

LUPAD: Localized UAV-based Black Pod Rot (*Phytophthora Palmivora*) Automated Disease Detection in Cacao Pods

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Theobroma cacao, widely known as cacao, is one of the most economically influential crops in the world. It serves as the primary raw material for the multibillion-dollar chocolate industry, supporting the livelihoods of approximately six million small-scale farmers globally. Once harvested, cacao seeds are processed to produce cocoa powder and cocoa butter—essential ingredients in a wide range of products, from confections and beverages to cosmetics and pharmaceuticals.

In the Philippines, cacao production has not kept pace with local consumption demands. Despite favorable growing conditions, the Davao Region—recognized as the “Cacao Capital of the Philippines” Philippine Council for Agriculture and Fisheries (PCAF) (2021)—and nearby provinces such as Misamis Oriental continue to face supply shortages. For instance, the Janog Cacao Plantation records yield fluctuations between 100–500 kilograms of dried beans per harvest season, with 300 kilograms considered satisfactory and anything below 200 kilograms representing a deficit. This variability shows

the vulnerability of smallholder cacao farms to environmental and pathological stressors. In particular, fungal pathogens such as *Phytophthora palmivora* (*P.Palmivora*) cause black pod disease, which has been documented to inflict significant annual yield losses Avila-Quezada et al. (2023).

Traditional disease management in cacao farms typically involves manual inspection and subjective classification of pods. The Department of Agriculture (2021) reported that this method is labor intensive and error prone, often failing to detect infections in their early stages. These challenges were reaffirmed during a field interview with the owner of Janog Cacao Plantation in Initao, Misamis Oriental, a 5-hectare farm with over 2,500 cacao trees planted.

According to the owner, routine inspection of cacao pods requires walking across the entire plantation, which takes up to three weeks to complete for one full cycle. This process becomes even more demanding during the rainy season, when black pod rot—locally known as *butikol*—spreads rapidly due to excess moisture that favors the growth of *P.palmivora*. On average, only about 1 in 10 cacao trees remain healthy, as the disease can quickly spread to nearby pods if infected ones are not pruned or removed promptly.

Currently, farmers rely primarily on visual inspection to detect early symptoms, such as small dark spots or discoloration, and remove affected pods immediately to prevent further contamination, since curative treatments are

rarely used. However, due to the large size of farms and the labor-intensive nature of manual inspection, some infected pods go unnoticed.

To address these persistent threats, modern agriculture has increasingly turned to advanced technological solutions for early disease detection and intervention. Unmanned Aerial Vehicles (UAVs) and deep learning algorithms have emerged as powerful tools in precision agriculture, offering efficient and scalable monitoring of large plantations. UAVs, equipped with high-resolution cameras and multispectral sensors, can rapidly survey wide areas, while cutting-edge models such as You Only Look Once (YOLO) provide high-accuracy plant disease identification Vyas and Dutt (2023). Early detection during the pre-harvest phase, as supported by Upadhyay et al. (2025); Choudhary et al. (2024), enables timely interventions to mitigate crop losses and ensure quality harvests.

Existing technological interventions for cacao disease detection, such as mobile applications that utilize image processing and machine learning, have made strides in bridging the gap. For instance, Tan et al. (2018) developed AuToDiDACP, an app designed to detect black pod rot, while Tovurawa et al. (2025) used convolutional neural networks (CNNs) to classify cacao leaf diseases. However, these solutions are predominantly dependent on static image inputs and close-range data collection. As noted by Taesiri et al. (2023), such

methods can cause models to focus only on the most discriminative regions of the plant, potentially missing early-stage infections or atypical symptoms that may be spread across the pod's surface. Additionally, mobile-based approaches require farmers to manually photograph individual pods, which is laborious and impractical for large-scale plantations, thereby limiting mobility and scalability.

With these challenges in mind, this study introduces a UAV-based cacao disease detection system that uses YOLO object detection algorithm to overcome the constraints of static, close-range data collection. By capturing images from various angles and altitudes, this approach enables more comprehensive monitoring of cacao plantations such as Janog Cacao Plantation, where manual inspection is physically demanding and time-consuming. Integrating deep learning models with UAV technology allows for the detection of disease symptoms across the entire pod surface that traditional methods may miss.

The proposed system will be developed followed by field tests at Janog Cacao Plantation in Initao, Misamis Oriental, to evaluate its performance and functionality in real-world agricultural environment.

1.2 Statement of the Problem

The Philippine cacao industry faces persistent challenges that hinder its ability to meet the demands of both the domestic and international market. Although the country has favorable climate conditions and fertile land, especially in the Davao Region, which represents 78% of national production, it continues to fall short of its annual production target of 50,000 metric tons. According to the Department of Agriculture (2021), this shortfall is largely due to cacao diseases, particularly black pod disease caused by *P. Palmivora*, which leads to post-harvest losses of up to 90%.

Traditional detection methods rely on manual inspection, which is labor intensive, slow, and prone to human error, leading to delayed intervention and significant crop losses. Although existing studies explore machine learning and imaging technologies for cacao disease detection, they primarily use static imaging and mobile-based approaches, limiting monitoring and scalability.

To address this gap, this study proposes the integration of an Unmanned Aerial Vehicle (UAV) with You Only Look Once (YOLO) technique for detection of cacao pod disease, particularly *P. Palmivora*, without human effort. The system also includes geotagging, using QGIS to pinpoint where the affected cacaos are, which are processed and viewed in a web-based application where farmers can monitor their cacao farms.

1.3 Objectives of the Study

This study aims to design and develop a UAV-based system that predicts *P.Palmivora* disease in cacao pods using deep learning model (object detection and disease detection) and GPS geotagging for precise location mapping. Specifically, it seeks to:

1. Design and configure a UAV capable of autonomous navigation over cacao farms.
2. Implement an object detection model for cacao pod detection and a classification model for identifying black pod rot disease, or *P.Palmivora* infection.
3. Develop and implement a monitoring system that tracks the UAV's flight status and detection for cacao pod disease.
4. Test the system's detection accuracy, classification performance, geotagging precision, and overall operational efficiency.

1.4 Significance of the Study

The study will be conducted at Janog Cacao Plantation in Initao, Misamis Oriental. This holds significance for multiple sectors within the agricultural and technological landscape. By field-testing a UAV-based disease

detection system in an actual cacao farm setting, the research will demonstrate the feasibility and practical benefits of integrating precision agriculture technologies into local farming operations.

For cacao farmers, particularly those managing large plantations like Janog Cacao Plantation, the system will offer a practical and accessible solution for early disease detection. It enables timely intervention to prevent further contamination, helping reduce crop losses, improve yield quality and quantity, and promote stable income and long-term sustainability in farming practices.

For the cacao and chocolate industry, the study will contribute to developing a more disease-resilient cacao supply chain, ensuring stability and reliability of production. This helps sustain both local and global markets by maintaining consistent raw material availability, controlling production costs, and supporting economic growth in cacao-dependent regions.

For the agricultural sector, the research promotes the modernization of farming through precision agriculture and remote sensing technologies. It enhances productivity and sustainability, particularly in disease-prone areas where manual inspection is labor-intensive and inefficient.

For the government and policymakers, the study's outcomes can serve as a basis for aligning technological innovation with the goals of the Philippine

Cacao Industry Roadmap. It provides valuable insights for policy formulation, funding assistance, and large-scale implementation of technology-based interventions. Furthermore, it contributes to the realization of Sustainable Development Goals (SDG 8: Decent Work and Economic Growth, and SDG 15: Life on Land) by promoting sustainable agriculture, increasing farmer income, and fostering innovation.

Lastly, for future researchers, this study serves as a reference for further exploration and enhancement of precision agriculture systems, UAV applications, and plant disease detection technologies. It also provides a real-world benchmark for testing similar systems under tropical agricultural conditions.

1.5 Scope and Limitations

This study will focus on the development and testing of a UAV-based disease detection system for cacao farms in Initao, Misamis Oriental. The system integrates three major components: (1) a YOLO-based model for detecting visible symptoms of *P. Palmivora* infection in cacao pods, (2) GPS and QGIS for precise geolocation and spatial mapping of affected areas, and (3) a web-based application for monitoring and visualization of detection results.

The scope of the study is limited to identifying external symptoms of black pod disease—such as visible pod rot and discoloration. Internal in-

fections that do not manifest outwardly cannot be detected by the current implementation. Moreover, while the system can assist in identifying potentially infected pods, it does not automate subsequent farm management tasks such as pruning or removal of diseased pods, which must still be performed manually by farmers.

The imaging capability of the UAV is constrained by the use of a 720p camera, which may limit the level of visual detail captured and affect detection accuracy under certain environmental conditions. External factors such as lighting, weather conditions, and UAV flight stability may also influence detection performance.

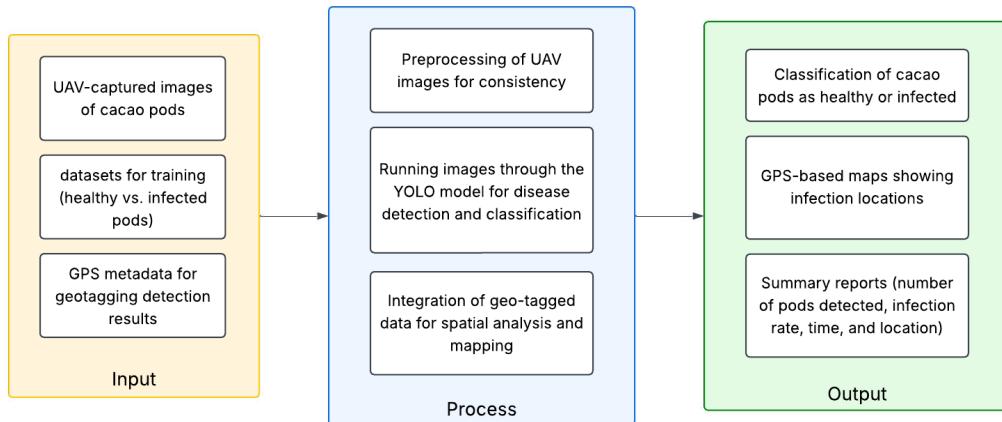
Despite these constraints, the programmable nature of the UAV allows the use of its Software Development Kit (SDK) to define autonomous flight paths, enabling systematic data collection across cacao rows. However, the degree of automation depends on the reliability of the programmed commands and the environmental conditions encountered during flight missions.

These limitations define the operational boundaries of the proposed system and provide considerations for future improvements.

1.6 Conceptual Framework

Figure 1.1

IPO Model



The study's conceptual framework is presented through an Input-Output-Process Model. The process begins with the input stage, where drones are used to capture images of cacao pods in the farm. These images serve as the primary source of information and are compared with sets of sample images showing both healthy and diseased pods. Along with the images, location data is recorded so that each detection can be linked to its exact place in the farm.

