

Crop Care+: Intelligent Drone for Real-Time Farm Monitoring and Action

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Abstract- *This paper presents the design and development of CropCare+, an intelligent drone-assisted system aimed at improving efficiency and sustainability in modern agricultural practices through precision farming techniques. The proposed system integrates targeted pesticide and water spraying, real-time crop health monitoring using image processing, soil moisture sensing, and automated irrigation support through a ground-based control unit. A quadcopter-mounted Raspberry Pi captures crop images using an RGB camera and performs on-device machine learning inference to identify crop stress, pest infestation, and disease conditions. Environmental parameters such as soil moisture, temperature, and humidity are continuously monitored using an ESP32-based ground unit, which controls irrigation sprinklers through relay mechanisms based on real-time field conditions and drone feedback. The system enables precise intervention by triggering localized spraying only in affected areas, thereby reducing chemical usage and conserving water. Experimental evaluations demonstrate that the proposed approach reduces manual labor, minimizes resource wastage, and enhances decision-making through real-time data acquisition and visualization on a remote dashboard. CropCare+ provides a scalable and cost-effective prototype for drone-assisted precision agriculture, bridging the gap between conventional farming practices and intelligent, data-driven farm management systems.*

Index Terms- *Drone Technology, Health Monitor, Pesticide Sprinkling, Water Supply Automation.*

I. INTRODUCTION

Autonomous drones are progressively revolutionizing modern agriculture by enabling precision farming techniques that substantially enhance resource efficiency and crop productivity. The Crop Care+ designed to perform a variety of essential agricultural functions that collectively address the multifaceted challenges faced by farmers today. Specifically, this system facilitates targeted pesticide and water spraying to ensure uniform and efficient application,

continuous real-time monitoring of crop health for early detection of stress factors, thorough soil moisture and environmental condition assessment, early identification of crop stress and diseases using image processing, and intelligent irrigation support through a ground-based automated control system. Tailored to the precise water requirements of crops. These capabilities aim to transform traditional farming into a data-driven, sustainable practice by minimizing waste while maximizing output.

Traditional agricultural practices often involve extensive manual labor and reliance on separate monitoring tools, which can be time-consuming, labor-intensive, and prone to errors. The conventional approach lacks integration, resulting in delayed detection of crop stress or pest invasions, which can lead to reduced yields and increased costs. Furthermore, many existing automated farming technologies focus on isolated tasks and require complex infrastructure, limiting their adaptability and scalability across diverse farming environments. There is a pressing need for an integrated platform that provides timely and actionable insights across multiple aspects of field management.

The proposed system combines a drone-based aerial monitoring unit with a ground-based sensing and control unit to deliver a holistic solution for modern farm management. The aerial unit, equipped with a Raspberry Pi and RGB camera, performs crop health analysis using onboard image processing and machine learning techniques, while the ground unit continuously monitors soil moisture and environmental parameters and controls irrigation infrastructure through relay-based actuation to deliver a holistic solution for modern farm management. Equipped with precision spraying mechanisms, the drone can apply pesticides and water accurately and

efficiently across large fields, reducing chemical runoff and water wastage. Its visual and spectral sensors facilitate continuous crop health monitoring by detecting changes in plant coloration, growth, and vigor, which helps identify nutrient deficiencies or environmental stress at early stages. Soil quality is assessed through onboard sensors and data analysis, providing critical information about moisture levels, pH, and nutrient content essential for informed fertilization decisions. Early disease detection algorithms analyze visual cues and environmental data to alert farmers before infections spread widely. Additionally, the automated irrigation control system dynamically adjusts watering schedules based on real-time soil moisture and crop needs, thereby conserving water and enhancing plant growth.

Contributions

- 1.Design and development of a versatile autonomous drone platform capable of executing multiple integrated agricultural tasks to streamline farm management.
- 2.Precision pesticide and water spraying system that ensures accurate application tailored to crop and field conditions.
- 3.Implementation of real-time crop health monitoring utilizing advanced image processing and multispectral data to provide farmers with timely insights.
- 4.Soil moisture and environmental monitoring module using ground-based sensors to support data-driven irrigation decisions.
- 5.Early disease detection tools that enable proactive interventions, reducing crop losses and improving yield quality.
- 6.Drone-assisted irrigation control using an ESP32-based ground unit that automates water sprinklers based on soil moisture thresholds and system recommendations.
- 7.Field validation demonstrating the system's practical benefits in enhancing efficiency, reducing inputs, and promoting sustainable agricultural practices.

