DISEASE ASSESSMENT, MONITORING, AND DETECTION SMART AGRICULTURE USE IN DRONE TECHNOLOGY

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Abstract

Plant diseases are one of the major threats to global food production. Efficient monitoring and detection of plant pathogens are instrumental in restricting and effectively managing the spread of the disease and reducing the cost of pesticides. Traditional, molecular, and serological methods that are widely used for plant disease detection are often ineffective if not applied during the initial stages of pathogenesis, when no or very weak symptoms appear. Moreover, they are almost useless in acquiring spatialized diagnostic results on plant diseases. On the other hand, remote sensing (RS) techniques utilizing drones are very effective for the rapid identification of plant diseases in their early stages. Currently, drones, play a pivotal role in the monitoring of plant pathogen spread, detection, and diagnosis to ensure crops' health status. The advantages of drone technology include high spatial resolution (as several sensors are carried aboard), high efficiency, usage flexibility, and more significantly, quick detection of plant diseases across a large area with low cost, reliability, and provision of high-resolution data. Drone technology employs an automated procedure that begins with gathering images of diseased plants using various sensors and cameras. After extracting features, image processing approaches use the appropriate traditional machine learning or deep learning algorithms. Features are extracted from images of leaves using edge detection and histogram equalization methods. Drones have many potential uses in agriculture, including reducing manual labor and increasing productivity. Drones may be able to provide early warning of plant diseases, allowing farmers to prevent costly crop failures.

Keywords: *disease, detection, drones, precision agriculture, image analysis*

➢ Introduction

Plant diseases are responsible for enormous yield losses and for threatening global food production hence, proper detection and reliable diagnostic methods for identifying the etiological agents of disease are essential to conserving time and money by preventing or limiting crop damages. Classically, diseases were recognized based on traditional methods; these methods, often subjective, were strictly dependent on the observer and though time-consuming overall, were prone to inaccuracy. Additionally, human scouting is expensive and, in many cases, impractical due to human error and/or the occurrence of cryptic when not mild symptoms, making diagnosis at early stages impossible. Therefore, a technologically driven agricultural revolution is important to permanently solve the problems mentioned earlier at a reasonable cost with little environmental impact. With the continuous adoption of recent advanced technologies such as Internet of Things devices, intelligent algorithms, sophisticated sensors, and modern machines, agriculture has changed. It is currently changing from being accomplished by human workers to using smart agricultural machines and robots. Smart agricultural machines and robots have been developed which detect plant diseases early on and at the same time monitor their longdistance movement. Many researchers have used high-resolution imagery collected from satellites, airplanes, on-the-ground machines, and drones to identify agricultural diseases. Satellites and airplanes can cover vast areas in a short amount of time. However, satellites and airplanes have poor spatial and temporal image resolutions compared to drones and are highly susceptible to weather conditions that can affect overflight. Therefore, aerial remote sensing (RS) using drones (Unmanned Aerial Vehicles (UAV) or Unmanned Aerial Systems (UAS)) with intelligent visual systems may be an efficient and inexpensive way for farmers to detect crop and plant diseases in a variety of agricultural fields, from the most intimate greenhouse to the largest farm. Digital (red, blue, and green or RBG), multispectral, hyper-spectral, fluorescent, and thermal infrared-based imaging sensors paired with effective algorithms mounted on drones can efficiently detect, differentiate, and quantify the severity of the symptoms induced by various pathogens under field condition, as confirmed by the plethora of studies conducted on important cereal crops such as, rice, maize, wheat, fruit trees (including citrus, olive, and grapevine, vegetables (including potatoes, soybeans, and tomatoes, and many forest trees, such as, pine, that have demonstrated the reliability of drones for diagnostic purposes.

