International Research Journal on Advanced Engineering Hub (IRJAEH)
e ISSN: 2584-2137
Vol. 03 Issue: 03 March 2025
Page No: 403-411
https://irjaeh.com
https://doi.org/10.47392/IRJAEH.2025.0055

Machine Learning Based Smart Drone System for Spraying Pesticides

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Abstract

This project introduces a smart drone system designed to spray pesticides selectively, targeting only affected plants or those specified by the user through an intuitive user interface. Leveraging machine learning (ML) and real-time image analysis, the drone identifies plant conditions—such as diseases or stress—and applies pesticides with precision. Users upload images or specify plant conditions via the interface, and the system recommends suitable pesticides based on the diagnosed issues. By focusing on affected areas, this approach minimizes pesticide use, reduces environmental impact, and ensures healthier crop management. This innovative solution combines technology and sustainability, advancing modern agricultural practices.

Keywords: *Machine Learning (ML), Unmanned Aerial Vehicle (UAV), Fixed-wing, Helicopter, and Multi-copter.*

1. Introduction

The agricultural sector faces growing challenges to enhance productivity while reducing environmental impact and adopting sustainable practices [1]. Traditional pesticide application methods often lead to issues such as overuse, uneven distribution, and harm to non-target species, highlighting the need for more efficient and eco-friendly solutions. To address these challenges, integrating advanced technologies like machine learning (ML) and drones into agricultural practices has become increasingly important. Machine learning, a subset of artificial intelligence, enables systems to analyze data, identify patterns, and improve performance without explicit programming for every scenario. When combined with drone-based pesticide spraying, ML algorithms can process complex datasets—such as crop health indicators, pest infestation patterns, and weather conditions—to optimize spraying parameters. This results in targeted application, reduced chemical usage, and minimized environmental impact [2]. The process begins with data collection, where sensors, drones, or other monitoring equipment capture real-time information about crop health, soil conditions, and pest presence. The collected data is then cleaned, organized, and analyzed to identify actionable patterns [3]. A machine learning model is trained on historical and real-time data to predict or recommend precise pesticide or fertilizer application strategies. Using the model's output, a spraying plan is generated to determine the exact locations and quantities for application. Finally, a drone executes the plan with precision, followed by monitoring and adjustments to ensure crop health and optimize the process further (Figure 1). The process begins by collecting data from the field using sensors, drones, or other monitoring equipment to gather information about crop health, soil conditions, and pest presence. Next, this data is processed to clean, organize, and analyse it for useful patterns [4]. Once the data is ready, a machine learning (ML) model is applied to make predictions or recommendations based on historical and real-time data. Using the model's output, a spraying plan is generated, determining where and how much pesticide or fertilizer should be applied.

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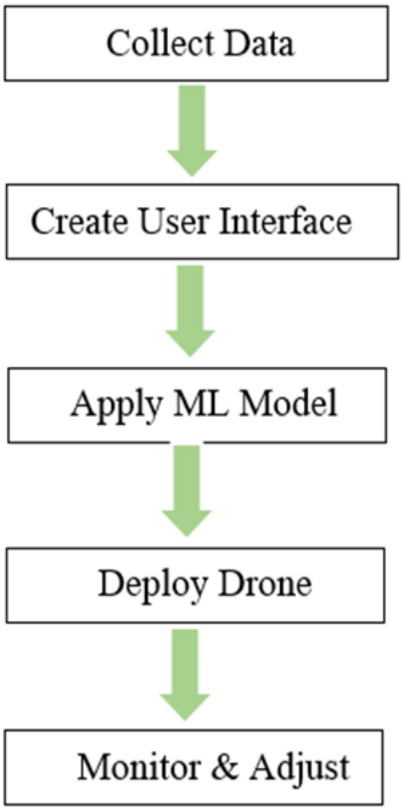

Figure 1 Work Flow of the Project

Afterward, a drone is deployed to execute the plan by spraying the crops with precision [5]. Finally, the field is monitored, and adjustments are made if necessary to optimize the process and ensure the health of the crops