This project aims to bridge the gap between conventional farming methods and emerging digital agriculture solutions. By integrating key agricultural operations into a single drone-based platform, it seeks to empower farmers with actionable

information and automation capabilities that promote sustainability, reduce environmental impact, and boost productivity with minimal manual intervention. The system represents a significant step toward next-generation smart farming technologies adaptable to evolving agricultural challenges.

II. RELATED WORK

Agricultural drones have been increasingly researched and deployed to support various farming tasks, primarily focusing on pesticide and chemical spraying. Several existing systems demonstrate effective spraying capabilities but lack comprehensive functionalities that integrate real-time monitoring and automated irrigation. One representative study developed a smart agriculture drone with machine learning–based image processing to autonomously spray pesticides, targeting different crop classes with preset spray modes [IoT, 2024]. While this drone achieved real-time crop detection and targeted spraying, its functionality was limited to spraying only, without integrated real-time crop health monitoring or irrigation control. Similarly, UAV sprayers equipped with multi-rotor platforms have been shown to efficiently spray pesticides in complex terrains, improving cost and reducing environmental impact by minimizing chemical usage [Pest Manag. Sci., 2019].

Several works have also explored the use of UAVs for aerial imagery and remote sensing for weed mapping and pest detection. These systems typically employ high-resolution multispectral or RGB cameras to collect detailed field imagery, enabling post-flight analysis and assessment [Biological Forum, 2023; Remote Sens., 2018]. However, these passive imaging UAVs primarily focus on data acquisition and offline analysis rather than real-time field intervention. Although the integration of deep learning techniques, such as convolutional neural networks (CNNs), has significantly enhanced the classification and early detection of crop diseases and stresses, most implementations still rely on offline data processing [IJERT, 2024].

Furthermore, real-time crop health monitoring using drones remains limited by onboard hardware

processing capabilities and payload constraints, which hinder the deployment of live field condition assessment systems. Automated irrigation control through UAV platforms is even more nascent, with only a few prototypes reported that incorporate sensor-driven water management to autonomously optimize irrigation schedules. In summary, the limitations of current agricultural UAV systems include:

- Functionality restricted primarily to pesticide or fertilizer spraying.
- Lack of embedded real-time crop health monitoring and disease detection.
- Absence of automated irrigation control integrated within UAV frameworks.
- Heavy reliance on offline data processing for remote sensing applications.
- Payload and computational constraints limiting multi-sensor fusion and real-time analytics.

The proposed Crop Care+ system addresses these gaps by integrating pesticide and water spraying, real-time crop health monitoring, soil quality analysis, early disease detection, and automated irrigation control into a single drone platform. This unified approach advances beyond traditional UAV systems by enabling live, data-driven decision-making, thereby enhancing precision agriculture efficiency and sustainability.

III. METHODOLOGY

A. Hardware Architecture

The hardware framework of the *Crop Care+* system is built around a quadcopter platform, which provides stable flight dynamics, efficient maneuverability, and sufficient payload capacity for sensors, cameras, and spraying components.



Fig.1. Ardu-Copter

The drone's structure is made from lightweight and durable materials such as carbon fiber and aluminum to ensure both strength and agility during flight. The APM 2.8 flight controller serves as the primary navigation and stabilization unit. It continuously receives input from onboard sensors, including the gyroscope, accelerometer, magnetometer, and GPS module, to maintain flight stability and follow pre-programmed GPS-based paths. These components enable precise movement and uniform coverage across the agricultural field. The APM 2.8 is interfaced with four Electronic Speed Controllers (ESCs), which drive the brushless DC motors (BLDCs) to generate lift and thrust. Power is supplied through a high-capacity lithium-polymer battery, ensuring adequate energy for extended field operations.



Fig.2. APM 2.8 Ardupilot

The spraying system is composed of dual liquid tanks—one for pesticides and another for water—each connected to a mini-pump and solenoid valve. The valves are controlled electronically to regulate spray flow based on the drone's flight speed and altitude, ensuring even and efficient coverage. The spraying mechanism is synchronized with flight operations through communication between the APM 2.8 controller and the Raspberry Pi, minimizing waste and optimizing chemical utilization. The discharge flow rate (Q) is controlled based on altitude and velocity to ensure uniform spraying and minimal wastage. The relationship between nozzle flow rate and liquid velocity is given by:

$$Q=A \times V$$

where A is the nozzle outlet area (m^2) and V is the exit velocity of the fluid (m/s).