Drones are equipped with digital, multispectral, hyperspectral, thermal, and fluorescence sensors which offer finer resolution of plant diseases and assist in plant disease detection at earlier stages than is possible with satellite systems. Data acquired by drones can be simultaneously sampled by their autonomous systems at various heights in the atmosphere; these data can then be rapidly elaborated to provide forecasting models across fields, regions, and even whole continents. Finally, information can be delivered to farmers, allowing them to make appropriate decisions regarding timely management of disease. Hence, precision agriculture (Smart Agriculture) may benefit greatly from using drone remote sensing technology because of its cheap cost and high-flying flexibility. There are a large number of studies on using drone platforms with different sensors for plant disease sensing. For example, drones were equipped with a hyperspectral image sensor to obtain an image of winter wheat yellow rust and realize its effective detection. Similarly, multispectral imaging and a drone system were used to explore myrtle rust on myrtle, and infested corn plants were detected with drones using visible light images from digital cameras. Effective algorithms are required to analyze the images gathered by drones. Traditional machine learning methods have shortcomings due to their reliance on manual feature extraction methods, which is especially ineffective in complex environments. Deep learning algorithms have recently emerged as a promising new alternative to enhance computer vision-based systems for autonomous crop disease monitoring.

Simply, UAVs are any aerial vehicles that are remotely driven, meaning no pilot on board. They are considered one of the important innovations of present-day precision agriculture. Precision agriculture (PA) is a method to transform agriculture by reducing time and labor and increasing production and management efficiency. With the development in technology and computational skills, there have been changes in agricultural patterns such as using digital planters, harvesters, sprayers, etc. Agriculture has transformed over time from being carried out by manual labor to mechanical labor due to the adoption of technological changes. Previously, plant diseases in agriculture fields were monitored visually by people who have experience scouting and monitoring plant diseases. This type of observation is psychological and subject to bias, optical illusion, and error. This generated the need for external image-based tools that can replace unreliable human observations. This also allows for extended coverage in a limited amount of time. The potential of UAVs for conducting detailed surveys in precision agriculture has been demonstrated for a range of applications such as crop monitoring, field mapping, biomass estimation, weed management, plant population counting, and spraying. A large amount of data and information is collected by UAVs to improve agricultural practices. Different kinds of data recording instruments, cameras, and sensor installation equipment have been developed for agricultural purposes. Some additional reasons for increasing usage of UAVs and drones in agriculture include UAV prices decreasing gradually, agriculture operations being carried out in areas with low population and activities, and UAVs having a large occupancy and great scouting capability. Although the images can be obtained from various sources, such as satellites and aircrafts, and can cover a large area compared to those of an unmanned aerial system, the resolution in the images is not conducive to drawing significant conclusions. This leads to other advantages of using drones for high-resolution aerialimages. Increased efficiency, stability, accuracy, and productivity are other advantages of UAVs that allow growers and experts to make better, timelier management decisions. The application of PA technology not only increases economic profit but social benefits measured in sustainability. A study carried out by Van Evert et al. reported that the application of PA in potato cultivation increased economic profit by 21% and social profit by 26% compared to agricultural practices without precision agriculture.

The use of agriculture UAVs is hindered by many challenges such as battery efficiency, low flight time, communication distance, and payload. The limited flight duration due to increased payload and decreased efficiency of batteries obstructs when performing critical agricultural activities in larger fields, such as pesticide and nutrient application. Other challenges associated with its use are engine power, stability, maintaining altitude, and maneuverability in wind and turbulence. UAVs have been used for a variety of reasons in agriculture. Traditionally, visual observations would determine crop nutrient status, their pests, diseases, and environmental stress. Currently, most UAVs are used for detecting stress in plants, for quantifying biomass, vegetation classification, canopy cover estimation, yield prediction, plant height assessment, and lodging assessment. Agriculture UAVs have been used for mapping agriculture fields, spraying chemicals, planting, crop monitoring, irrigation, diagnosis of insects and pests, artificial pollination, and livestock population dynamics. A combination of UAVs with hyper and multispectral cameras has been predominant in a wide range of agricultural operations for disease identification purposes. Recently, Chang, Zhou, Kira, Marri, Skovira, Gu, and Sun used UAVs to measure solar-induced chlorophyll fluorescence and photo-chemical reflectance through single bifurcated fiber and a motorized arm to measure radiance. Artificial Intelligence (AI) and deep learning are incorporated with UAVs to increase the precision of crop disease identification and monitoring. Penn State University, Food and Agriculture Organization, International Institute of Tropical Agriculture, International Maize and Wheat Improvement Center and others have developed PlantVillage Nuru to identify viral diseases in cassava plants. Nowadays, AI and DL are collaborated to ease the process of plant disease detection. Plant Village Nuru has been integrated with theWest African viral epidemiology platform (WAVE 2) to track the spread of cassava brown streak disease.