2. Agricultural Drone

Initially, the drone was originated as a military tool and was given different names such as Unmanned Aerial Vehicle (UAV), Miniature Pilotless Aircraft, or Flying Mini Robots. Nowadays it is being utilized in the business sector, infrastructure sector, farming, security, insurance claims, mining, entertainment, telecommunication, and transport sector, etc. The drone has a powerful market opportunity as is evident from the data given in Table 1. Such a broad application of drones has resulted in a very fast improvement in drone technology, thereby making it more user-friendly day by day [6-9]. Nowadays, the application of small unmanned aerial vehicles (UAVs) is growing at a very fast rate in agribusiness Drones are semi-automatic devices that are continuously shifting toward fully automatic devices. These devices have an enormous potential for agricultural planning and related spatial information collection. In spite of some innate barriers, this technology can be utilized for productive data analysis. Initially, UAVs were radio-controlled devices operated by a pilot from the ground, however, modern drones are GPS based autopilot aerial vehicles. The type of cameras, sensors, controlling devices depends on the application of a drone. The three main types of UAVs platforms are Fixed-wing, Helicopter, and Multi-copter [10].

Fixed-wing UAV: These UAVs have stationary wings in the shape of an aerofoil which creates the lift needed when the vehicle reaches a certain speed. A commonly used Fixed wing UAV. Helicopters: It has a single set of horizontally rotating blades attached with a central mast for producing lift and thrust. This type of UAV. A helicopter is capable of vertically take off and land, fly forward, fly backward, and hover at a particular place. These features allow the use of helicopters in congested and remote areas where fixed-wing aircraft are unable to operate. Multi-copters: Rotorcraft with multiple sets of horizontally rotating blades (typically 4–8) have the capability to provide lift and control movements of UAV. In the past decade, the unmanned aerial vehicle (UAV) market was captured by fixed-wing and helicopters. Nowadays, the use of small drones in precision agriculture has shifted focus towards multi-copters that at present covers almost 50% of the available UAV model [11]. The advantages, disadvantages, and applications of fixed-wing drones, helicopters, and multi-copters are summarized. Performance of tiny sensors (accelerometers, magnetometers, gyros, and pressure sensors, etc.), used in drone technology, is continuously increasing and their size is reducing day by day. Moreover, the development of powerful processors, GPS modules, and increment in the range of digital radios is a continuous process, and thus drone technology is also improving. New innovations in embedded systems and motors have made it possible to reduce the size of UAVs and improved their payload capability (Figure 2).

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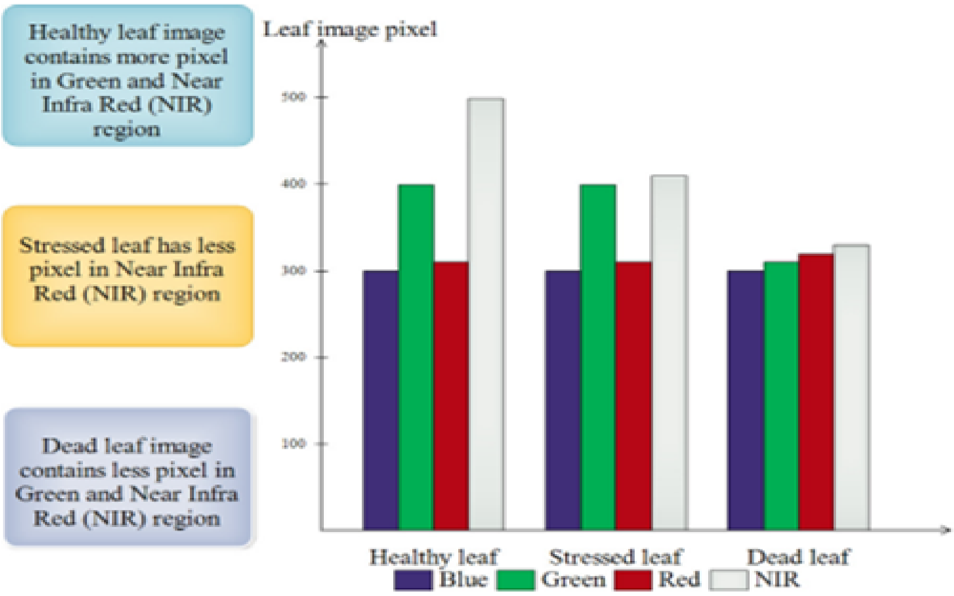