This dynamic control maintains optimal spray coverage and ensures consistent droplet distribution across the crop canopy.

B. Sensor Integration and Data Acquisition

The data acquisition unit is built around a Raspberry Pi 4 Model B, which serves as the local processing and communication hub. It interfaces with a Pi Camera Module, multispectral camera, soil moisture sensor, and temperature and humidity sensors to gather real-time field data during flight. The Pi Camera captures RGB images of crop leaves and stems. The soil moisture sensor continuously monitors the volumetric water content of the soil, while temperature and humidity sensors record environmental parameters that influence crop growth and disease spread. The sensor data is transmitted to the Raspberry Pi using a low-power wireless communication protocol such as Zigbee or LoRa. The Raspberry Pi receives and processes the sensor data locally to analyze soil and environmental conditions. Based on the analysis results, the Raspberry Pi generates control commands and sends them to the ESP32. The ESP32 then activates the water pump for irrigation according to the received command, ensuring water is supplied only when required. Additionally, for water and pesticide spraying applications, the Raspberry Pi controls a relay module to switch the pump ON or OFF depending on the analyzed irrigation and spraying requirements. This automated decision-based control helps optimize water usage and improve crop management efficiency.

The CropCare+ system employs edge-based machine learning inference using a Raspberry Pi onboard the drone. Crop images captured by the RGB camera are pre-processed and analyzed locally using TensorFlow Lite and OpenCV frameworks. The trained classification model identifies crop conditions such as healthy growth, pest infestation, disease symptoms, nutrient deficiency, or water stress.

Performing inference at the edge eliminates reliance on continuous internet connectivity, reduces latency, and enables faster real-time decision-making during flight. Processed results, along with sensor readings and system actions, are transmitted via GSM to a

virtual dashboard for monitoring, logging, and post-analysis.

C. Software Design and Control Algorithms

The software architecture combines onboard control algorithms with cloud-based analysis. The Raspberry Pi coordinates image capture, sensor reading, and communication tasks, while Google Colab performs disease detection and crop classification. For irrigation, a threshold-based control logic is implemented on the Raspberry Pi. The irrigation pump is triggered when the measured soil moisture $M(t)$ falls below the predefined threshold M_{th} , and stops when it reaches optimal levels:

$$\begin{aligned} M(t) < M_{th} &\Rightarrow \text{Irrigation ON} \\ M(t) > M_{th} &\Rightarrow \text{Irrigation OFF} \end{aligned}$$

This ensures that irrigation is automatically managed based on real-time soil conditions. The Raspberry Pi also transmits live field parameters and Colab-generated health status to the ground control station, where the farmer can monitor performance through a graphical dashboard.

D. System Workflow

The operational sequence of the *Crop Care+* drone begins with autonomous takeoff and navigation along a GPS-defined path managed by the APM 2.8 flight controller. During flight, the Raspberry Pi collects data from all sensors and processes images captured by the Pi Camera and multispectral camera. The processed data helps assess plant health, soil moisture, and environmental conditions in real time. When stress or disease symptoms are detected, the system performs targeted pesticide spraying. If the soil moisture is below the set threshold, When water stress is detected, the drone transmits a control signal to the ESP32 ground unit, which activates the irrigation sprinklers for the affected area. All actions, including spraying and irrigation, are logged and transmitted to the dashboard for farmer supervision and manual override if required. Throughout the process, the drone continuously transmits field parameters and decisions to the ground control unit for monitoring. Upon completion, the drone returns to its base station, and a comprehensive operation report is generated summarizing the spraying activity, irrigation data, and crop condition analysis.

IV. PERFORMANCE EVALUATION AND RESULTS

A. Payload Capacity and Flight Endurance

The payload capacity of the CropCare+ quadcopter was analyzed by considering thrust-to-weight ratio, battery discharge capability, and overall flight stability. The drone structure, propulsion system, and power electronics were selected to support liquid spraying operations without compromising maneuverability or safety. Experimental testing confirmed that the system can reliably carry a useful payload in the range of 1.5 to 2.0 kg, which includes liquid payload, pumping mechanism, tubing, nozzles, and mounting hardware. For practical agricultural operation, a payload configuration consisting of 1.0 liter of water or fertilizer solution and 0.5 liter of pesticide solution was selected. Including the spraying mechanism, the total payload weight was approximately 1.8 kg, which ensured stable flight characteristics and efficient spraying. The drone was powered using a 4S 14.8 V, 5200 mAh lithium-polymer battery, chosen for its high energy density and ability to supply large burst currents required by BLDC motors. Under loaded conditions with spraying payload, the drone achieved an average flight endurance of 12–15 minutes, while under no-load conditions, the endurance increased to approximately 18–20 minutes. This flight duration was sufficient to complete a full spraying cycle for small to medium-sized agricultural plots within a single sortie, validating the suitability of the selected battery and propulsion configuration.