➢ MATERIALS AND METHODS

❖ Types of UAVs, Their Platforms and Peripherals Used in Disease Monitoring and Identification

Now a days, as discussed earlier, different agricultural activities have been carried out by UAVs. Among them, UAVs are increasingly used for disease monitoring and identification. They work together with different components such as cameras, sensors, motors, rotors, controllers, etc. One of the basic uses of UAV is to capture images. The information contained in images is extracted and transformed into useful information by image processing and deep learning tools. Electromagnetic spectra also provide useful information, which is used to make decisions regarding plant physiological stress. The comparison between the spectroscopy in the specific region helps to assess the condition of the plants in real-time under field conditions. Plant disease is identified by observing the physiological disturbances caused by foliar reflectance in a near-infrared portion of the spectrum in a UAV captured image. In addition, the disturbances in the photosynthetic activities of the crops caused by many diseases are also observed as reflectance in the red wavelength range. There are various types of UAVs for different agricultural operation purposes. In relation to UAVs, these UAV structures are called platforms. Primarily, there are two types of agricultural UAV platforms: fixed wing and rotatory wing. A fixed-wing UAV is comparatively larger in size and used for large-area coverage. Rotary-wing UAVs are further divided into two types: helicopter and multirotor. Helicopters have a large propeller at the top of the aircraft and are used for aerial photography and spraying. Similarly, multirotors have different varieties depending upon the number of motors the aircraft possesses. Different types of multirotors are the quadcopter (four rotors), hexacopter (six rotors), and octocopter (eight rotors).

❖ Cameras and Sensors

Aerial imaging is one of the most important factors when it comes to the application of UAVs. Usually, the image quality determines the selection of UAVs. However, the type of sensor and the purpose of the study also dictate the choice of platform. Thus, the UAV platforms are loaded with different cameras and sensors. For example, a DJI Mavic 2 is upgraded with a Sentera single NDVI camera (Sentera, Saint Paul, MN, USA) to monitor the drought stress in crapemyrtle plants. However, UAV platforms are limited to their payload. An increase in payload decreases the speed, stability, and flight time of the UAV. The choice of sensors depends upon the purpose of the study. Drought stress is better observed using thermal sensors in the early stages, while multispectral and hyperspectral sensors are used for long-term results. Pathogen infections in crops are better diagnosed using hyperspectral and thermal sensors in the early stages, but RGB sensors, multispectral, and hyperspectral can be used to detect the severity of infection in later stages. In this subsection, we will discuss different cameras and sensors used in plant disease monitoring and observation.

(DJI Mavic air UAV with single NDVI camera over the automatic detection)

- **RGB Camera**

RGB (Red–green–blue) cameras are commonly used types of cameras that produce images that measure the intensity of three colors and define values of each color in pixels: red, green, and blue.

a.RGB Camera

RGB (Red–green–blue) cameras are commonly used types of cameras that produce images that measure the intensity of three colors and define values of each color in pixels: red, green, and blue. RGB cameras are used to generate 3-dimensional (3D) models of agricultural crops and provide an estimation of crop biomass. RGB cameras are also used with NIR and multispectral cameras to improve accuracy while calculating the biomass. If the near-infrared filter is replaced by a red filter, it is called a modified RGB camera. Commercial RGB cameras are cheap and have poor spectral resolution.

- **Multispectral Cameras**

Multispectral cameras are considered to be one of the most appropriate sensors for agricultural analytics, as they have the capacity to capture images in high spatial resolution and determine reflectance in near infrared bands. Multispectral and NIR cameras create vegetative indices that rely on near-infrared or other bands of light. Multispectral cameras use different spectral bands: mostly red, blue, green, red-edge, and near-infrared. They can be differentiated into two groups based on bandwidth: narrowband and broadband. Most of the aerial images for monitoring crop health issues use multispectral cameras as they are used to calculate indices such as NDVI and others including NIR. The absence of multispectral sensors in agricultural UAVs will hinder the early detection of plant diseases. The evaluation of multispectral image bands captured in an aerial image at different heights was carried out in 2019 by Xavier and colleagues to detect ramularia leaf blight in cotton. However, the differentiation in the severity index was not significan. In a study conducted by RU, 35 vegetative indices were used to detect.