Figure 2 Identification of Leaf Condition

Table 1 Drone's Application in Various Industries

S.No	Industry	Drone Application
1.	Infrastructure	Investment monitoring, Maintenance, Asset inventory.
2.	Agriculture	Analysis of soils and drainage, Crop health monitoring, Yield prediction, Pesticides and fertilizer spot spraying.
3.	Transport	Delivery of goods, Medical Logistic.
4.	Security	Monitoring lines and sites, Proactive response.
5.	Entertainment and Media	Advertising, Entertainment, Aerial Photography, Shows and Special Effect.
6.	Insurance	Support in claims settlement process, Fraud Detection.
7.	Telecommunication	Tower maintenance, Signal broadcasting.

The above table shows how drones have been applied in various domains and this also signifies the broad collaboration of this project. Refer Figure 3 to 6.

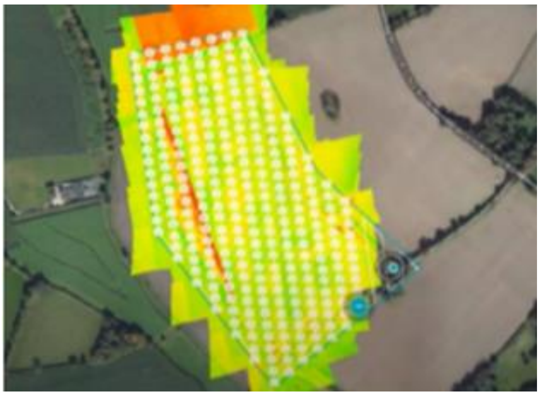

Figure 3 Field Mapping

Figure 4 Crop Monitoring

3. Crop Health Monitoring

Farmers monitor crops daily to detect threats like diseases, pests, and slow growth. Traditional methods involved manual visual inspections and sample collection. For over 50 years, color and infrared photography has been used for crop monitoring, with drones now widely applied for tasks like field mapping and identifying diseases or nutrient deficiencies using advanced image analysis. Vegetation indices derived from drone-captured images help differentiate healthy plants, detect water stress, and estimate yields. Key UAV developments include:

- **2010:** E. Raymond Hunt Jr. developed a lightweight camera system for wheat monitoring using UAVs.
- **2012:** Jacopo Primicerio created a hexacopter for vineyard management, improving control and efficiency.
- **2015:** Hassan-Esfahani introduced "Aggie Air" for capturing multispectral images for crop health monitoring.
- **2016:** Santesteban used drones to assess water status in vineyards via aerial thermal images.

Monitored crop health data is then displayed in a user interface, allowing farmers to visualize real-time crop conditions. The interface presents information such as vegetation indices, water stress levels, and potential disease outbreaks, often through color-coded maps and charts. This enables farmers to make informed decisions quickly, taking corrective actions to optimize crop health and yield.