The information collected then moves to the process stage. Here, the pod images are first checked to make them clear and consistent for analysis. After this, the system studies the images to identify whether pods are healthy or show signs of disease. The location data gathered during drone flights is

combined with the results, allowing the system to create maps that show the areas where diseases may be present. This stage transforms raw images into useful information that can guide farmers in managing their crops.

In the output stage, the system produces results that are directly useful for farm management. These include the classification of cacao pods as healthy or infected, maps that point out exactly where the infected pods are located, and summary reports. The reports provide details such as the total number of pods detected, the percentage that are infected, and the specific times and places where infections were found.

1.7 Definition of Terms

For clarity and consistency, the following terms are defined as they are used in this study:

Bounding Box - A rectangular box generated by the YOLO model to localize and highlight detected objects, such as healthy or diseased cacao pods, within an image.

Convolutional Neural Network - A deep learning architecture for visual analysis, serving as the backbone of the YOLO model in this study.

Dataset - A structured collection of related data, such as images of cacao

pods, used to train and evaluate deep learning models for disease detection in this study.

Deep Learning Algorithms - A subset of machine learning algorithms, particularly neural networks, used to analyze large datasets and recognize patterns in images or other inputs, enhancing precision agriculture applications.

Disease Detection - The process of identifying and diagnosing plant diseases, often involving technology such as image analysis and machine learning algorithms for early intervention.

Field Tests - Practical trials conducted in real-world agricultural environments to assess the effectiveness and performance of the proposed UAV and deep learning-based system for detecting cacao pod diseases.

Geotagging - The process of adding geographical location data, such as latitude and longitude, to images or data collected by UAVs, enabling spatial tracking and mapping of disease occurrences in cacao farms.

Ground Station - The control and monitoring interface (web application) where UAV mission results, disease detections, and geotagged mappings are displayed for farmers.

Ground Sampling Distance - The distance between pixel centers measured on the ground, used to estimate real-world size from UAV-captured images.

Image Processing - The technique of manipulating and analyzing digital images using algorithms to extract meaningful information, often for detecting patterns such as plant diseases.

Object Detection - A computer vision technique used to identify and locate multiple objects within an image, as performed by the YOLO model in this study.

***Phytophthora palmivora* (P.*Palmivora*)** - A fungal pathogen responsible for causing black pod disease in cacao plants, which leads to significant yield losses in cacao production.

Pod - Refers to the fruit of the cacao tree that contains cacao beans; it is the primary site for disease detection, particularly for symptoms caused by pathogens like P.*Palmivora*.

Pre-harvest Detection - The process of identifying signs of disease or stress in crops, specifically cacao pods, before they are harvested, allowing for timely intervention to prevent yield loss and improve crop quality.

QGIS - An open-source Geographic Information System software that provides tools for geospatial data processing, mapping, and analysis. In this study, it is used for automating geotagging and visualizing infected cacao trees.

Static Imaging - The process of capturing fixed, non-moving images, often used in traditional disease detection methods, which may miss early-stage infections or dispersed symptoms.

Telemetry - The process of wirelessly transmitting data, such as flight status and image acquisition logs, from the UAV to the ground station.

Unmanned Aerial Vehicles (UAVs) - Aerial devices, typically drones, that operate without a human pilot, often equipped with cameras and sensors, used for monitoring agricultural environments and gathering data for analysis.

You Only Look Once (YOLO) - An advanced real-time object detection model that can quickly identify and classify objects within images, used for detecting diseases on plant surfaces in this study.

CHAPTER 2

REVIEW OF RELATED LITERATURE

This chapter presents relevant information and related studies that support the development of the proposed system.

2.1 Cacao Diseases and Diagnosis

Cacao (*Theobroma cacao*) is highly vulnerable to various diseases that threaten yield and production quality. One of the most aggressive fungal pathogens is *Phytophthora megakarya*, responsible for black pod disease, as discussed by Andrews et al. (1997). This disease affects all parts of the cacao plant, including pods, leaves, and stems, particularly in humid conditions.

In West Africa, *P. megakarya* is a major threat, whereas in the Philippines, a different variant, *Phytophthora palmivora* (P.*Palmivora*), is the primary cause of pod rot, as mentioned by Solpot (2020). This pathogen was first documented in Luzon in 1918 by Reinking and remains a significant challenge for local farmers. According to Acebo-Guerrero et al. (2012), *P. palmivora* can cause annual losses of 20–30%, with severe cases reaching up to 90% under high humidity.

Studies suggest that infected cacao plants can contribute to the spread

of the disease to neighboring trees. Field experiments conducted by Ndoumbe-Nkeng et al. (2004) demonstrated that pod removal reduced black pod incidence by 22% and 31% in the first year and by 9% and 11% in the second year, confirming the role of contaminated pods in disease transmission. However, research by Babin (2018) later revealed that insect pests, particularly *Helopeltis bakeri*, a mirid bug, also facilitate the spread of fungal pathogens. These insects feed on pods and shoots, causing severe damage and creating potential entry points for fungal infections, as supported by Guest (2007).

Other notable diseases affecting cacao include Cacao Swollen Shoot Virus (CSSV), a viral disease that causes swelling of shoots and veins; Vascular Streak Dieback (VSD), a fungal infection that results in yellowing and leaf shedding; Witches' Broom Disease (*Moniliophthora perniciosa*), which causes abnormal shoot proliferation ('brooms') and negatively impacts pod development; and Frosty Pod Rot (*Moniliophthora roreri*), which appears as white fungal growth on pods, leading to pod rot and significant crop losses.

Farmers and researchers distinguish between healthy cacao plants and those infected with diseases by observing specific visual symptoms on various parts of the plant, such as leaves, pods, stems, and roots. Initial signs include small, circular brown spots on the pod surface, as described by the Ministry of Agriculture, Land and Fisheries). These spots rapidly expand, turning dark

brown or black, eventually covering the entire pod. Under wet conditions, white fungal growth may appear on the lesions. Infected pods often emit a characteristic fishy odor and, if untreated, become blackened and mummified.

2.2 Current Approaches to Cacao Disease Detection and Quality Control

Traditional Methods

The Department of Agriculture (2021) highlighted that most cacao farms in the country are owned and managed by smallholding farmers, many of whom have acquired farming knowledge through ancestral practices or personal experience. This includes manually distinguishing between cacao pods with black pod rot, then separating them after harvest. However, this approach has limitations. According to Forest Phytophtoras of the World, once exposed to pathogens, healthy pods may develop internal infections within 15 days, making early detection and intervention crucial. Delays in identifying and removing infected pods reduce the effectiveness of disease management efforts and increase the likelihood of disease spread, especially in pre-harvest settings.

To mitigate cacao diseases, farmers employ several cultural and chemical control methods including sanitation and pruning, according to Acebo-

Guerrero et al. (2012). Pruning improves air circulation and reduces humidity, creating less favorable conditions for fungal growth. On the other hand, sanitation involves removing diseased pods and plant debris, helping eliminate sources of inoculum (increase immunity to a disease) and prevents reinfection. Additionally, Merga (2022) highlighted that farmers frequently harvest cacao pods to reduce the inoculum load of pathogens such as *Phytophthora spp.*, thereby minimizing disease transmission. Scientists and fungicide experts developed copper-based compounds and metalaxyl to control black pod disease, as reported by Opoku et al. (2007). When combined with crop sanitation, fungicide application has been shown to significantly reduce disease incidence and improve yields.

Destructive and Non-destructive Disease Detection

In cacao classification, traditional destructive techniques are often employed to assess the quality of cocoa beans. Among these methods, Nguyen et al. (2022) reported that the cut-test stands out as the most widely used due to its simplicity and effectiveness—it involves slicing beans to inspect mold, germination, and fermentation. Though practical, it is labor-intensive and less precise. With this, Quelal-Vásquez et al. (2020) introduced chromatographic analysis, which offers a higher level of sensitivity, capable of detecting

metabolites and contaminants even in trace quantities. While highly reliable, chromatographic analysis is more complex and requires specialized equipment, making it less accessible for routine quality control in cacao production. Since these approaches are destructive in nature, they result in the loss of sampled beans, making it less ideal for large-scale quality control.

In contrast, Alvarado et al. (2023) listed non-destructive techniques such as imaging sensors, spectroscopy, and thermal imaging to monitor plant health. These methods facilitate the early detection of diseases, allowing for timely interventions that can prevent the spread of infections and reduce crop damage.

For instance, a study on ginseng root diseases highlighted the urgency of developing efficient non-destructive testing methods for early-stage detection and limiting further spread. Silva and Almeida (2024) explored edge computing for real-time classification of leaf diseases using thermal imaging, which converts infrared (IR) radiation into visible images. Near-Infrared (NIR) Spectroscopy and Hyperspectral Imaging (HSI) also analyze internal attributes of cacao, such as moisture content, fermentation levels, and fat composition Alvarado et al. (2023). Additionally, imaging-based computer vision detects surface defects and size variations, enhancing quality control, reducing waste, and ensuring better cacao processing outcomes.

Pre-harvest Disease Detection

Pre-harvest disease detection is significant in maintaining crop health and preventing losses. Traditional methods, such as manual inspection, have been shown to be labor-intensive, time-consuming, and prone to human error, especially in large-scale cacao farming. According to Tan et al. (2018), these limitations often result in delayed detection and intervention, which can lead to the spread of diseases like *P. Palmivora*, a major cause of black pod disease in cacao. Researchers have emphasized the importance of early detection tools to address these challenges, highlighting that timely interventions can significantly reduce crop damage and yield loss. According to Choudhary et al. (2024), UAVs equipped with high-resolution cameras and multispectral sensors offer an efficient solution, enabling farmers to monitor large areas in real-time and detect disease symptoms before they become widespread. This technology allows for early identification of subtle symptoms, such as discoloration or texture changes in leaves and pods, which are often missed by manual inspections, as pointed out by Upadhyay et al. (2025).

The integration of UAVs in precision agriculture has been increasingly recognized for its ability to enhance the accuracy and speed of disease detection. According to Vyas and Dutt (2023), UAVs can cover vast agricultural areas quickly, providing farmers with comprehensive, up-to-date data. This

system not only improves the timeliness of disease detection but also enables targeted actions to mitigate disease outbreaks. According to Taesiri et al. (2023), by combining UAV technology with advanced image processing and geotagging, the detection process becomes more precise, ensuring that even subtle and atypical symptoms are identified. This proactive approach to disease management during the pre-harvest phase is essential for reducing crop losses and improving the overall sustainability and productivity of cacao farming.

Computer-aided Cacao Disease Detection Technology in Agriculture

Recent advancements in cacao plant disease detection have leveraged artificial intelligence (AI) and image processing to improve classification accuracy and disease management. These methods, as stated by Upadhyay et al. (2025), automatically learn and extract intricate features from raw image data, capturing subtle patterns associated with specific diseases. They surpass traditional manual methods, leading to improved detection accuracy.