- **Hyperspectral Cameras**

The major difference between multispectral and hyperspectral cameras is that hyperspectral cameras collect light of different narrow size bands for every pixel in the image captured. Though multispectral cameras are able to capture light reflected by biomolecules, the differences lie in the bandwidth and placement of the light, which helps us to isolate responses from the different molecules. These cameras have particular properties in detecting lights emitted from biomolecules such as chlorophyll, mesophyll, xanthophyll, and carotenoids. The major drawback of using a hyperspectral camera is the high cost of cameras and the huge amount of unnecessary data when not properly calibrated. Abdulridha and colleagues used a hyperspectral imaging

- **Thermal Cameras**

Thermal cameras capture infra-red lights in the range of 0.75 to 1000 _m and provide the temperatures of the objects in the form of a thermal image. The advantages of thermal cameras are the low cost as compared to other spectral cameras and that RGB cameras can be converted to thermal cameras with certain modifications. Originally, thermal cameras were used for inspecting drought stress in crops. Thermal images include the temperature of the surrounding objects and have low resolution compared to images captured by other major cameras. Thermal sensors are also used in detecting crop diseases and monitoring crops.

- **Depth Sensors**

Depth sensors are common peripherals used in agricultural UAVs that provide extra feature-depth in the RGB pixels. The depth in a depth sensor is defined as the distance between the sensor and the point of an object at the time of image capture. The

- **Image Pre-Processing**

Image pre-processing involves a series of steps before extracting data from the images. The major objective of image pre-processing is to reduce errors and to prepare to extract data from the image. After the high spatial geo-referenced aerial images are captured using UAVs, a large amount of data has to be extracted. Thus, it is very important that the images are error-free. The images may have been degraded while capturing due to noise, shadow, etc. It is very important to have critical knowledge of plant diseases for pre-processing the images and choosing an appropriate method to increase the accuracy of identification. Image pre-processing includes a series of steps to make it appropriate to extract data from the images. These include enhancement of images, their segmentation, color space conversion, and filters. However, Sonka et al. categorize the steps of image pre-processing as pixel brightness transformation, geometric transformation, local pre-processing, and image restoration. Pixel brightness transformation modifies the brightness of the image depending on the pixel of the image, for which they have two classes: brightness correction and grey scale transformation. Similarly, geometric transformation correlates the coordinates of the input image pixel with the points in the output image and determines the brightness of the transformed point in the digital raster. Local pre-processing utilizes the neighborhood of the pixel to generate the new brightness
value in the output image. Finally, image restoration is the method in pre-processing that is used to discard degradation factors, such as lens defects, wrong focus, etc., in the image.

- **Methods for the Detection of Plant Disease**:

The “Old Generation”Appropriate and reliable evaluation of crops’ phytosanitary status, intended as the observation of occurrence and outbreak of plant diseases, is very important, as timely estimation of disease incidence, symptom severity, and the resulting impacts on economically important crops is decisive for managing agronomical interventions such as pesticide application time. Themethods for disease detection have been categorized into direct and indirectmethods. Directmethods, known as “old generation”methods, include traditional (symptomology, microscopy, and incubation method), molecular diagnostic methods (e.g., polymerase chain reaction (PCR), rapid fragment length polymorphisms (RFLP), real-time PCR, loop-mediated isothermal amplification (LAMP), recombinase polymerase amplification (RPA), and point-of-care diagnostic methods), and serological methods. However, due to their slowness and low capacity, these methods are not well-suited for implementation in the field, delaying early detection and response to disease outbreaks. To effectively prevent and control future outbreaks, a quick and high-throughput approach for the early detection of plant diseases must be developed., Traditional methods usually follow the evaluation of characteristic disease symptoms and visible signs of the pathogens. The evaluation of disease symptoms is performed by trained experts and can be affected by temporal variations. Moreover, traditional methods strictly depend on individual experience, and these methods become accurate and reliable only if the guidelines and standards for assessment are properly followed. Microscopic identification depends on the observation of pathogen inoculum (e.g., mycelia, spores, and fruiting bodies).