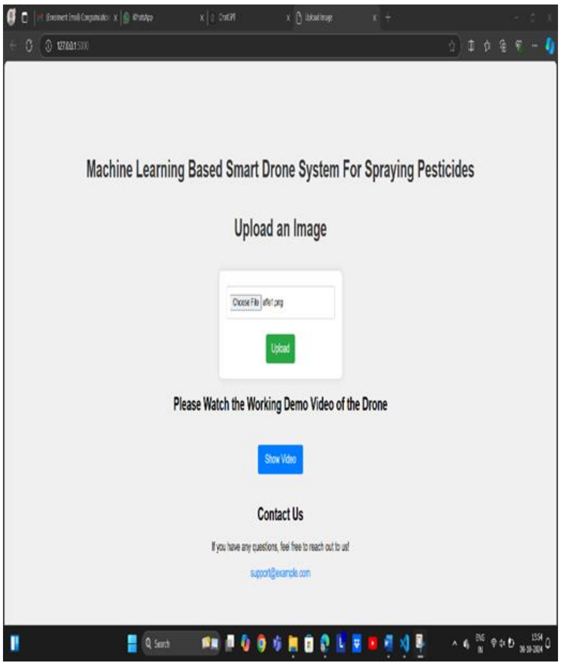

Figure 5 User Interface for uploading Affected Plant Image

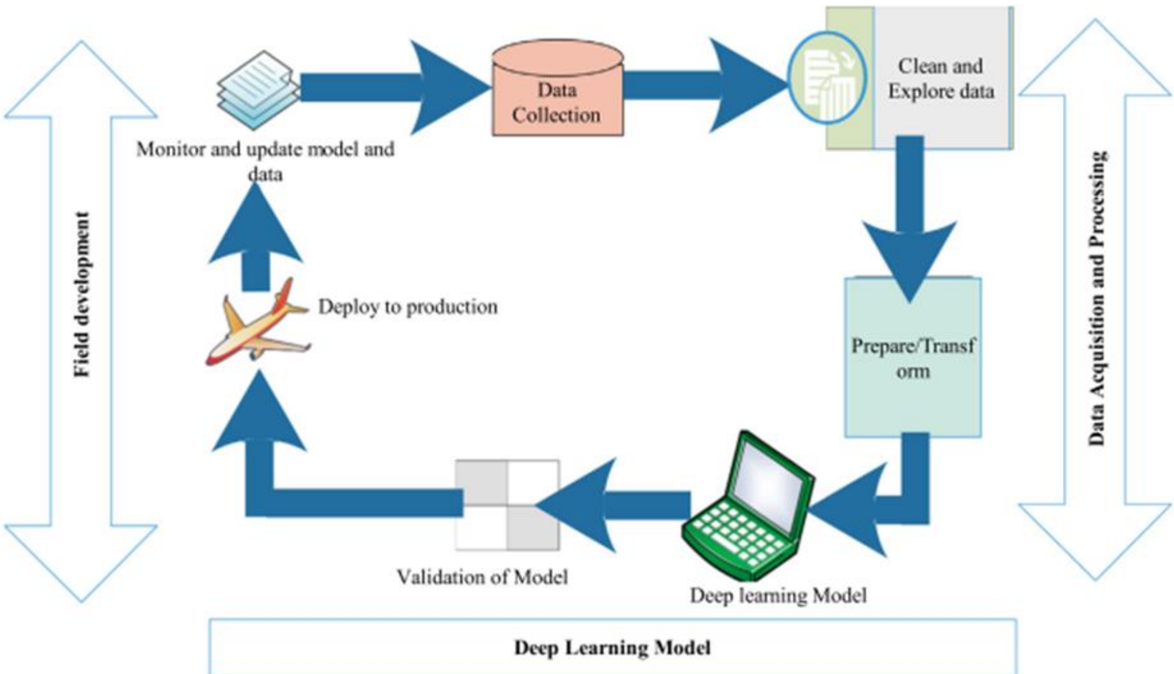

Figure 6 Work Flow Diagram of Deep Learning-Based System Used for Precision

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4. Dataset Details

For this project, Teachable Machine was used to train a machine learning model. The dataset comprises three classes:

- Turmeric Golden Blight
- Turmeric Leaf Spot
- Healthy Turmeric Plants

Approximately 1,000 images per class were collected, resulting in a total dataset of 3,000 images. These images were split into 80% for training and 20% for testing, ensuring robust model performance. This system, powered by drone-based image capture and classification, facilitates the detection of crop health issues with enhanced accuracy and efficiency.

5. Pesticide Spraying

Traditional pesticide application methods, such as manual mechanical sprayers, are still widely used but come with significant drawbacks, including health risks for operators, excessive chemical use, uneven application, and environmental pollution. These methods are also time-consuming and labour-intensive, resulting in higher cost and low efficiency. To address these issues, drone-mounted sprayers have been introduced as a more effective solution. Drones equipped with advanced systems can carry pesticide tanks, follow pre-mapped routes, and target specific areas, making them ideal for inaccessible fields and reducing the overall impact on the environment. Recent advancements have focused on integrating smart technologies, such as machine learning, into drone systems for precision agriculture. These drones can identify affected plants or healthy plants uploaded by users via a user interface and recommend appropriate pesticides based on plant conditions. This targeted approach minimizes chemical usage, enhances application efficiency, and reduces environmental harm. Early UAV developments, such as Yamaha's pesticide helicopter in 1983, laid the groundwork for current innovations. Modern systems now incorporate components like GPS, sensors, and PWM controllers, ensuring stable, efficient, and adaptive spraying, transforming agriculture into a more sustainable and data-driven practice.

