with the highest accuracy being 77.0% for Black Spot and 58.40% for Greening. Among the three models, the best variable results are:

- **YOLOv5 B16E15:** This model demonstrates the highest accuracy for Melanose (99.50%) and Healthy (98.0%), but the second lowest accuracy for Black Spot (74.80%) and Greening (58.10%).
- **YOLOv8 B16E50:** This model performs similarly to YOLOv5 B16E15 with a 99.50% accuracy for Melanose and 98.10% for Greening. However, it slightly outperforms in Canker (84.40%), Black Spot (75.5%) and Greening (56.6%).
- **YOLOv9 B16E40:** This model exhibits the highest accuracy among all models for Black Spot (77.00%) and Canker (87.30%) but performs similarly to other YOLOv9 models for Melanose (99.5%) and Healthy (98.30%).

To sum up, the performance of all the YOLO models in detecting melanose is excellent. They have trouble correctly identifying Greening and Black Spot, though. Because it is more accurate than other models in detecting Healthy and Canker, where other models falter, YOLOv9 B16E40 is the best model overall for disease detection.

5.7 Final Analysis

Finally, comparing three YOLO models YOLOv5s, YOLOv8m, YOLOv9m has gained an accuracy of 83.4% ,82.9%, 84.10% respectively which is almost similar but in the case of YOLOv9m, it was very much faster than the YOLOv8m, YOLOv5s model.

- **YOLOv9:** YOLOv9m has the highest reported accuracy among the three versions, with an accuracy of 84.10%. This indicates that it performs slightly better than the other versions in terms of correctly detecting objects in images.
- **YOLOv5:** YOLOv5s comes in second place with an accuracy of 83.4%. While slightly lower than YOLOv9m, it still demonstrates strong performance in object detection tasks but was very slow.
- **YOLOv8:** YOLOv8m has the lowest reported accuracy among the three versions, with 82.9%. Although it's slightly lower than the others, it's quite competitive and has advantages in other aspects such as speed or resource efficiency than YOLOv5s.

Notably, YOLOv9m stands out for its remarkable speed despite its higher accuracy compared to YOLOv5s and YOLOv8m. This indicates efficient optimization in its architecture, allowing it to achieve both high accuracy and fast processing times simultaneously. On the other hand, YOLOv8m, although slightly less accurate, compensates with faster speeds, making it a favorable choice in time-sensitive applications.

Lastly, the choice between YOLOv5s, YOLOv8m, and YOLOv9m depends on specific application requirements. YOLOv9m offers the highest accuracy, making it suitable for tasks where precision is paramount. YOLOv5s, while slightly slower, still provides strong performance in object detection. YOLOv8m, with its balance of accuracy and speed, proves to be an efficient option for real-time applications where computational resources are limited. Ultimately, understanding the trade-offs between accuracy and speed is essential in selecting the most suitable YOLO model for a given task.

Chapter 6

Conclusion

In conclusion, our study on disease detection in citrus fruits using the YOLO (You Only Look Once) algorithm three models YOLOv5s, YOLOv8m and YOLOv9m showed effective results in detecting diseases. YOLO provides a robust and efficient solution for identifying and locating citrus diseases in images, contributing to precision agriculture and proactive disease management. It would alert farmers about the disease and allow them to take immediate action to keep other plants safe. Through experiments and evaluation, the effectiveness of YOLO in automating the detection process was verified and its ability to deal with complex scenarios and different symptoms of citrus diseases was demonstrated. The model's ability to perform object detection at a detailed level greatly improves its practicality where both YOLOv5 and YOLOv8m had almost the same accuracy and model YOLOv9m variant batch 16 Epoch 40 showed slightly better result. It is hoped that this work will positively impact how citrus is grown and provide growers with a valuable tool for early disease detection and intervention. Integrating YOLO into citrus disease management can lead to more efficient resource allocation, reduced plant losses, and ultimately sustainable citrus cultivation. Although this research has resulted in significant advances, there is still room for future exploration and improvement by expanding the dataset to include additional disease classes and exploring opportunities for real-time implementation with alert generation.

Chapter 7

Future Work

Some of the concepts using real-time data might be researched in the future, offering real time detection capacity. We can use YOLO and other models to help us achieve our goal. We will collect more data for more accurate results because we collected our data manually and it was insufficient

- Focusing on Real-time disease detection
- Implementation of a warning system could be facilitated through real-time disease recognition.
- Link disease detection with targeted treatment recommendations.
- Integrate weather data (temperature, humidity, rainfall) with disease detection models.
- Developing a mobile application to identify illness and provide immediate treatment.

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