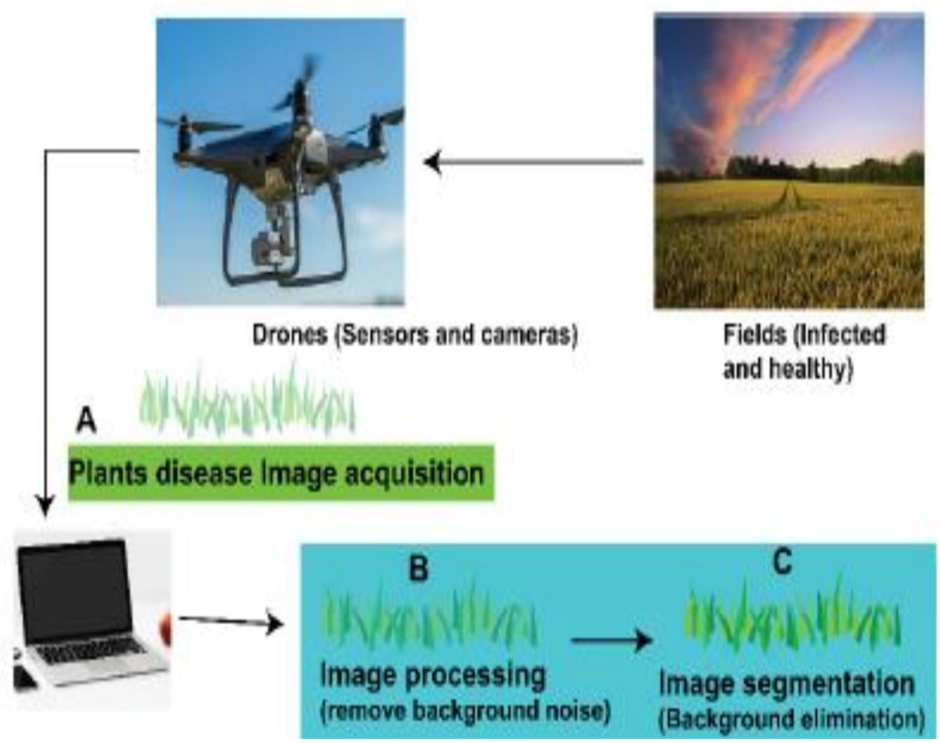
- **Methods for the Detection of Plant Disease: The “New Generation”**

Indirect methods, known as “New Generation”, essentially exploit biomarker-based techniques such as metabolite profiling from plant–pathogen interactions as well as stressbased detection techniques such as imaging and spectroscopy using drones. Recently, various indirect methods have been launched, in particular drones, which can estimate disease more accurately compared to molecular, serological, and microbiological diagnostic techniques. Sensors have been mounted on drones to measure reflectance, temperature, or fluorescence. Sensors of various types have been developed (RGB, multispectral, hyperspectral, thermal, and fluorescence), representing emerging tools for the detection, identification, and quantification of plant diseases, as shown in Table. Sensors are the key components of any drone that allow it to navigate, detect, and locate potential crop diseases from visual data and to provide a map of the condition of the crops that could be useful to farmers or other machines collaborating with the drones to carry out various tasks autonomously with little or no human involvement. The advantages and disadvantages of various sensors mounted on drones are shown in Table 1. The accuracy and use of multispectral and hyperspectral images for disease diagnosis are greatly improved. This is because of the sensitivity of spectral measurements to stress and change during a crop’s development and with disease severity. Nonetheless, implementing a hyperspectral data acquisition protocol in the field presents significant challenges. Several elements might affect spectral reflectance, including technical characteristics (resolution, brightness, etc.), sample preparation circumstances (laboratory or field), and sample characteristics (size, texture, humidity, etc.). More research into reflectance using crop vegetation indices is needed throughout crop development and infection.

- **The Operating Mechanism of Drones Used to Detect Plant Diseases**

Drones are aerial robots that operate independently of a human pilot. These aircraft may be piloted by hand from a distance using remote control, or they can complete missions independently using a computer running Artificial Intelligence (AI) programs. One of the most transformative steps toward “precision agriculture” is the widespread use of agricultural drones. Drones can execute flying missions at varying heights and viewing angles, allowing themto survey hazardous and challenging places previously inaccessible tomanned aircraft or satellites.