One such study by Bacilio and Barbosa (2022) introduced an objective classification system for cacao pods. Their model combines Local Binary Pattern (LBP) features and a Color Histogram (CH) with an Artificial Neural Network (ANN) to differentiate between healthy and unhealthy pods. This

research underscores the importance of machine learning in agricultural diagnostics, ensuring that disease identification is both efficient and accurate. Similarly, Tan et al. (2018) developed AuToDiDAC, an automated mobile tool designed to detect black pod rot, one of the most devastating diseases affecting cacao plants.

Another notable contribution comes from Basri et al. (2020), who proposed a mobile image processing application for identifying pests and diseases in cacao fruit. Their deep learning-powered system processes real-time images, categorizing fruits as healthy, pest-infected, or disease-affected with high accuracy. A subsequent review by Basri et al. (2020) further explored the role of image processing in modern cocoa plantations, revealing that color-based disease detection models achieve an average accuracy of 82.85%. The authors advocate for integrating machine learning models to optimize disease prediction and support precision agriculture.

Meanwhile, Buenăño Vera et al. (2024) proposed a deep learning model for diagnosing monilia and black pod diseases in cacao pods. Using EfficientDet-Lite4, their model was trained on a dataset of diseased and healthy pods and later deployed in a mobile application to assist farmers. The app's intuitive design and real-time disease identification make it a valuable tool, particularly for small-scale farmers with limited access to expert guidance.

Building on these innovations, Tovurawa et al. (2025) applied deep learning and Exploratory Data Analysis (EDA) to cacao disease detection. Their research focused on a custom Convolutional Neural Network (CNN) that outperformed other models in accurately classifying cacao diseases. By utilizing a dataset from Ghanaian cacao farms, this study provides a locally relevant solution that could enhance crop resilience and farmer livelihoods.

2.3 Unmanned Aerial View (UAV) Technology in Agriculture

The advancement of drone-based technologies and deep learning algorithms has significantly contributed to precision agriculture, particularly in large-scale crop monitoring and quality assessment. Alam et al. (2022) developed a drone-based crop product quality monitoring system that utilizes vision cameras and a Gaussian kernel support vector machine (SVM) to classify vegetables into rotten and non-rotten categories. Their approach extracts chromatic, contour, and texture features from image datasets of tomatoes, cauliflower, and eggplants to enhance classification accuracy. The system demonstrated a 97.9% true positive rate and 95.4% overall accuracy, highlighting its effectiveness in agricultural product quality monitoring.

Similarly, Mazzia et al. (2020) explored the refinement of satellite-driven vegetation indices using UAVs and machine learning. While satellite

imagery plays a crucial role in crop monitoring, its limitations in capturing detailed intra-row crop variations can lead to inaccuracies. Their study proposed a deep learning framework that integrates high-resolution UAV multispectral data to improve Normalized Difference Vegetation Index (NDVI) maps. By training a convolutional neural network (CNN) with UAV-acquired datasets, their approach produced refined NDVI maps that provided more accurate crop status assessments. This refinement enabled the generation of 3-class vineyard vigor maps using a K-means classifier, offering a valuable tool for site-specific crop management.

In a related study, Vardhan and Swetha (2023) introduced a deep learning-based approach for detecting plant diseases using drone-captured imagery. Their model utilized a convolutional neural network (CNN) trained on a comprehensive dataset of plant species exhibiting various diseases. The study demonstrated high proficiency in disease classification and detection, even under challenging imaging conditions. By integrating real-time drone monitoring with deep learning, their approach presents a scalable and efficient solution for improving plant health assessment, further advancing the role of smart agriculture in modern farming practices.

2.4 You Only Look Once versions (YOLO) for Object Detection

The You Only Look Once (YOLO) framework has become one of the most influential deep learning models for real-time object detection. Its successive versions have continuously evolved to address limitations in accuracy, speed, and computational efficiency. According to Ultralytics Terven et al. (2023), the YOLO family progressed from YOLOv1 to the most recent YOLOv11, each version integrating new architectural strategies and optimization methods to improve detection across diverse applications.

YOLOv8, released in January 2023, introduced an anchor-free decoupled head design, separating classification from bounding box regression. This design enhanced optimization, particularly for small-object detection, and allowed flexible deployment through multiple model sizes (Nano to X), enabling a tradeoff between speed and accuracy Wang et al. (2023). YOLOv8 also extended its capabilities beyond detection to include classification and segmentation, making it versatile in agricultural monitoring and disease diagnosis tasks Vyas and Dutt (2023). YOLOv8, released in January 2023, introduced an anchor-free decoupled head design that separates classification from bounding box regression. This architectural refinement enhanced optimization, particularly for small-object detection, while supporting flexible deployment across multiple model sizes (Nano to X), enabling a balance between speed and ac-

curacy, as discussed by Wang et al. (2023). In addition, Vyas and Dutt (2023) highlighted that YOLOv8 extended its functionality beyond detection to include classification and segmentation, making it highly versatile for agricultural monitoring and disease diagnosis tasks.

YOLOv9, launched in February 2024, improved feature aggregation by incorporating *Programmable Gradient Information (PGI)* and the *Generalized Efficient Layer Aggregation Network (GELAN)*. These innovations enhanced the retention of gradient information across layers, thereby boosting detection accuracy while maintaining efficiency for edge devices and mobile platforms, according to Vina (2025). Furthermore, YOLOv10, released in May 2024, further optimized object detection by introducing a *Non-Maximum Suppression (NMS)-free* design through consistent dual-label assignment. This improvement allowed more stable predictions across multiple objects, eliminating redundant bounding boxes and enhancing both training efficiency and precision in dense detection environments, as reported by Vina (2025).

The latest version, YOLOv11, released in September 2024, emphasized efficiency and scalability. With approximately 22% fewer parameters than YOLOv8m while achieving higher mean Average Precision (mAP), YOLOv11 demonstrated superior accuracy-to-complexity performance. Benchmark evaluations confirmed its ability to outperform YOLOv8, YOLOv9, and YOLOv10

in both detection accuracy and inference speed, making it well-suited for large-scale and resource-constrained agricultural applications, as described by Vina (2025).

Table 2.1

Comparison of YOLO Versions

YOLO Version and Key Features	Release Year
YOLOv8 — Introduced an anchor-free and decoupled head architecture; enhanced small-object detection and supported multi-task learning (detection, classification, segmentation).	2023
YOLOv9 — Integrated Programmable Gradient Information (PGI) and GELAN for improved gradient preservation, feature aggregation, and detection accuracy on edge devices.	2024 (February)
YOLOv10 — Adopted a Non-Maximum Suppression (NMS)-free framework with consistent dual-label assignment; improved stability and precision in dense detection scenarios.	2024 (May)
YOLOv11 — Achieved 22% parameter reduction compared to YOLOv8m while attaining higher mean Average Precision (mAP); optimized for scalability, efficiency, and inference speed.	2024 (September)

Across the YOLO series, significant improvements have been achieved in both accuracy and efficiency. Early versions such as YOLOv3 and YOLOv4 established the foundation for reliable object detection, while YOLOv8 in-

troduced a major advancement in versatility through its anchor-free design. According to Ultralytics Vina (2025), YOLOv11 provides the best balance of speed, precision, and scalability, particularly for detecting small and complex objects. Considering the objectives of this study—accurately identifying subtle cacao pod lesions under varying environmental conditions—YOLOv11 is regarded as the most suitable version. However, YOLOv8 remains a practical alternative due to its maturity, widespread adoption, and efficient deployment on hardware-limited UAV systems.

2.5 Geotagging using QGIS in Agriculture

Geotagging plays a vital role in precision agriculture by connecting crop-related data with specific locations in the field. This spatial connection helps farmers make smarter, more targeted decisions about managing their crops. For example, Mohidem et al. (2021) showed that combining geotagged aerial images with vegetation indices significantly improves how accurately crop conditions can be monitored. This makes it easier to spot and address issues in particular areas of the field. Likewise, Rahman (2021) used QGIS software to geotag individual durian trees in Malaysia's Kluang Valley. By linking each tree's location with detailed ground data—such as tree height, canopy size, soil pH, and leaf dimensions—the study created a more precise

and efficient way to monitor the health and growth of each tree. This method allowed for a more organized and data-driven approach to plantation monitoring by enabling the spatial joining of field measurements with geographic coordinates. Rahman (2021) highlights the effectiveness of QGIS in supporting precise and efficient geotagging workflows, underscoring its relevance as a valuable tool in agricultural decision-making and crop health assessment.

2.6 Synthesis

Historically, cacao farmers and researchers have relied on traditional disease management methods such as visual inspection, pruning, sanitation, and fungicide application (Acebo-Guerrero et al. (2012); Opoku et al. (2007)). However, these approaches have limitations, including reliance on farmer expertise, risk of misdiagnosis, and environmental concerns from fungicide use.

To improve accuracy, laboratory-based techniques like PCR and chromatographic analysis (Nguyen et al. (2022); Quelal-Vásconez et al. (2020)) have been used, but they are often time-consuming, destructive, and impractical for field applications. This has driven interest in non-destructive methods, including remote sensing, imaging, and AI-based approaches.

Recent research has explored hyperspectral, thermal, and fluorescence imaging for early disease detection, leveraging plant stress-induced changes

in light absorption and reflection (Alvarado et al. (2023); Silva and Almeida (2024)). Meanwhile, AI and deep learning, particularly CNNs, have enhanced automatic disease classification (Baculio and Barbosa (2022)). Notable developments include a system integrating LBP and Color Histogram with ANN for cacao pod classification and Tan et al. (2018) AuToDiDAC, a mobile app for black pod disease detection.

Despite these advancements, challenges persist. Many existing studies rely on static images, which may fail to capture the full morphology of cacao pods, leading to incomplete assessments. Moreover, mobile-based approaches, while accurate, often face limitations in convenience and coverage. To overcome these issues, this study proposes the integration of a UAV system with the YOLO object detection framework and CNN for automated, real-time cacao pod disease detection. Based on comparative analysis, YOLOv11 demonstrates the most effective balance between speed, precision, and scalability, particularly in detecting small and complex objects (Vina (2025)). Therefore, YOLOv11 is recommended as the optimal version for this study, offering superior detection accuracy, computational efficiency, and adaptability for UAV-based agricultural applications.