6. Framework for UAV-Based Pesticide Spraying

The framework for this UAV-based pesticide spraying system integrates machine learning, drone technology, and an intuitive user interface to enable precise pesticide application (Table 2). The process begins with users uploading images of plants through the interface. These images are processed by a machine learning model trained to classify plant conditions as healthy or affected. Based on the analysis, the system provides recommendations for suitable pesticides and generates a spraying plan targeting only the affected plants.

Table 2 Comparison of Machine Learning Algorithm Used in Agriculture

Table 4 – Comparison of different machine learning algorithms used in agriculture.

Algorithm	Application	Experimental data	Testing Accuracy
ANN [59]	Pesticide spraying	60 m × 80 m field divided in 10 m × 10 m units	99.97%
CNN (VGG)[65]	Crop Disease Detection	Openly available database of 87,848 photographs	99.53%

In 2019, Sheng Wen et al. designed a UAV integrated variable spray system that was based upon an artificial neural network (ANN). Utilizing sensor data, ANN model, and data acquisition, a program was written in Keil Software for applying pesticides as per the requirement. Software named UAVDDPS was designed to predict droplet deposition. The ANN model predicted the deposition rate of chemicals and accordingly, the flow rate of the spray system was regulated. An experiment was conducted in a paddy field and it was found that the ratio of droplet deposition to prescription value in each unit is approximately equal. The error between the predicted droplet deposition and actual droplet deposition was found to be less than 20%. In 2019, Kislay Anand, Goutam designed a drone named aero drone for field. The system is built on a combination of hardware and software components. The machine learning model is developed using Tensor Flow, while a Raspberry Pi serves as the central control unit for the drone. Navigation and stability are ensured using GPS and gyroscope modules, while Pulse Width Modulation (PWM) controllers manage the spraying mechanism. The framework is designed to enhance application precision, reduce chemical usage, and minimize environmental impact. By combining advanced technologies, this framework represents a practical and efficient solution for modern agricultural challenges. Monitoring and chemical spraying. The aim was to minimize the time of spraying and the loss of pesticide. A simulation platform was proposed to assign the mission on the field and to check the sensibility and accuracy of this plan. Results proved that the work performed by this quad-copters integrated system was efficient and the mission time of each quadcopter was almost the same. This scheme showed good results however it was only tested for a rectangular farmland (Table 3).

Table 3 Image Processing Sensors Used in Precision Agriculture

Table 5 – Image Processing Sensors used in precision agriculture.

Sensor	Features used	Advantages	Disadvantages
Visible (RGB) Camera [50]	Colour, Size, Shape, Edges, Surface	• Easy to identify by visual inspection. • Cheap and small in size • Small payload for UAV • High resolution camera • Easier to use	• Have only three bands • Unable to detect many features • Unable to find irregularities in data • Needs higher image resolution
Multispectral Camera [51]	Appearance and geometrical features, NVDI	• Images in more spectrum bands than the Red Green and Blue (RGB) can be captured • More information than an RGB digital image • Captures spectral bands near infrared (NIR) • Provide information about reflectance of visible light and vegetation indices.	• Needs computer • More heavy and more costly • Images captured depends on the climatic conditions • Image resolution limits • The altitude at which the UAV can fly and the image acquisition
Hyper spectral Camera [51]	RVI and NDVI Indices	• Creates images using thousands of narrow bands • Multidimensional datasets • Can detect more features than multispectral camera • Acquires entire at each point	• Need fast computers • More costly and complex • More difficult to use. • Big data storage capacity is needed • High payload
Thermal Camera [29,48]	Crop Water Stress Index (CWSI)	• Have greater spectral and spatial resolutions. • Quick determination of canopy surface temperature • Small size • Low weight	• Thermal images depend upon weather condition • Accuracy of the system depends upon the resolutions of camera. • Model that estimates plant water status, depends upon many variables