Many agricultural tasks, such as detecting and treating crop diseases, have recently seen widespread use of various drone types fitted with high-resolution video sensors. Drones have been categorized into two major types based on the movement of wings, i.e., fixed-wing and rotary-wing on the one hand, and hybrid Vertical Take-Off and Landing (VTOL) drones on the other. More advanced cameras and sensors are carried by fixed-wing and VTOL drones than by multirotor rotary-wing drones, particularly when it comes to heavy hyperspectral sensors. Drones with advanced cameras can help farmers to increase crop output while saving time and money by automating tasks that previously required a team of people to complete. However, rotary multirotor drones can fly at lower altitudes, and their cameras offer superior Ground Sampling Distance resolution. The advantages and disadvantages of both types of drones for field-based agricultural applications are shown in Table. Drone systems to detect plant diseases comprise four sections, as shown in Figure. A mechanism depicting the structure and operational mechanism of drone technology for plant disease detection recommended by for assessing plant diseases is presented in Figure.



(Fig. disease detection recommended by for assessing plant diseases is presented)

Novel Approaches to Detecting Plant Diseases, including RS Combined with Drones Plants can be affected simultaneously by several plant pathogens, such as nematodes, fungi, viruses, viroids, bacteria, and phytoplasmas. Recent novel approaches have been used that can rapidly, easily, and reliably detect plant pathogens at pre-symptomatic to early stages of plant diseases, when symptoms are unclear and appear on few plants. This method includes Lateral flow microarrays, Analysis of Volatile Organic Compounds (VOCs) as biomarkers, Remote sensing (RS) drone usages, electrochemistry, Phage display, and biophotonics. Lateral flow microarrays (LFM) are a hybridization-based nucleic acid detection method that uses an easily visualized calorimetric signal to detect plant pathogens rapidly. However, this method depends on the availability of strong and reliable host and pathogen biomarkers discovered through transcriptomics and metabolomics approaches. A class of interesting plant metabolites highly suitable for plant health evaluation are Volatile Organic Compounds (VOCs) as biomarkers; plants are known to release VOCs into their immediate proximity for most various biological and ecological purposes, with these compounds being responsible for growth, defence, survival, and intercommunication with other surrounding and/or associated organisms. Representing a mediation tool for plant-to-plant and plant-to-pathogen communication, VOCs released from the leaf surfaces are known as terminal metabolites and can reflect the physiological status of plants.

- **Applications of Drones for Plant Disease Detection**

Researchers are investing in identifying infected and uninfected leaves as well as in categorizing various disease severity degrees with visual symptoms even before the manifestation of visual symptoms. Modern methods for disease identification make use of machine learning algorithms to sift through information gathered through a variety of acquisition methods.

- **Diseases with Drones**

Traditional machine-learning techniques are applied for plant disease identification utilizing drone images. Backpropagation NN (BPNN) was an early model that was used to apply spectral data collected from remote sensing hyperspectral photographs of tomatoplants to estimate infection severity on plant leaves from photos. A five-stage rating BPNN using that information. The findings supported the feasibility of using ANN with Backpropagati to use the Classification and Regression Tree model to identify leafroll illness. Their strategy relied on analyzing hyperspectral photos of grapevines taken by drones. Similarly, the authors of [57] used multispectral photos taken by drones to extract spectral bands, vegetation indicators, and biophysical properties of both damaged and healthy plants. Due to their high accuracy in making predictions, SVM models are widely utilized in the field of plant disease diagnosis. SVM was used for close-range hyperspectral imaging of barley to identify drought stress at an early stage. Red Edge Normalized Difference Vegetation Index (RENDVI) and Plant Senescence Reflectance Index (PSRI) were used in the model's training process. Misclassification can be further minimized by the use of several SVM classifiers based on color, texture, and shape features for disease identification on plant leaves.

Remote sensed data were initially used by the University of North Dakota, USA, where farmers were involved in verifying the effectiveness of fungicide applications against plant diseases in a sugar beet crop. Moreover, the loss due to accidental spray drift of fungicides was quantified. Remote sensor data have been used to investigate physical damage due to pests, inundation, wind, and hail as well. In this instance, growers and ranchers in rural areas were connected via satellite. Farmers were given a first-time opportunity to use high-resolution imagery, which allowed them to identify crop stress due to diseases, pests, and damage. The information obtained was then used to draw boundaries around crop stress areas.