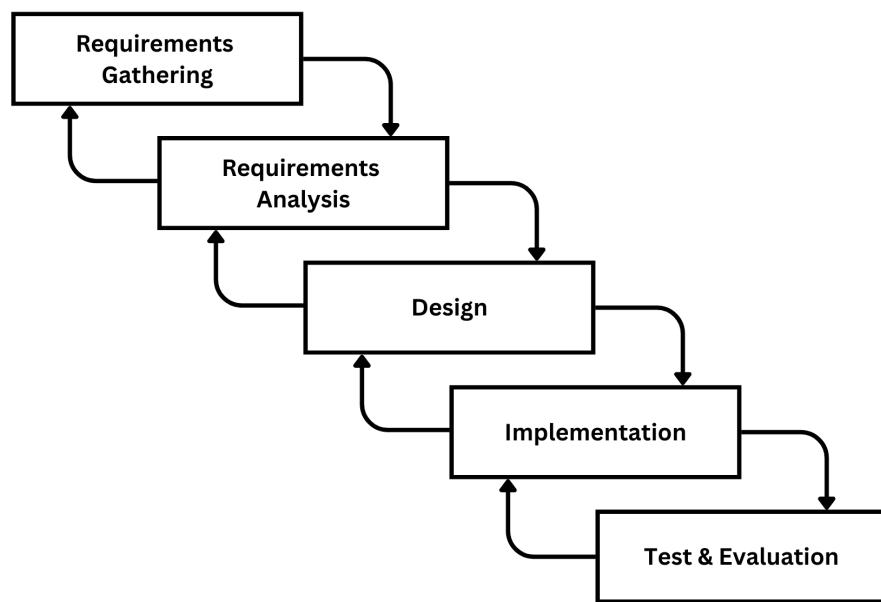
CHAPTER 3

METHODOLOGY

This chapter will present the methodology of the study. It will describe the research design, setting, data-gathering procedures, and the planned design and implementation of the proposed system to ensure that the study will be conducted systematically and aligned with its objectives.

3.1 Research Design

Figure 3.1
Modified Waterfall Model of SDLC



The methodology will be adopted from the Modified Waterfall Model of the Systems Development Life Cycle (SDLC). The methodology will be selected due to its structured yet flexible nature, allowing for sequential phases with opportunities for feedback and refinement. This will be particularly important in agricultural technology development, where both technical precision and field validation will be critical. For this study, it will enable the researchers to systematically design, implement, and evaluate the integration of UAV-collected imagery with YOLO for early disease detection in cacao pods, ensuring that each phase will be thoroughly reviewed before progressing to the next, while still accommodating necessary adjustments. Figure 3.1 shows the stages necessary for development.

3.2 Research Setting

Figure 3.2

Janog Cacao Plantation in Initao, Misamis Oriental



Figure 3.2 shows the location of the Janog Cacao Plantation in Initao, Misamis Oriental, which serves as the research setting of this study. The plantation covers an area of approximately five (5) hectares and contains around 2,500 cacao trees. Each tree has an average height of 2 to 2.5 meters and is planted at 3-meter intervals, forming organized rows that are suitable for structured UAV flights. The site represents typical small to medium-scale cacao farms in the region and is relevant to the Philippine cacao industry, which continues to face challenges from black pod disease.

The UAV used in the study flies at 1-meter height, slightly below the

canopy height, to capture side-view images of the cacao pods along the tree trunks and branches. This flight position allows clearer observation of the pods and provides detailed visual data for disease detection. The structured layout of the farm enables systematic flight paths and consistent data collection across different areas of the plantation.

Farmers in the area also serve as observers and end-users, providing feedback on the practicality of UAV operations and the usability of the detection system. The cacao plantation's accessibility to researchers, combined with its representation of real farming conditions where advanced monitoring systems are rarely applied, makes it an ideal site for testing the feasibility and effectiveness of the proposed UAV-based cacao pod disease detection system.

3.3 Research Setup

The research setup utilizes a UAV (Unmanned Aerial Vehicle) equipped with a built-in high-definition camera and a GPS module to conduct low-altitude monitoring of the cacao farm in Initao, Misamis Oriental. Flying at 1-meter height the UAV to capture detailed side-view images of cacao pods, ensuring that early signs of black pod disease can be identified without requiring high-altitude aerial passes.

The UAV follows predefined paths along the rows of cacao trees to

maintain systematic coverage of the plantation. Images are taken at regular intervals while moving at a steady pace, ensuring consistent data collection. Each image is automatically geotagged with precise coordinates provided by the integrated NEO-M8N GPS module. This process allows the researchers to later map infected pods within the farm using QGIS for visualization.

Since the UAV comes with a built-in imaging system, minimal hardware modifications are required. The programmable flight commands ensure repeatability in data collection, making the dataset reliable for training and validating the YOLO-based detection model.

Figure 3.3

UAV Flight Paths in the Cacao Farm



Figure 3.3 presents the UAV's flight paths across the cacao farm. The drone moves parallel to the rows of cacao trees, ensuring overlapping coverage of pods and reducing blind spots. Flying at a low altitude provides close-range, high-resolution imagery of cacao pods, enabling accurate detection of visible symptoms of *Phytophthora palmivora*. This approach minimizes issues related to lighting, wind, and stability while ensuring that the captured data is clear and consistent for system evaluation.

3.4 Data Gathering

To ensure a well-rounded and effective system design, data for this study will be collected from various relevant sources:

Sources of Data

Cacao Farmers and Field Personnel. Surveys and interviews will be conducted with cacao growers and farm workers to gather insights on existing practices for disease detection, issues encountered in the field, and expectations for a UAV-based system.

Agricultural Specialists. Input from agricultural professionals will be obtained to identify key disease symptoms, validate detection criteria, and provide guidance on monitoring strategies for cacao pod health.

Existing Literature and Research Studies. A review of literature,

including studies by Baculio & Barbosa (2022), Vera et al. (2024), and Solpot (2020), will support system design by providing benchmarks on accuracy, image processing, and machine learning in agriculture.

Technology Experts. Consultations with UAV technicians, AI developers, and computer vision experts will be sought to ensure the system's technological components such as image acquisition and model training are both feasible and optimized for agricultural environments.

Data Gathering Procedure

To gather relevant data that will inform the design and development of the cacao pod disease detection system, this study will utilize both questionnaires and interviews.

Questionnaire. A structured questionnaire will be distributed to cacao farmers and field personnel to gather information about their current practices in detecting cacao pod diseases, the challenges they face in early identification, and their perspectives on using UAV-based solutions. Before distribution, the questionnaire will be reviewed and approved by the research adviser, agricultural specialists, and academic authorities to ensure that it is technically sound, ethically appropriate, and aligned with the objectives of the study.

Interview. Interviews will be conducted with cacao farmers, agricultural experts, plant pathologists, UAV technicians, and AI developers. These interviews aim to collect in-depth insights on disease symptoms, detection indicators, drone imaging strategies, and technical requirements for integrating YOLO into an agricultural setting.

Existing Literature. A review of relevant literature will be conducted to understand the current state of disease detection systems in agriculture, particularly focusing on cacao pod diseases. This will include studies on the use of UAVs, AI-driven disease detection models (such as YOLO), and the challenges associated with deploying such technologies in farming environments and provide a foundation for comparing the proposed system with existing solutions.

Data Finding Analysis

To gather relevant data, this study will employ multiple data collection methods.

Qualitative Analysis. Thematic analysis will be applied to interviews and open-ended survey responses. This approach will help identify recurring themes such as difficulties in manual disease detection, trust in machine learning techniques, and challenges related to the adoption of UAVs. Insights from

this analysis will inform user-centered system design and guide improvements in usability and functionality.

Quantitative Analysis. Descriptive statistical analysis will be used for the structured survey data. This includes calculating frequencies, percentages, and average values to measure levels of technological readiness, prevalence of black pod disease, and the willingness of users to adopt UAV-based solutions for monitoring. These metrics will provide measurable indicators to support system feature prioritization.

Feasibility Analysis. Sensor specifications and machine learning model performance will be assessed through expert consultations and a review of relevant literature. This includes evaluating the accuracy of YOLO for disease detection and the practicality of drone operation in cacao farm environments using a performance matrix.

Spatial Analysis. Given that the UAV system captures geo-tagged images, spatial analysis will be conducted to examine the geographical distribution of detected disease cases. This analysis will help visualize infection hotspots across the farm and support precision intervention strategies. Tools such as heatmaps or geospatial clustering may be used to map and interpret disease spread over time and space.

3.5 Requirement Gathering

User Definition

Following the requirements gathering process, the primary user of the system has been identified.

Farmers - The primary user of the system, responsible for utilizing UAVs to detect early signs of cacao pod diseases and making informed decisions for crop management.

Table 3.1

System Requirements

Category	System Requirements
Input Requirements	<ul style="list-style-type: none"> - The system shall collect images of cacao pods captured by UAVs for disease detection. - The system shall allow users to initiate UAV image capture and review sessions through a simple interface. - The system shall utilize annotated image datasets for training the AI model, specifically focusing on black pod disease. - The system shall use GPS metadata from UAVs as input to geo-tag disease detection results.
Process Requirements	<ul style="list-style-type: none"> - The system shall process captured images using the YOLO model to identify and classify diseased cacao pods. - The system shall preprocess input images for consistency. - The system shall utilize a labeled image dataset of cacao pods.

Category	System Requirements
	<ul style="list-style-type: none"> - The system shall include a manual annotation process where images are labeled with infection presence and location.
Output Requirements	<ul style="list-style-type: none"> - The system shall display detection results, highlighting infected areas on cacao pods in real-time or after processing. - The system shall classify each detected pod as either healthy or infected. - The system shall provide GPS coordinates alongside detection results for mapping infected areas. - The system shall generate summary reports including: total number of pods detected, number and percentage of infected pods, detection time and location.
Control Requirements	<ul style="list-style-type: none"> - The system shall implement secure access with user authentication to ensure that only authorized users (farmers) can access the system. - The system shall maintain logs of image captures, analysis sessions, and user feedback for audit and traceability. - The system shall validate all image inputs and user entries to ensure accurate and usable data is processed.
Performance Requirements	<ul style="list-style-type: none"> - The system shall be capable of processing high resolution images in real-time or near real-time with minimal latency. - The system shall efficiently manage and store large datasets of images and detection results, supporting scalable usage over time. - The system shall maintain uptime and availability to ensure uninterrupted use during farming operations.