B. Spray Coverage and Field Area Estimation

The spray coverage capability of the CropCare+ system was evaluated based on nozzle flow rate, effective spray width, flight speed, and available liquid payload. A calibrated miniature DC pump with an average discharge rate of 120–150 mL per minute was used for pesticide and fertilizer spraying. With a total sprayable liquid volume of 1.5 liters, the effective spraying time was approximately 12.5 minutes. During spraying operations, the drone was flown at a controlled speed of approximately 1.5 m/s, while maintaining a consistent altitude to ensure uniform droplet distribution. The effective spray width achieved using the selected nozzle configuration was approximately 1.2 meters. Based

on these parameters, the total area covered in a single flight was calculated to be approximately 1350 square meters, equivalent to 0.13 hectares or about 0.33 acres. This analysis demonstrates that the proposed system is suitable for segmented field coverage. For larger agricultural areas, multiple sorties can be planned sequentially, allowing efficient utilization of battery capacity and precise control over chemical application.

C. System Effectiveness Compared to Existing Agricultural Drones

Conventional agricultural drones are primarily designed for uniform pesticide spraying, where chemicals are applied across the entire field irrespective of actual crop condition. While effective for blanket treatment, this approach often leads to excessive chemical usage, increased operational costs, and higher environmental impact. In contrast, the CropCare+ system integrates real-time crop health analysis, sensor-driven decision-making, and targeted spraying, resulting in significantly improved efficiency.

By using onboard image processing and machine learning models, the system identifies specific regions affected by pest infestation, disease, or stress and applies spraying only where required. This selective spraying approach reduces pesticide and fertilizer usage by an estimated 25–35% compared to conventional spray-only drones. Additionally, the integration of a ground-based ESP32 unit enables automated irrigation control based on actual soil moisture conditions, which is typically absent in existing UAV-based solutions. The combined use of aerial monitoring, edge-based intelligence, and ground-level automation makes CropCare+ more effective than existing systems, as it transforms the drone from a simple spraying platform into an intelligent decision-support and action system.



Fig.3. Pesticide/Water Spraying

VI. CONCLUSION

The CropCare+ system demonstrates a practical prototype of a drone-assisted precision agriculture platform that integrates aerial monitoring, edge-based machine learning, and ground-level automation. By combining real-time crop image analysis with continuous soil moisture monitoring, the system supports informed decision-making for targeted spraying and irrigation while reducing manual labor and resource wastage by integrating real-time monitoring, automated pest management, and data-driven decision-making. Through the continuous collection and processing of soil parameters such as moisture, pH, and temperature, combined with periodic crop imaging, the system is capable of detecting early signs of diseases, nutrient deficiencies, and pest infestations. The automated pesticide spraying mechanism ensures that interventions are precise, targeted, and efficient, reducing chemical usage while maintaining or improving overall crop health. Cloud connectivity enables farmers to remotely access real-time field data, receive alerts, and manually intervene if necessary, facilitating timely and informed decision-making that enhances operational efficiency. By automating critical aspects of crop management, Crop Care+ minimizes the dependence on manual labor, optimizes resource utilization, and ensures consistent care for crops throughout different growth stages. This approach not only improves productivity and crop yield but also promotes environmentally

sustainable practices by reducing overuse of pesticides and conserving water through precise monitoring. The integration of sensing, actuation, and cloud-based communication demonstrates the effectiveness of IoT-enabled solutions in addressing challenges of modern farming, such as labor scarcity, unpredictable climate conditions, and inefficient resource usage.

Looking forward, the system can be further enhanced by integrating additional environmental sensors for more comprehensive field monitoring, implementing advanced machine learning models for predictive analysis of crop health and pest management, and incorporating drone-assisted imaging for rapid assessment of large-scale agricultural fields. These enhancements would facilitate proactive interventions, improve scalability, and support precision agriculture on a commercial level. Overall, Crop Care+ exemplifies a significant advancement toward autonomous, intelligent, and resource-efficient crop management systems, offering a practical and sustainable framework that can revolutionize traditional farming practices and support the growing global demand for food production.

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