- **Regression Analysis**

Regression analysis is one of the most common methods of analyzing UAV imagery. After orthorectification of images, the values for each band, such as NIR, Red, Green, Blue, etc., are extracted. For those extracted values, the regression model is run to investigate the spectral characteristics of the parameters. Generally, different types of regression analysis models are run depending upon the type of dataset acquired: linear and non-linear and simple and multiple analysis. At the end of the large dataset analysis, the cross-validation of regression (RA) model is important because when a model is chosen, it is predicted that the observation will be the same in the future as well, but it may not always be similar. Thus, data are split, and two portions are formed. A set is used to form a regression analysis model, while the other set is reserved as a future observation to fit into the model.

Crop	Disease [1]
Apple, Blueberry, Cherry, Corn, Grape, Orange, Peach, Bell Pepper, Potato, Raspberry, Soybean, Squash, Strawberry, and Tomato	Cedar-Apple apple rust, scab, apple black rot, apple powdery mildew, gray leaf spot, corn common rust, northern corn leaf blight, grape black rot, esca complex, Pseudocercospora leaf spot, HLB, bacterial spot of peach and bell pepper, early and late blight of potato, squash powdery mildew, strawberry leaf scorch, early and late blight of tomato, target leaf spot, leaf mold, bacterial leaf spot, TMV, and yellow leaf curl virus of tomato
Citrus	HLB
Citrus	HLB
Corn	Corn leaf blight, common rust and grey leaf spot
Cotton	Ramularia blight
Cotton	Cotton root rot
Grape	Leaf stripe disease
Grape	Vine diseases
Grape	Esca complex

❖ Outlook, Future Trends, and Limitations

To improve crop output and attain food security in vast agricultural areas, monitoring and identifying crop/plant diseases early on with accuracy, dependability, timeliness, and efficiency is crucial. In this review, we began by describing methods for detecting plant diseases, e.g., old and new generations. The old generation includes traditional, molecular, and serological methods. However, these methods are not well suited for the early detection of plant diseases. The new generation includes sensor-mounted drones that accurately detect plant diseases at the earliest stages, enabling prevention of future outbreaks by applying suitable management measures. Second, we emphasized various sensors that may be installed on drone platforms, including digital, multispectral, hyperspectral, thermal, and fluorescence sensors. Hyperspectral sensors are more robust than digital and multispectral sensors, whereas thermal sensors can be used during either day or night, providing more insight into plant status than other sensors. Third, different types of drones and their operating mechanisms were shown. VTOL and fixed-wing drones can carry more cameras and sensors than rotary-wing drones. Hence, VTOL and fixed-wing drones fly for a longer time and can cover large areas. However, these types are expensive and can encounter issues when hovering. Fourth, we looked at novel approaches such as lateral flow microarrays, biomarkers, electrochemistry, phage display, and biophotonics while focusing on drones.

➢ CONCLUSIONS

In conclusion, the application of drones in plant disease assessment offers efficient monitoring and detection capabilities for smart agriculture. Rapid population growth and climate change are the leading causes of food insecurity. The advancements in UAVs and their systems to diagnose crop stress, pests, and diseases have greatly benefitted growers. Increasing farm productivity and lowering the cost of production using advanced technology is helping growers to increase yields and sustainability on their farms. The development in the automatic detection of plant diseases using UAVs has emerged as a novel technology of precision agriculture. Drones provide increased accessibility, improved coverage, and rapid data collection, enabling timely disease detection. With advanced sensors and imaging techniques, drones can capture valuable data on plant health indicators. These data can be processed using analytics and machine learning algorithms to identify disease patterns and assess severity. Integration of drones into plant disease assessment systems allows for real-time monitoring, early detection, and targeted intervention. Drones can contribute to sustainable farming practices, minimization of yield losses, reduced need for chemical treatments, and support for precision agriculture strategies. Continued research addressing the challenges mentioned above can further enhance the potential of drones in plant disease assessment for a resilient agricultural future.

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