3.6 Design and Implementation

3.6.1 System Architecture

Figure 3.4
System Architecture of the Study

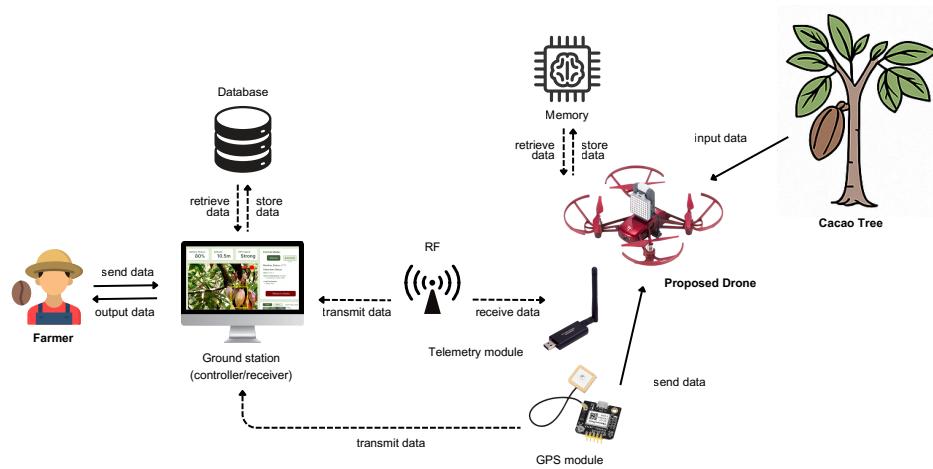


Figure 3.4 illustrates the system architecture of the study. The process begins with the cacao trees, which are the central focus of the system. To monitor them, a proposed drone is deployed over the farm. This DJI RoboMaster TT is equipped with cameras and sensors that collect input data—primarily images and environmental readings—from the trees as it flies at the same level as them. The data captured by the drone is transmitted to an open-source controller with a camera module, which acts as the drone's mini computer. This device processes the incoming images and sensor data. Additionally, a

GPS module connected to the system sends precise geolocation data to the processor, tagging the collected images with accurate coordinates. Once the data is processed, it is temporarily stored in a memory unit. From there, the data is transmitted using a telemetry module, which serves as a bridge between the drone and the ground systems. The telemetry module sends the data wirelessly via RF to the web-based system, which acts as both a controller and a receiver. It receives the telemetry data and displays it in a user-friendly format, allowing the farmer to monitor the status of the cacao trees. The farmer can also send commands or control inputs back to the system using the system. All this information can be stored and retrieved from a database for later analysis or reference. The farmer is empowered with clear insights about the farm's condition without needing to be physically present at each tree.

3.6.2 Flowchart of Hardware and Software

Figure 3.5

Hardware Flowchart



`figures/hardware_flowchart.pdf`

Figure 3.5 illustrates the operational workflow of the UAV system; it begins with powering on the UAV, followed by the initialization of its key sensors, including the camera, GPS module, and obstacle detection system. Once the sensors are active, the system checks for telemetry connectivity with

the ground station; if the connection fails, the drone retries until successful. After establishing a link, the mission plan is loaded from the ground station, and the UAV proceeds to takeoff. During flight, two processes run in parallel: the drone continuously captures images and videos with GPS geotags for later processing, while simultaneously monitoring its environment for obstacles and adjusting its path when necessary. The system then checks whether the mission plan has been completed. If it is complete, the UAV proceeds to land; if not, it continues executing the remaining tasks until completion. Only after landing are the stored image and location data transmitted to the ground station for processing. The operation then concludes with system power down.

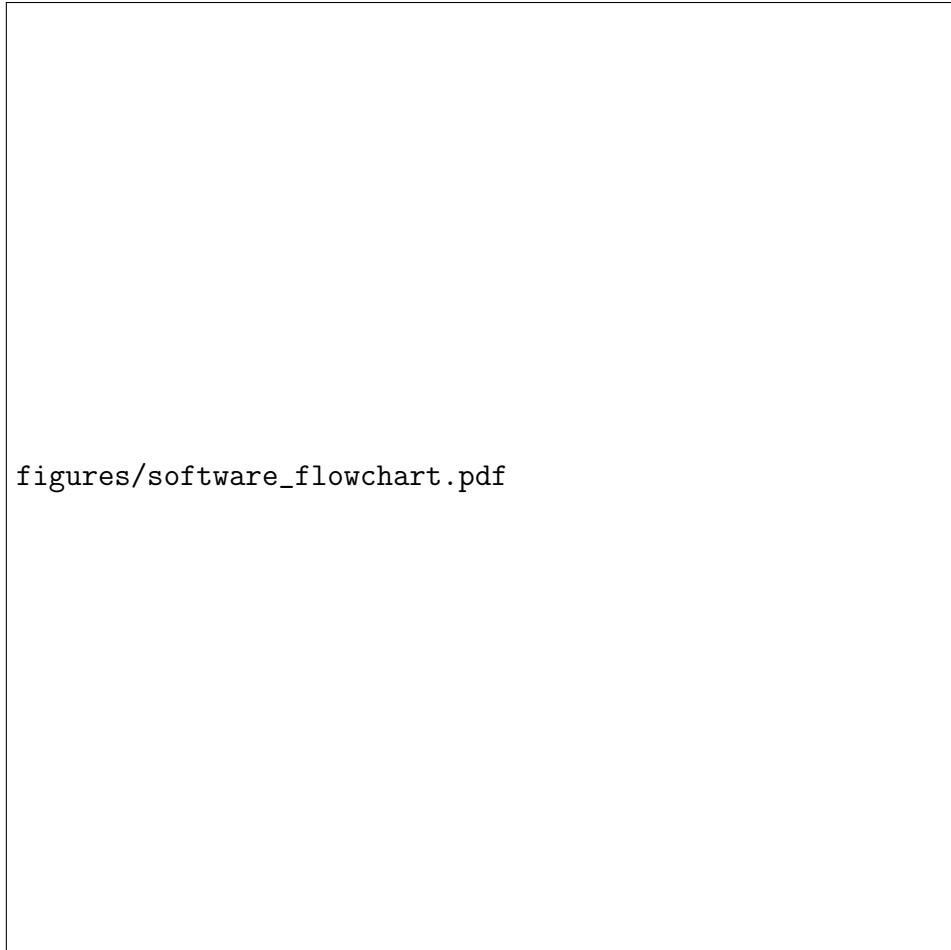
Figure 3.6*Software Flowchart*`figures/software_flowchart.pdf`

Figure 3.6 shows the software workflow, starting with the user logging into the system and creating a mission plan that defines waypoints, altitude, and capture intervals. This plan is then sent to the UAV through SDK, after which the system awaits mission status updates. At this stage, a decision point determines whether the mission has been completed. If the mission is

successful, the system retrieves the uploaded images with their GPS metadata; otherwise, it continues waiting until completion. Once the data is received, the images undergo preprocessing such as resizing, normalization, and augmentation before being passed through the YOLO algorithm for disease detection and classification. The detection results are then associated with GPS coordinates to ensure spatial accuracy and are mapped in QGIS to generate a clear visualization of affected areas. From this stage, two operations run in parallel: results are displayed on the dashboard for immediate user insight, while the same results are saved into the database for reporting and long-term storage. Finally, the processes converge, and the mission concludes to complete the workflow.

3.6.3 Ground Station Architecture

Figure 3.7

Ground Station System Design and Workflow

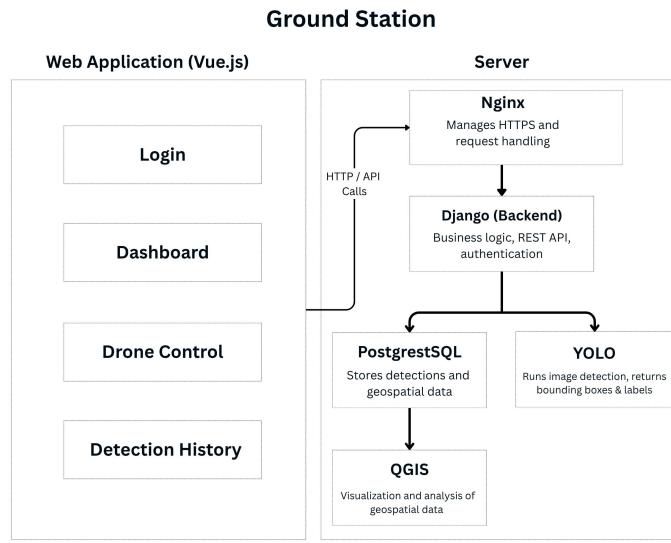


Figure 3.7 presents the entire system that manages the processing of UAV data and delivers results to the end user. It is composed of two closely connected parts: the web application and the server components.

The web application, developed in Vue.js, serves as the main user interface, providing modules for authentication, drone mission control, and visualization of detection outputs. The dashboard summarizes key statistics such as the number of pods identified as healthy or infected, while the history module allows users to review past detections and track trends over time, enabling farmers to monitor crop health and make informed decisions.

The server side of the Ground Station integrates several core technologies. Nginx acts as the web server and reverse proxy, handling HTTPS traffic and routing requests. Django functions as the application server, implementing the system's logic, managing authentication, and exposing a REST API for the web application. The detection process is carried out by the YOLO module, which receives aerial images and returns bounding boxes, labels, and confidence scores. Finally, PostgreSQL, extended with geospatial capabilities, stores the detection results along with their associated GPS coordinates. This allows the system to perform spatial queries and display disease distribution on a map. QGIS connects to the PostgreSQL/PostGIS database to visualize and analyze these spatial results, providing an advanced geospatial analysis platform for validating detections and generating detailed maps.

The operational workflow begins when images captured by the UAV are transmitted to the Ground Station. Django submits the images to the YOLO detection module and then attaches geospatial information derived from the UAV's GPS data. These enriched results are stored in PostgreSQL and subsequently retrieved by the web application for display. QGIS also retrieves this geospatial data directly from PostgreSQL to produce interactive maps and conduct further spatial assessments of the detected crop conditions.

3.6.4 Graphical User Interface Design

The Graphical User Interface (GUI) of the Ground Station was developed to provide farmers and system operators with an accessible and practical platform for cacao disease monitoring. It is organized into four core modules—Login, Dashboard, Drone Control, and History—each wireframed to emphasize usability, efficient workflows, and direct support for the study's objectives.

Login Page

Figure 3.8

Wireframe of Login Page

LOGIN PAGE	
CACAO DISEASE DETECTION WELCOME TO CACAO DISEASE DETECTION Log in to control your drone and monitor plant health.	LOGIN SIGN UP Login to your account <input type="text"/> Email Address <input type="password"/> Password Forgot Password? <input type="button" value="Log In"/> Don't have an account?

