

Drone Technology for Crop Health Monitoring and Pesticide Application

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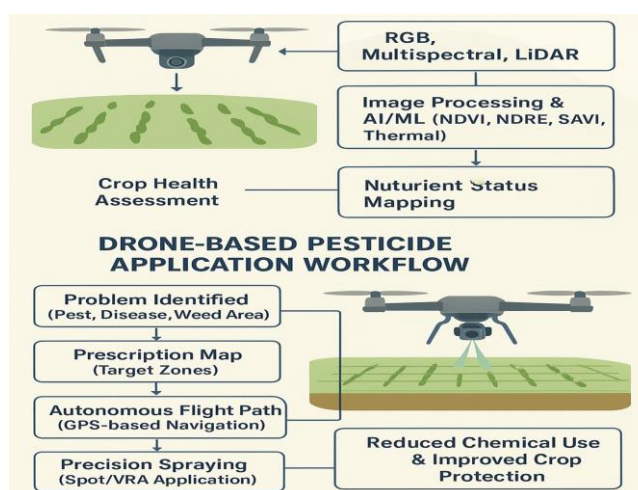
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INTRODUCTION

Agriculture is rapidly transforming into a knowledge-based industry with state-of-the-art innovations in technologies related to drones, sensors, artificial intelligence (AI), geographic information systems (GIS), and precision farming tools. Of the technologies listed, drone technology is poised to be one of the most impactful innovations within modern agriculture.

Drones, or unmanned aerial vehicles, are a means for farmers to monitor health, assess variability in the field, and apply pesticides and fertilizers with high precision in rapid, accurate, and cost-effective manners. It is an indispensable tool in the management of the farm in a sustainable way owing to various functionalities, including high-resolution imaging, early detecting of crop stress, and targeted chemical application.

Drone-based agriculture reduces human drudgery, increases efficiency, and minimizes chemical wastage, thus improving environmental protection. Drones help in real-time decision-making to allow higher productivity along with improved efficiency of resource use under diverse cropping systems.



2. Types of Drones Used in Agriculture

2.1 Multi-Rotor Drones

Multi-rotor drones are best suited to close-range monitoring of crops, field scouting, and operations on small to medium-sized farms where detailed observations are needed.

They can hover in one position, so they are very suitable for spot spraying, application of pesticides on location, and observing specific field problem areas.

These drones are easy to operate, highly maneuverable, and well adapted to rugged terrains or irregularly shaped fields where precision movement is needed.

2.2 Fixed-Wing Drones

Fixed-wing drones are designed for long-duration flights, enabling them to efficiently cover large areas, thus becoming useful for extensive farmlands.

They are ideal tools for generating high-quality crop maps, conducting large-scale survey operations, and producing detailed orthomosaic images for farm analysis.

Although fixed-wing drones provide higher speed and operational efficiency, they need a longer runway or open space for smooth takeoff and landing.

2.3 Hybrid VTOL - Vertical Take-Off and Landing Drones

Hybrid VTOL drones combine the long flight endurance and high efficiency of fixed-wing drones with the vertical takeoff, landing, and hovering capabilities of multi-rotor systems.

They are good options for big farms with uneven terrains, different topographies, or limited landing spaces due to their capability to operate under difficult field conditions.

These drones can carry out long-duration missions, yet perform stable vertical operations, making them quite versatile for both monitoring and spraying tasks.

3.3 Applications in Crop Monitoring

1. Early Detection of Pest and Disease Outbreaks

It allows for the detection of subtle changes in crop color, texture, and canopy structure that often are undetected by a field manual scout, offering an earlier warning of a pest or disease outbreak.

High-resolution multispectral data helps in the identification of stress zones even before symptoms become visible. It thus allows farmers to recognize pest hotspots or disease-infected patches at an early stage.

Early diagnosis allows for timely intervention with appropriate pest management strategies that reduce yield loss, minimize the use of chemicals, and prevent widespread area infestations.

2. Mapping Nutrient Deficiency Zones

Drones equipped with multispectral sensors accurately detect nutrient deficiency zones by analyzing plant reflectance patterns that indicate chlorophyll levels and photosynthetic activity.

These nutrient stress maps help in differentiating between nitrogen, phosphorus, potassium, or micronutrient deficiencies based on changes in leaf color and spectral signature.

By precisely locating nutrient-deficient areas in the field, farmers can adopt site-specific nutrient management that minimizes wastage of fertilizer, improves nutrient-use efficiency, and enhances crop productivity.

3. Monitoring Irrigation Efficiency

Thermal cameras mounted on drones sense changes in the temperature of canopies, which reflect variations in water availability and soil moisture status across the field.

Dry or water-stressed plants show higher canopy temperatures, while over-irrigated zones appear cooler, making it possible for farmers to locate inefficient irrigation patterns.

This information helps optimize irrigation scheduling, detect clogged or leaking lines in drip or sprinkler systems, conserve water, and improve water-use efficiency under water-scarce conditions.

4. Estimating Crop Growth Stage and Biomass

LiDAR and photogrammetry from drones create highly accurate 3D models of crops, which serve to estimate crop height, canopy volume, and the general structure of growth.

These measurements enable farmers to identify growth stages, monitor the progression of crop development throughout a season, and estimate biomass accumulation with high accuracy.

This information empowers better decision-making on fertilizer topdressing, irrigation timing, and harvest planning that improves crop yield and uniformity.

5. Identifying Weed Infestation

Drones detect weed-infested areas by analyzing the spectral difference between crop plants and unwanted weed species, which generally have unique reflectance patterns. It allows farmers to locate the exact site of weed patches and their severity within the field. Drones enable selective herbicide application, thus reducing chemical

use, lowering the cost of production, and minimizing environmental contamination linked with broad-spectrum spraying.