In 2019, Martinez Guanter et al. have designed and developed an aerial pesticide spraying system that considered the limitations of payload. It was designed using low-cost material so as to make a low-budget drone. UAV with approximately 6 kg take-off weight, with GNSS receiver and telemetry system was designed. The modular nozzle had two configurations, one has four nozzles with 250 mm spacing and the other has a single anti drift nozzle. Pump speed was controlled from a remote-control station. The pumping range was between 0.10 ltr/min to 0.22 ltr/min. A PWM based control system was used for autonomous application. The efficiency and reliability of the hardware system were tested in super-high-thick olive and citrus plants. The experimental results showed that the developed system was able to save approximately €7/ha in comparison to the previously used system. In 2020, Karan Kumar Shaw et al. has designed an octocopter with a lower weight spraying system. Payload was determined by considering the sizes of the tank storage (that was 6 Litres), fluid density, nozzles (fine

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spray), and pump. According to payload requirement, 8 Brushless Direct Current (BLDC) motors, Electronic Speed Controller, Propeller, 12 V pump, FPV camera, video transmitter, and LI-PO battery were selected for system design. This octocopter design was good for farm monitoring, however, there was a need to change the manually controlled system into an AI-based autonomous system to improve its performance. During recent years, a lot of changes can be observed in the drone flight controllers as well as in the spraying system. The spraying system upgraded from a semi controlled device to AI-based fully automated system. The blocks used in a fully automatic pesticide spraying system. A fully automatic pesticide spraying system is capable of spot spraying by analyzing the real-time data. It does not require any human efforts in chemical spraying, that makes it a great choice toward safer and more economical system. In precision agriculture, different tasks that need an aerial image processing system are crop monitoring, and pesticide spraying. Image processing efficiency of the system depends upon aerial platforms, machine learning algorithms, and image capturing systems. A comparative study of the different aerial platforms has been presented.

7. Result and Discussion

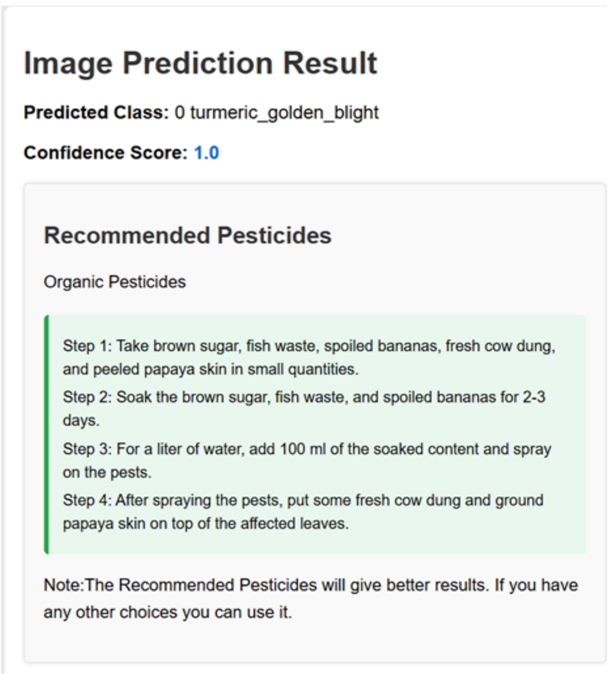

Figure 7 UI for Recommending Pesticides

The developed user interface (UI) provided actionable pesticide recommendations based on the ML model's classification of plant health conditions. This feature aims to guide farmers in selecting appropriate pesticides tailored to the specific needs of affected crops, enhancing treatment efficiency and reducing unnecessary chemical usage. During testing, the system accurately identified a user-uploaded image of a plant infected with turmeric golden blight disease, as shown in Figure 7. However, when the drone captured an image of the same plant, it mistakenly classified the disease as turmeric leaf spot instead of turmeric golden blight. Despite this misclassification, the system followed its rule to avoid spraying pesticides unless both the user-uploaded and drone-captured images confirm the same disease. This protocol ensures pesticides are only applied when the condition is accurately verified, reducing unnecessary spraying. This approach highlights the importance of accurate disease classification and the system's ability to make informed, real-time decisions, promoting precise pesticide use, environmental sustainability, and cost efficiency ((Figure 8).