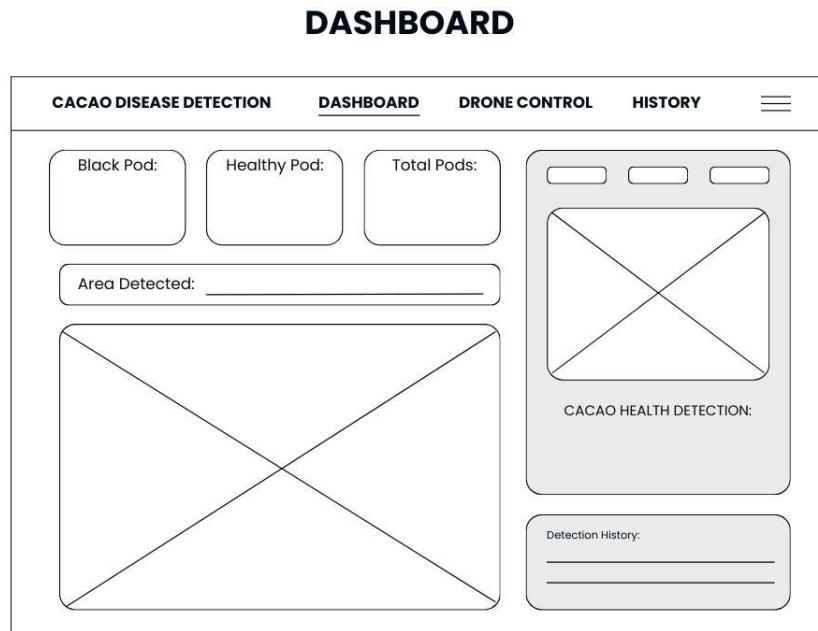
Figure 3.8 shows the login page, which functions as the secure entry point to the system. It requires valid user credentials and integrates valida-

tion mechanisms to protect detection data. This security feature is essential for safeguarding sensitive agricultural information and ensuring that only authorized individuals can access UAV mission results.

Dashboard Page

Figure 3.9

Wireframe of Dashboard



The dashboard, shown in Figure 3.9, serves as the central monitoring hub of the system. It provides real-time visualization of UAV detection outputs, including the number of healthy and infected cacao pods as identified by the YOLO model. This module directly supports the study's aim of enabling

farmers to quickly interpret crop conditions and make informed management decisions.

Drone Control Page

Figure 3.10
Wireframe of Drone Control

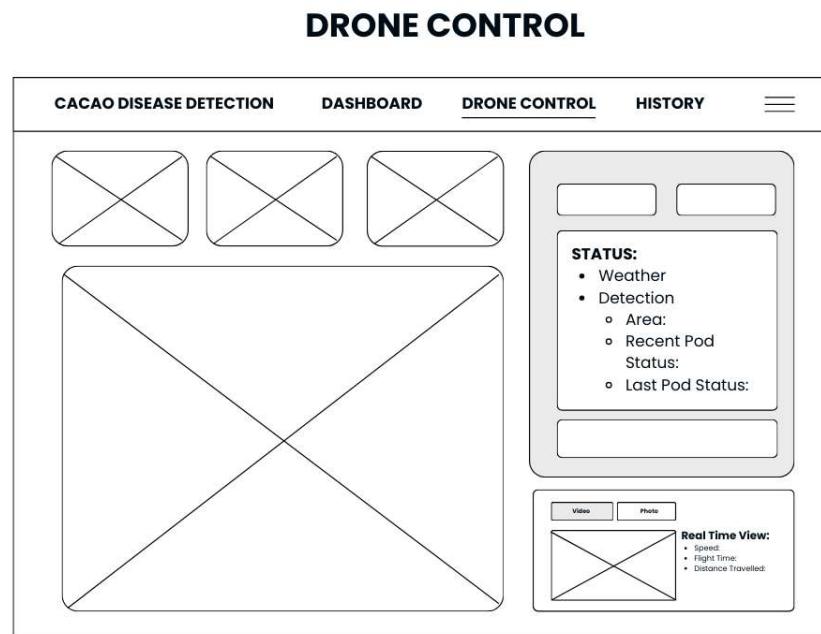
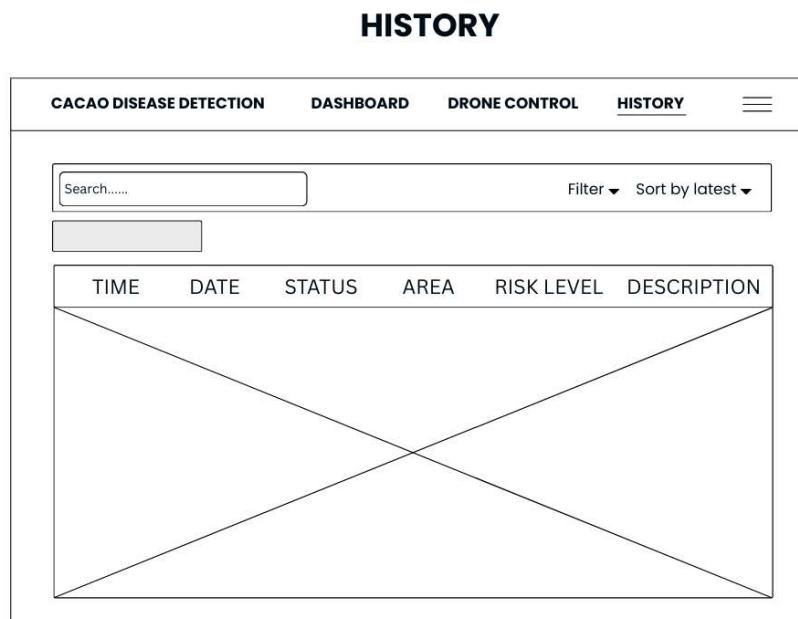


Figure 3.10 illustrates the drone control module, which enables operators to configure flight missions, issue commands, and monitor UAV status. By integrating UAV operations into the GUI, this page ensures that image acquisition for disease detection is efficient, systematic, and directly connected to the research workflow.

History Page

Figure 3.11

Wireframe of History Module



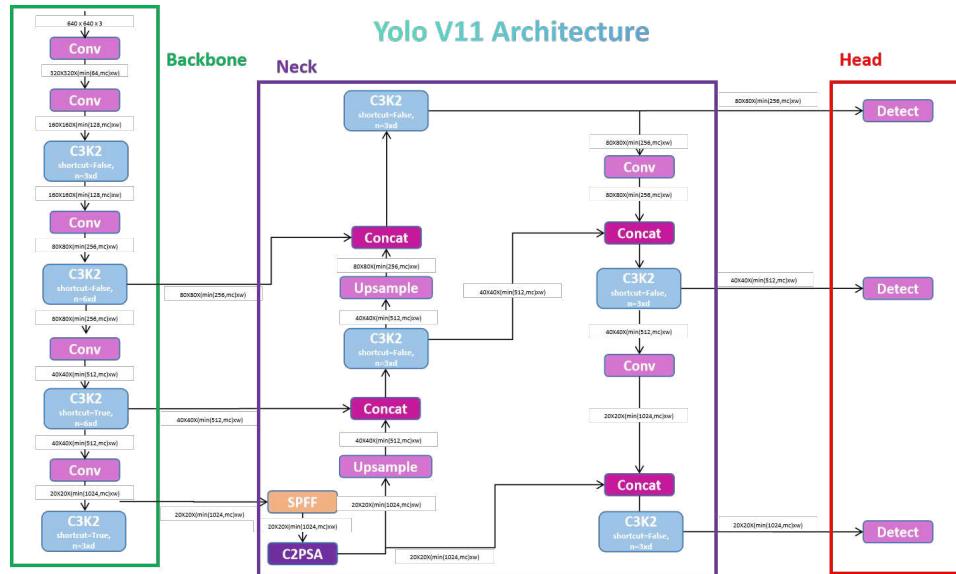
The history module, depicted in Figure 3.11, provides an archive of past detection missions and results. Users can browse, filter, and review earlier UAV detections, which supports long-term disease monitoring and analysis of crop health trends. This functionality reinforces the study's goal of offering farmers a reliable tool for tracking disease progression and assessing the effectiveness of interventions.

3.6.5 YOLO-Based Detection Implementation

YOLO (You Only Look Once) algorithm, a CNN-based object detection framework that employs Convolutional Neural Networks to simultaneously determine the location of objects within an image and classify them. Unlike traditional image classification models, which merely indicate the presence of an object, YOLO predicts both what the object is and where it is situated by drawing bounding boxes around it in a single processing step.

Figure 3.12

Architecture of YOLOv11, showing backbone with new C3K2 blocks, attention modules (C2PSA), Spatial Pyramid Pooling Fast (SPFF), and multi-scale detection heads (adapted from Khanam and Hussain, 2024)



YOLOv11 is employed since it introduces architectural improvements in

feature extraction, particularly for small-object detection, and achieves higher accuracy with fewer parameters compared to earlier versions. YOLOv11 also provides scalable model variants that allow researchers to balance accuracy and computational requirements, making it highly suited for UAV-captured aerial imagery where cacao pods may appear small, numerous, and partially obscured. Figure 3.12 shows the backbone for feature extraction, the neck for aggregating multi-scale feature maps, and the detection head outputs used for classifying and locating objects at various scales.

Dataset Collection Method

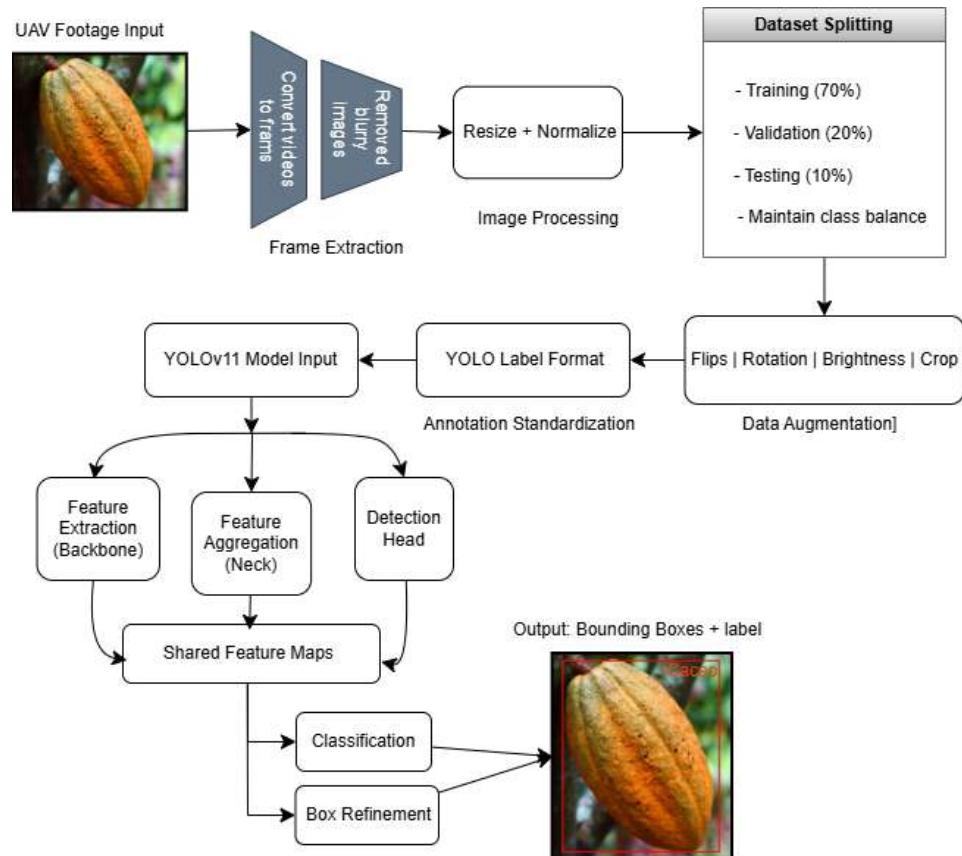
The dataset for this study will consist of both a custom dataset and external sources to ensure diversity and robustness. A custom dataset will be generated using images captured by a DJI RoboMaster TT's built-in camera during scheduled flights over cacao plantations. Capturing images from multiple angles and altitudes will enhance the comprehensiveness and reliability of the dataset. In addition, publicly available image datasets such as those from Kaggle will be incorporated to supplement the collected data and increase variability. To ensure the model performs well in diverse real-world conditions, the combined dataset will include images of both healthy and diseased cacao pods under different lighting conditions, weather scenarios, and backgrounds.