6. Yield Forecasting and Variability Mapping

Spatial variability within the field could be analyzed, and zones of high or low productivity could be identified from time-series drone data collected during different crop growth stages. Vegetation indices-NDVI, NDRE, and EVI-have been used to estimate crop vigor, biomass accumulation, and canopy density and have since become indicators to predict yield potential. Accurate yield forecasting underpins better market planning, resource allocation, harvest scheduling, and financial decision-making by both farmers and supply-chain stakeholders.

7. Damage Assessment after Storm, Flood or Drought

with swift flights over the field, drones survey areas of agriculture after storms, floods, droughts, hailstorms, and other extreme weather to assess the extent and severity of crop damage. High-resolution aerial maps pinpoint the areas of complete damage, partial zones of damage, and surviving crop patches, offering reliable data on insurance claims and government compensation processes. This rapid assessment allows farmers to better plan re-sowing, rehabilitation measures, and future mitigation strategies.

4. Drone Technology for Pesticide Application

4.1 Advantages

Precision Spraying

Drones permit precision spraying, targeting only the affected or required areas of the field, hence reducing the wastage of pesticides by almost 30–50% compared to conventional spraying.

Reduced Human Exposure

The spraying drones minimize farmers' direct contact with hazardous chemicals, reducing health risks while making agricultural practices much safer.

Time and Labor Saving

Spraying drones can cover about 10–30 acres per hour depending on the tank capacity and the condition of the field, saving a lot in terms of labor and operation time.

Uniform Application

Drones ensure the uniformity of pesticide application through consistent droplet size, spray height, and distribution across the field.

Accessibility

Drones are especially effective in those areas that are difficult for spraying by traditional methods,

such as slopy terrains, waterlogged fields, dense crop canopies, or hard-to-reach locations.

4.2 Components of a Spraying Drone

The general composition of a spraying drone includes a chemical tank, which, depending on the model and its operational requirements, has a capacity that ranges from 10 to 30 liters. It has a pump system that regulates the flow rate of the pesticide during spraying operations. Different nozzles can be installed depending on droplet size required for efficient and correct deposition of pesticides. It relies on a GPS system for accurate navigation, path planning, and mapping of the terrain. During spraying, the flight controller governs stability, altitude, and flight path. A rechargeable battery and power system supply the energy required to enable drone operation and the spraying mechanism.

4.3 Techniques Used in Drone Spraying

Variable Rate Application (VRA)

This technique regulates the application rate based on the particular needs of a crop to optimize pesticide usage and reduce environmental impact.

Spot Spraying

Spot spraying involves targeting chemicals on the infected or stressed patches as identified through drone-based mapping, avoiding unnecessary pesticide application.

Swarm Spraying

Swarm spraying involves the deployment of multiple drones working simultaneously in coordinated flight to efficiently cover large farms and significantly increase spraying speed and field coverage.

5. Benefits to Farmers

- ✓ Drone spraying also aids farmers in reducing the input cost of pesticides, as it minimizes the wastage and optimizes chemical application.
- ✓ It contributes to higher productivity and increased crop yield by ensuring timely and accurate pest and disease management.
- ✓ Drones allow quick interventions during outbreaks, which are very important in reducing crop loss.
- ✓ The technology reduces water consumption because drone spraying requires less water compared to traditional knapsack or tractor-mounted sprayers.
- ✓ Drones help with climate-resilient agriculture by enhancing resource efficiency and lowering the carbon footprint related to farm operations.

6. Challenges in Adopting Drones

- ✓ High initial investment costs make it difficult for small and marginal farmers to own drones.
- ✓ Flight time is limited because of battery constraints, so recharging or swapping batteries during long operations may be necessary.
- ✓ Piloting a drone thus requires skilled pilots, and DGCA-approved remote pilot certification can itself prove to be a barrier.
- ✓ Spraying performance and safety can be affected by weather conditions: strong winds, rain, and fog.
- ✓ Some states have regulatory limitations and safety standards that farmers have to abide by before flying a drone.

7. Government Policies and Support in India

For ensuring the legal and safe operation of agricultural drones, the DGCA has put in place regulations since 2021. Subsidies are provided by the government under Sub-Mission on Agricultural Mechanization, wherein there is a provision for a subsidy of up to 75% for drones purchased by CHCs and FPOs. The promotion of Custom Hiring Centres is being done in order to offer rental services for drones, making drone technology affordable to small farmers. Large-scale demonstrations are being conducted by the

KVKs and SAUs to educate farmers and promote drone-based agriculture.

8. Future Prospects

The integration of AI with machine learning will be able to facilitate automated disease identification and real-time decision support for farmers. Autonomous swarming technology enables fleets of drones to spread pesticides at scale with limited human intervention. AI-enabled prescription maps will enhance ultra-precision spraying according to real-time crop health data and field variability. These can reduce operational costs and thereby enhance the use efficiency of drones, with solar-powered or renewable-energy-based charging stations. This will be followed by increased use of drones for spraying bio-pesticides and organic formulations in organic and residue-free farming systems.

9. CONCLUSION

Drone technology represents a qualitative leap toward precision, efficiency, and sustainability in today's farming. It can realize dual functions in crop health monitoring and pesticide application to enable farmers to identify problems early and intervene effectively. With the rise in government support, improvement in technology, and reductions in cost, it is expected that drones will play an increasingly crucial role in smart farming, resource conservation, and climate-resilient agricultural development.