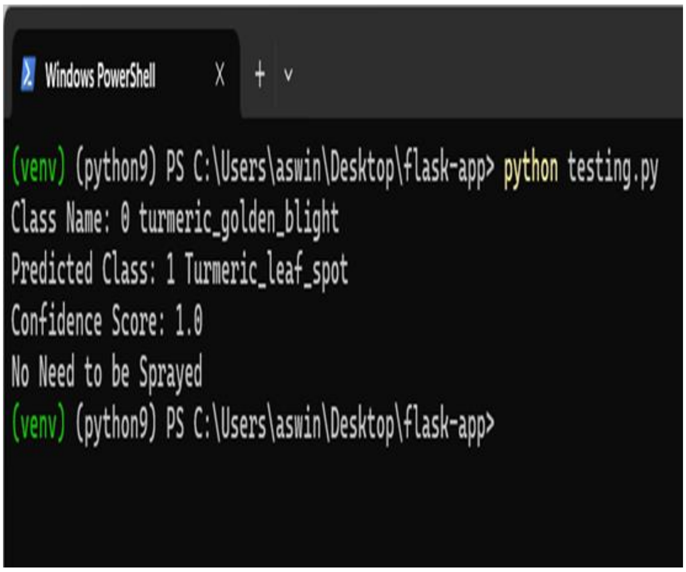

Figure 8 Testing Result 1

The user-uploaded image was identified as showing turmeric golden blight disease. When the drone captured and processed an image of the same plant, it also confirmed turmeric golden blight. Recognizing

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the match, the system followed its protocol and sprayed water as the appropriate response. This successful identification and action demonstrate the system's capability for accurate disease recognition and targeted treatment. By verifying the disease through both users input and drone analysis, the system ensures precise application, improving pest management efficiency. This approach optimizes resource use and supports sustainable farming by minimizing unnecessary chemical application (Figure 9).

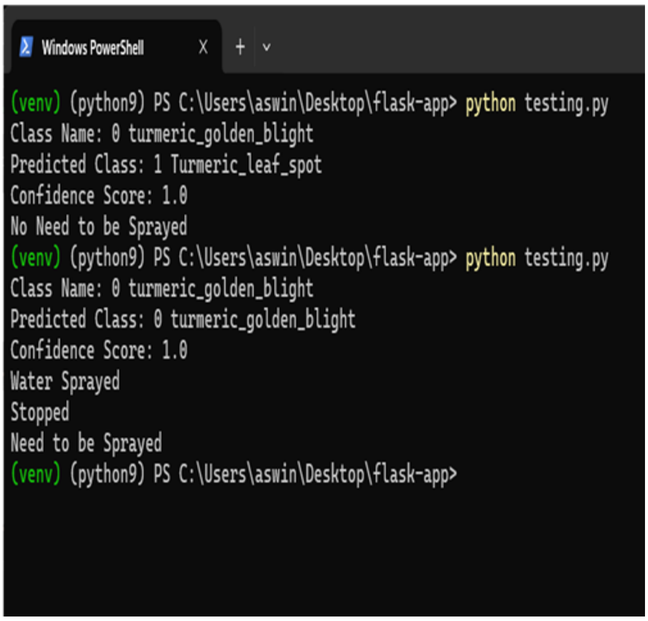

Figure 9 Testing Result 2

Conclusions and Future Challenges

This paper reviews the latest advancements in drone technology for precision farming, focusing on two main areas: crop monitoring and pesticide spraying. Drones have become more common in agriculture since 2017 due to their lower weight, cost, and improved payload capacity. Multi-copters and fixed-wing drones are widely used for crop monitoring, while unmanned helicopters handle pesticide spraying because of their larger capacity. Multi-copters are also increasingly used for spot spraying due to their stability. Cameras on drones have advanced from basic RGB to multispectral for better data collection. Drone controllers have evolved to AI-powered systems like Arduino Uno and Raspberry Pi, making drones more automated and easier to use. Machine learning has also helped make drones more user-friendly for farmers. A key feature of modern drone systems is their ability to display real-time crop data on a user interface (UI). Farmers can see detailed maps and charts showing crop health, water stress, and potential diseases. The UI can also recommend specific pesticides based on this data, helping farmers apply chemicals more efficiently and only where needed. Despite these advances, challenges remain, such as the high cost of drones, short battery life, weather-related visibility issues, and the need for farmers to learn the technology. Improvements in image processing and data analysis are also needed for better accuracy and ease of use.

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