Special attention will be given to capturing multiple stages of infection and varying degrees of pod visibility. All images will be manually annotated to label regions of interest, which is essential for the supervised training of the YOLO model.

Data Preprocessing

Figure 3.13

Workflow of the YOLOv11-based cacao disease detection system, showing data preparation, model input, and classification outputs.



The process begins with raw imagery collected through Unmanned Aerial Vehicles (UAVs) and external datasets. The UAV-captured videos are converted into individual frames at fixed intervals, ensuring that every pod instance is represented across varying viewpoints. Blurry, redundant, or low-quality frames are systematically removed to eliminate noise and improve dataset consistency. The selected images are resized and normalized according to YOLOv11’s input dimensions (e.g., 640×640 pixels), preserving the aspect ratio to prevent geometric distortion. Normalization scales pixel values into a uniform range (typically 0–1) to enhance computational efficiency and model stability.

The curated dataset is then divided into training, validation, and testing subsets, often following a 70–20–10 ratio. This split ensures balanced class representation and prevents overfitting by maintaining a consistent ratio of healthy and diseased pods across subsets. Data augmentation is applied exclusively to the training set to simulate real-world variability and improve the model’s generalization. Transformations such as random horizontal and vertical flips, rotations, brightness and contrast adjustments, and cropping expose the model to different illumination, orientation, and scale conditions. All annotations are standardized into the YOLO label format, which specifies object class IDs and bounding box coordinates in normalized values. This

standardized structure ensures seamless integration with YOLOv11's training and detection pipeline, enabling the model to correctly interpret positional and categorical information during learning.

Cacao and Disease Detection

The UAV-captured cacao images are fed into the YOLOv11 model for automated object detection and disease classification. YOLOv11 divides each image into a predefined grid structure, where each grid cell predicts multiple bounding boxes, corresponding confidence scores, and class probabilities. This design allows the model to simultaneously identify multiple cacao pods within a single frame, accurately localizing each pod even under challenging conditions such as dense foliage, overlapping objects, or inconsistent lighting. Detected pods are enclosed within bounding boxes that represent the system's prediction of their exact position within the image.

Once localization is complete, YOLOv11 proceeds with the classification of each detected pod as either healthy or infected with black pod disease. This classification is based on visual patterns learned during model training, including texture irregularities, surface discoloration, dark lesions, and other symptoms characteristic of infection. The model leverages deep feature extraction through its backbone network, multiscale feature fusion in the neck, and

final detection through its head architecture. The output consists of annotated images displaying bounding boxes and class labels, where healthy pods are distinctly marked from diseased ones. This end-to-end workflow enables precise, efficient, and scalable cacao pod monitoring, facilitating early detection and management of black pod disease in agricultural environments.

Visual and Object Geo-localization

The UAV is equipped with a GPS module and a forward-facing camera that captures images of the cacao pods during flight. Each image is associated with the DJI RoboMaster TT’s GPS at the moment of capture. The images are then processed using an object detection model (YOLOv11), which generates bounding boxes around identified cacao pods. A bounding box is defined by its pixel coordinates (x, y, w, h) , where (x, y) is the top-left corner, and w and h are the width and height in pixels.

To estimate whether the drone’s GPS can be used as an approximate location for a cacao pod, we use the size of the pod’s bounding box in the image together with the camera’s field of view and image resolution. This idea comes from the pinhole camera model, which relates an object’s real-world width, its distance from the camera, and its size in pixels. First, the

researchers computed the camera's focal length in pixels using the formula

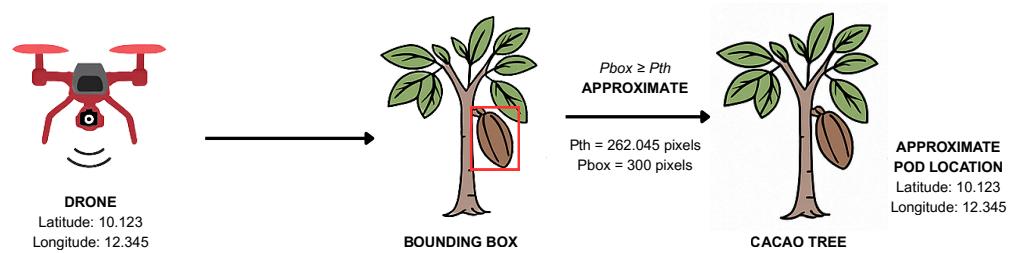
$$f = \frac{\text{image width in pixels}}{2 \tan(HFOV/2)},$$

where $HFOV$ is the horizontal field of view in radians. The DJI RoboMaster TT has a 5 MP image (2592 pixels wide) with a horizontal FoV of 82.6° . This gives a focal length of approximately 2620.45 pixels. The calculated pixel-width threshold for the cacao pod is

$$P_{\text{th}} = \frac{W \cdot f}{D_{\text{max}}},$$

where W is the real width of the pod (e.g., 0.10 m) and D_{max} is the maximum distance from the drone at which we are willing to accept its GPS as an approximate pod location (e.g., 1.0 m). Using these numbers, the threshold is about 262.045 pixels. This means that any cacao pod whose bounding box width is equal to or greater than 262.045 pixels is close enough that the drone's GPS can be used as an approximate pod location, while smaller bounding boxes correspond to pods that are farther away and whose GPS positions would be inaccurate.

Figure 3.14
Tree Geolocalization



As shown in Figure 3.14, the pod has bounding box with 300 pixels widths greater than the threshold (262.045 pixels) are close enough that the drone GPS can be used as an approximate pod location, while smaller boxes correspond to pods that are farther away.

3.6.6 UAV Drone System

Figure 3.15
DJI RoboMaster TT UAV



The DJI RoboMaster TT (Tello Talent), a programmable quadcopter equipped with a Vision Positioning System, a 5 MP camera, and an expansion kit for modular extensions. It was chosen for its lightweight design, stability at low altitudes, and compatibility with open-source programming platforms.

The RoboMaster TT integrates several important functions. Its flight system combines a flight controller and propulsion motors with the Vision Positioning System (VPS), which uses a downward-facing camera and infrared sensors to maintain stable hovering at low altitudes without relying on GPS. This feature is essential for operating indoors or close to the ground, such as at eye level within cacao plantations.

The onboard 5 MP camera enables the capture of still images and 720p HD video, suitable for documenting cacao pods. Power is supplied by a 3.8 V, 1100 mAh LiPo battery, supporting flight times of up to 13 minutes. Safety features include propeller guards, battery protection, and automatic landing in case of weak signals or low power. The expansion kit includes an ESP32-based open-source controller, providing UART, I2C, GPIO, PWM, and SPI interfaces for integrating additional modules such as the GPS receiver.

Command-based Mission Control with RoboMaster TT SDK

The Software Development Kit (SDK) enables command-based mission planning with the DJI RoboMaster TT. Through the SDK, the drone executes scripted flight commands such as `takeoff`, `forward(x)`, `back(x)`, `cw(angle)`, and `land`, allowing it to follow predefined flight paths across cacao rows. During these missions, the drone captures images of cacao pods at specific intervals, paired with location data provided by the integrated NEO-M8N GPS module.

An offline detection approach was adopted: the collected images and GPS coordinates are stored and later processed using the YOLO algorithm. The results of detection are then mapped in QGIS to identify and visualize areas affected by *Phytophthora palmivora*. This workflow synchronizes drone navigation, image acquisition, and geotagging while accounting for the hardware limitations of the RoboMaster TT.

GPS Integration and Data Handling

A NEO-M8N GPS module was connected to the open-source controller via UART for geolocation. The NEO-M8N is a high-performance GNSS receiver capable of tracking multiple satellite systems (GPS, GLONASS, Galileo, and BeiDou). It provides accurate position, velocity, and time data, which

were synchronized with each captured image to create geotagged datasets. This integration enabled the precise mapping of cacao pods and potential disease symptoms in QGIS.

All communications between the UAV and the ground station were established through a Wi-Fi connection. The SDK relies on UDP packets transmitted over Wi-Fi to send flight commands and receive status updates. For structured telemetry such as GPS coordinates and mission logs, the MQTT protocol was integrated as a lightweight messaging layer, ensuring reliable delivery of small data packets. Image files, due to their larger size, were transferred directly via the Wi-Fi link to the ground station.

After each mission, the drone transmitted images and GPS logs to a central database. The ground station retrieved these records from the database for preprocessing and analysis. This workflow ensured that raw images and geospatial metadata were securely stored and easily accessible for the YOLO-based detection system and subsequent spatial visualization in QGIS.

Telemetry Overlay

During flight, the UAV continuously records telemetry data consisting of timestamp, latitude, longitude, altitude, and orientation parameters (yaw, pitch, and roll). These telemetry values are synchronized with the video stream

and image frames, ensuring that every recorded frame has an associated spatiotemporal context for accurate tracking.

Figure 3.16

Telemetry Overlay



Telemetry overlay, as shown in Fig. 3.16, refers to the process of superimposing flight data directly onto the visual feed or processed image output. This provides operators with real-time situational awareness and enables more precise post-flight analysis. Telemetry overlay displays the UAV's recording time, positional coordinates, altitude, and orientation alongside the YOLOv11 bounding boxes of detected cacao trees. It helps users quickly interpret both detection and flight information together. This integration ensures that detections are not only localized within an image but also connected to the UAV's position and state during capture.

The inclusion of telemetry information serves multiple functions. (1) The timestamp allows for chronological indexing of detections, supporting analysis of cacao disease monitoring. (2) The geographic coordinates (latitude, longitude, altitude) provide a direct spatial reference to the UAV's position during detection. (3) The IMU-derived orientation (yaw, pitch, roll) supplies critical context on the UAV's attitude, which can affect the angle and scale of captured images.

Together, these parameters create a transparent record of the flight path and its associated detections, enabling accurate mapping, post-flight analysis, and data validation.

3.6.7 Materials and Cost

Table 3.2

Components and Cost

Component	Price (P)
Drone (DJI RoboMaster TT)	20,000.00
NEO-M8N GPS module	300.00
Total Cost	20,300.00

3.7 Test and Evaluation

Testing will be conducted to ensure that the system will operate accurately, efficiently, and be suitable for real-world use in cacao farm management.

The process will involve functional testing, usability testing, and performance testing. Functional testing will verify whether key features such as UAV image capture, detection of Phytophthora palmivora-infected cacao pods using YOLO, and geotagging of infected trees perform as intended, with each function tested through defined inputs and expected outputs. Usability testing will assess how easily end users, particularly cacao farmers, can navigate and interact with the system by performing essential tasks such as logging in, accessing detection results, and interpreting geotagged maps. Feedback will be collected using the System Usability Scale (SUS) to evaluate the overall user experience. Performance testing will measure the system's responsiveness and accuracy, focusing on the time taken from image capture to the display of results, as well as the efficiency in processing high-resolution images and managing data. Together, these tests will validate the system's reliability, user-friendliness, and effectiveness in supporting early disease detection and timely intervention.

3.7.1 Functional Testing

Functional testing will be carried out to ensure that every part of the system will work as intended. This testing will begin once the prototype is complete. It will focus on verifying key features such as capturing images through the drone, detecting healthy and infected cacao pods using the YOLO,

tagging infected trees' locations with GPS, and displaying results clearly on the dashboard. Each function will be tested by providing specific inputs and checking if the outputs match the expected results.

3.7.2 Usability Testing

Usability testing will be conducted to make sure the system is easy and practical for cacao farmers to use. After the prototype is ready, farmers will be invited to try important features such as logging in, flying the drone, viewing pod detection results, and checking the map showing infected trees. After using the system, they will fill out a short survey called the System Usability Scale (SUS), which measures how user-friendly the system feels. The survey uses a rating scale from 1 to 5 and asks about how easy the system is to learn, how confident they feel using it, and whether the features work well together. Scores are converted to a total out of 100, with scores above 68 generally meaning the system is easy to use. This process will help the team understand what works well and what needs improvement before the system is fully deployed.

Performance Testing

Performance testing will be conducted to evaluate the system's responsiveness, accuracy, and overall reliability based on its core functionalities. This will include measuring the accuracy of detecting *Phytophthora palmivora* infected cacao pods using the YOLO, assessing the precision of geolocation through the GPS module and QGIS, and recording the system's response time from image capture to the display of results on the dashboard. The testing will also evaluate the system using standard performance metrics such as Accuracy, Precision, Recall, F1-Score, and Error Rate to determine the effectiveness of the detection model. These evaluations will verify whether the system will meet its intended performance criteria and will be capable of supporting timely and informed decision-making in cacao disease management.

Table 3.3

Performance Metrics for Cacao Pod Detection

Metric	Equation
Accuracy	$\frac{TP + TN}{TP + TN + FP + FN}$
Precision	$\frac{TP}{TP + FP}$
Recall	$\frac{TP}{TP + FN}$
F1-Score	$\frac{2 \cdot \text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}$

Metric	Equation
Error Rate	$\frac{FP + FN}{TP + TN + FP + FN}$

Table 3.3 presents the performance metrics used to evaluate the cacao pod detection system. Accuracy measures the overall correctness of the system by calculating the proportion of correctly classified instances, including both infected and healthy pods, out of the total number of samples. Precision indicates the proportion of pods identified as infected that are actually infected, which is important to minimize false positives. Recall measures the proportion of actual infected pods that the system correctly identifies, ensuring that most infected pods are detected. The F1-Score provides a balance between precision and recall by calculating their harmonic mean, which is particularly useful when both false positives and false negatives need to be minimized.

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APPENDICES

APPENDIX A

LETTER OF CONSENT



UNIVERSITY OF SCIENCE AND TECHNOLOGY OF SOUTHERN PHILIPPINES
Alubijid | Cagayan de Oro | Claveria | Jasaan | Orosa | Paranaon

INFORMED CONSENT

I _____, hereby consent to participate/ be a respondent in this research titled:
"Automated Black Pod (*Phytophthora Palmivora*) Disease Detection in Cacao Pods using UAV"

I am aware that I should keep a copy of the Letter of Introduction and Consent Form for future reference

I understand that:

I am free to withdraw from the participation in this research at any time and I am free to refuse to answer particular questions

While the information gained in this study will be published as explained, I will not be identified, and individual information will remain confidential.

Data from this research will be kept under lock and key and reported only as a collective combined total.
No one other than the researchers will know my individual answers to their questionnaire.

Participant's Name/Signature: _____ Date: _____

I certify that I have explained the purpose of the research to the participant and consider that he/she/they understands what is involved and liberally consents to participate.

Very truly yours,

Novem Kate Barbosa

Thesis Leader

Jason F. Daohog

Thesis Researcher

John Patrick L. Rautraut

Thesis Researcher

Joel F. Sabuero Jr.

Thesis Researcher

Jeushian Ritz Reblando

Thesis Researcher



UNIVERSITY OF SCIENCE AND TECHNOLOGY OF SOUTHERN PHILIPPINES
Alubijid | Cagayan de Oro | Claveria | Jasaan | Oroquieta | Panaon

September 26, 2025

Engr. Jodie Rey Fernandez
Thesis Adviser
Department of Computer Engineering
University of Science and Technology of Southern Philippines

Dear Engr. Fernandez,

Good day!

We, the undersigned researchers of the study entitled "*Automated Black Pod (*Phytophthora Palmivora*) Disease Detection in Cacao Pods using UAV*", respectfully submit our Pre-Survey Interview Questionnaire for your review and validation.

The purpose of this questionnaire is to gather the necessary preliminary information that will serve as a basis for our main survey and strengthen the reliability of our study. We humbly request your evaluation regarding the clarity, relevance, and appropriateness of the questions to ensure that they align with the objectives of our research.

Your expertise and guidance will greatly help us refine our instrument and guarantee that it is valid for use in data collection.

Thank you very much for your time and support. We look forward to your feedback and recommendations.

Respectfully yours,

Novem Kate Barbosa

Thesis Leader

Jason T. Daohog

Thesis Researcher

John Patrick L. Rautraut

Thesis Researcher

Joel F. Sabuero Jr.

Thesis Researcher

Jeushian Ritz Reblando

Thesis Researcher

Noted by:

Engr. Jodie Rey Fernandez

Thesis Adviser

APPENDIX B

INTERVIEW CONDUCTED

Interviewer(s)	Jason T. Daohog / Jeushian Ritz Reblando / Novem Kate Barbosa
Note Taker	John Patrick Rautraut
Observer	Joel F. Sabuero Jr.
Location	Janog Cacao Plantation, Initao, Misamis Oriental
Date: 10-5-2025	Start Time: 1:30 PM End Time: 4:00 PM
Objectives	To understand existing farming practices, identify challenges in disease detection and management, and collect essential information for system development.
Name (Ngalan) (optional): <u>Erlinda Janog</u>	
Age (Edad):	
<p>1. How big is your cacao farm? <i>Pila kadako imong umahan sa kakaw? (sa hectares o square meters)</i> 5 hectares</p>	
<p>2. Does the size make your work harder or easier each day? <i>Ang kadako ba sa imong uma makapadali o makalisod sa imong trabaho adlaw-adlaw?</i> It makes the work harder since the area is large, and it takes more time to check all trees and manage spraying or pruning</p>	
<p>3. How do you usually enter your farm when you check the trees? (by road, by foot, etc.) <i>Giunsa nimo kasagaran pag-agip sa umahan kung mag-inspeksiyon ka sa mga kahoy?</i> By foot</p>	
<p>4. What problems do you face when going around your farm? <i>Unsa nga mga problema imong makita kung mubisita ka sa uma?</i> Spray, pruning, danggan, rain</p>	
<p>5. Are there things like tall trees, hills, rivers, or power lines in or near your farm?</p>	

Naa bay mga taas nga kahoy, bungtod, sapa, o mga kuryente nga linya sa sulod o duol sa umahan?

Yes

6. How do these affect your work with the cacao trees?

Pa-unsa ni siya naka-apekto sa imong pagtrabaho sa umahan?

No

7. What is the first thing you see when a cacao pod is diseased? (color, spots, wilting, etc.)

Unsay unang butang nga imong makita kung ang bunga sa kakaw kay naay daut? (kolor, naay mansa, ug uban pa)

Appearance

8. What signs do you look for before you say a cacao is unhealthy?

Unsa ang mga timailhan nga imong tan-awon una kung ang kakaw kay daut?

Color dots, phytophthora

9. How do you remember which tree has a diseased cacao? (note-book, marking, memory, etc.)

Giunsa nimo paghinumdom kung asa nga mga kahoy ang naay daut nga kakaw? (notebook, marka, hinumdoman ra, ug uban pa)

The affected tree won't affect another tree. It will only affect the pods in that affected tree

10. When you see a diseased cacao pod, what do you do first? (cut, spray, remove, etc.)

Kung makakita kag bunga sa kakaw nga daut, unsa imong buhaton una? (putlon, sprayan, tangtangon, ug uban pa)

Spray, unnoticed due to other

11. Which methods work best for you to control disease?

Unsa ang mga pamaagi ang mas epektibo para nimo aron makontrol ang daut?

Pest control spray

12. Which ones do not work well?

Unsang mga pamaagi ang dili kaayo epektibo?

Wrapping pods with plastic during the rainy season, since it causes mold formation.

13. How do you decide if you will treat, cut, or remove the sick pod?

Giunsa nimo pagpili kung tambalan, putlon, o tangtangon ang daut nga bunga?

Remove only

14. How many times do you check your cacao for disease? (per week or per month)

Kapila ka mag-inspeksyon sa mga daut na kakaw? (kada semana o kada bulan)

Everyday (3 weeks per area)

15. Do you check more often in the rainy or dry season?

Mas kanunay ba ka mag-inspeksyon sa ting-uwan o sa ting-init?

Both. Especially during rainy seasons, each pod should not be wrapped in a plastic since it will mold except for those who are already wrapped

16. What problems do you face when checking your cacao for disease?

Unsa nga mga problema imong naagian kung mag-inspeksyon ka sa mga daut nga kakaw?

Sometimes it's hard to see the pods because of the rain and thick leaves.

17. Can you tell a story when you found a disease too late?

Pwede nimo mahulagway pag diskubre nimo nga ulahi na nakita nga daut ang kakaw?

It happened during the rainy days when I couldn't check the trees. When I came back, some of the pods were already black and rotten

18. What happened to your harvest after that?

Unsay nahitabo sa imong ani pagkahuman ato?

Harvest 5-7 kilo (Peak season during november to december)

Documentation: