

Drone Technology in Precision Crop Management

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INTRODUCTION

The fast development of digital technologies is revolutionizing agriculture and the use of Unmanned Aerial Vehicles (UAVs), also referred to as drones, is proving to be a highly effective device for crop management through precision agriculture. Drones make it possible for farmers to monitor crops, analyze fields, spray pesticides and fertilizers precisely, calculate yields, and increase efficiency in the use of resources. They have been equipped with sensors, high-definition cameras, GPS, GIS, and AI-enabled analyses, and thus provide timely information useful for making decisions based on data. The use of drones has helped to save on labor, reduce input losses, cut down production expenses, and practice sustainable agriculture. This paper examines the phenomenon of precision agriculture, agricultural drones types, uses, applications in smart agriculture, advantages, problems, future perspectives, recommendations, and their contribution to sustainable agricultural development.

Agriculture is undergoing a technological revolution driven by digital innovations, automation, artificial intelligence, remote sensing, and precision farming practices. Among these emerging technologies, drones have become one of the most promising tools for improving crop management and enhancing agricultural productivity. Traditional farming methods generally rely on manual field inspections, which are time-consuming, labor-intensive, and often fail to detect crop stress, nutrient deficiencies, pest infestations, or disease outbreaks at an early stage. Such limitations reduce the efficiency of farm management and increase production costs.

Precision agriculture is achieved through the use of agricultural drones which take aerial photographs at high resolution and field data in real time. Today's agricultural drones come with GPS, multispectral, thermal, and RGB cameras as well as LiDAR sensors and precision spraying which enable the farmer to assess crop growth, field variation, detect pest and disease outbreaks, determine irrigation needs, and spray agrochemicals where they are most needed. The integration of agricultural drones with GIS, GNSS, remote sensing, cloud computing, and Artificial Intelligence (AI) has led to greater efficiency in the use of drones for precision crop management.

2. Precision Crop Management

Precision crop management refers to a scientifically-based approach to growing crops where new digital technologies are utilized in order to maximize crop growth taking into consideration the variability of factors in each agricultural plot. Instead of providing the same amount of inputs to the whole field, precision agriculture allows one to provide a proper input in proper amounts, at proper places, and at proper times. Thus, it improves the efficiency of using inputs, lowers production costs, minimizes the environmental impact and increases the productivity of crops.

Objectives

The key objectives of the use of precision crop management include improving crop productivity using scientific approach to farming, optimizing resource utilization in agriculture, lowering the cost of production due to reduction of waste, increasing sustainability, supporting decisions based on field information and raising the profits in farming.

3. Drones for Agriculture

Agricultural drones refer to unmanned aerial systems used for collecting information from fields and performing agricultural operations with precision. Their operation involves the use of GPS-controlled guidance system, flight control system on board, sensors and special software allowing for autonomous or semi-

autonomous flights depending on the purpose of drone operations. Depending on the application, drones can capture aerial images, monitor crop conditions, apply pesticides and fertilizers, estimate crop yields, and assess damage caused by natural disasters.

A typical agricultural drone consists of several essential components, including an airframe, flight controller, GPS receiver, electric motors and propellers, rechargeable battery, RGB camera, multispectral camera, thermal imaging sensor, optional LiDAR sensor, spraying tank with precision nozzles, ground control station, and data processing software. These integrated components enable drones to perform efficient and accurate agricultural operations.

4. Types of Agricultural Drones

Agricultural drones are differentiated into various types based on their design and field applications.

4.1 Multi-Rotor Drones

Multi-rotor drones are the most common drones used in agriculture due to their good stability, hovering ability, and easy-to-control nature. The most suitable applications for such drones include pesticide spraying, fertilization, crop scouting, and monitoring medium-sized and small-sized farms. High maneuverability of such drones allows for an accurate spraying process even in case of an irregular field shape.

4.2 Fixed-Wing Drones

As for fixed-wing drones, they look like traditional aircraft and can fly over large areas of agricultural lands for an extended period of time. The most typical applications for fixed-wing drones include aerial mapping and crop monitoring. Such drones are able to conduct surveys of hundred hectares during one flight due to their long flight time and high efficiency.

4.3 Hybrid Drones

Hybrid drones incorporate advantages of multi-rotor and fixed-wing drones, providing long flight endurance and vertical take-off and landing abilities. This type of drones is best

suited for commercial farms where field coverage plays a crucial role.

5. Applications of Drone Technology in Precision Crop Management

Drone technology has revolutionized precision agriculture through the provision of accurate, timely, and field-specific data to assist in scientific management of crops from planting up to harvesting.

5.1 Crop Monitoring

Drones are used to take high-resolution aerial photographs that allow for continuous monitoring of crop development, crop canopies, crop vigor, and field conditions. The ability to detect the existence of crop stress provides an opportunity for farmers to determine the poor performance of certain areas in the field.

5.2 Precision Spraying

The use of drones with spray equipment assists in applying chemicals such as pesticides, herbicides, fungicides, plant growth regulators, and liquid fertilizer in places where these chemicals are needed only. This will ensure even application of chemicals, reduction of chemical wastage, lower need for laborers, increased safety of operators, and reduced environmental pollution.

5.3 Pest and Disease Detection

Use of multispectral and thermal cameras in drones helps in early detection of pests and diseases in crops. This helps to intervene early, reduce crop losses, reduce the amount of pesticides applied, and increase effectiveness in crop protection.

5.4 Nutrient Management

Drone imagery combined with vegetation indices such as the Normalized Difference Vegetation Index (NDVI) helps identify nutrient-deficient areas within agricultural fields. This information supports variable-rate fertilizer application, nutrient deficiency mapping, and balanced nutrient management, thereby improving fertilizer-use efficiency and crop productivity.

5.5 Irrigation Management

Thermal imaging cameras mounted on drones detect moisture stress and evaluate water distribution across agricultural fields. This information helps farmers schedule irrigation more efficiently, conserve water resources, reduce water wastage, and improve crop performance under varying environmental conditions.

5.6 Weed Management

Through their ability to detect patches of weeds in crop fields, drones enable precise spraying of herbicides. The precision method of spraying herbicides leads to lower herbicide usage, decreased cost of production, reduced environmental pollution, and efficient weed management.

5.7 Yield Estimation

Using high-resolution images taken by drones and Artificial Intelligence technology, there can be precise prediction of the crop yield before harvesting. The predicted crop yield helps in planning for harvesting, storage, marketing, and logistics.

5.8 Crop Damage Assessment

After natural calamities like floods, droughts, hailstorm, cyclone, or storm, drones can quickly assess the damages done to crops. The acquired data help in assessing insurance claims, disaster management, and government compensation schemes.

6. Integration with Smart Agriculture

Drones have become a fundamental part of today's smart agriculture through the integration of drones with many sophisticated digital technologies. The use of Artificial Intelligence allows for automated interpretation of images, detection of diseases, and decision-making systems. Machine learning is applied to improve crop prediction models and increase the accuracy of agricultural analytics. The use of Internet of Things (IoT) technologies makes it possible to get real-time field information to complement information collected by the drone. GIS and GPS technologies allow for precise mapping, navigation, and spatial analysis of the fields.

Remote sensing technologies help monitor the crops and assess resources; cloud computing and big data analytics allow for efficient storage and analysis of agricultural data.

7. Advantages of Drone Technology

The advantages of drone technology for agriculture include agronomic, economic, and environmental advantages which make modern agricultural practices more effective.

First of all, from the agronomic point of view, drone technologies help monitor crops constantly, identify the presence of stress symptoms on crops, manage nutrients more effectively, control pests and diseases, schedule irrigation more accurately, and increase crop yields.

Secondly, economically, drone technologies require less labor input, save costs because of the precise application of inputs, decrease operational costs, increase efficiency of farm management, and help become more profitable and make a more efficient use of agricultural resources.

Finally, environmentally, drones help minimize the carbon footprint of agriculture because of the precise application of fertilizers and pesticides, reducing water losses and GHG emissions.

8 Challenges

Although there are many strengths associated with agricultural drones, some challenges need to be addressed. High cost is the first challenge that hampers the adoption of these devices on a wider scale because farmers have to invest huge amounts in drone devices initially. Short battery life reduces the period for which drones can fly, while adverse weather conditions, including heavy rains and winds, can also hamper drone operations. Technical skills are needed for efficient and productive usage of drones since the drone operator must have knowledge about flight planning and image processing, along with device maintenance. Data analysis is another issue because special software and knowledge is needed for handling the data collected by drones.

9. Future Perspectives

The future prospects of drone technology in the agricultural sector are very promising owing to technological developments and growing demand for precise agricultural techniques. Autonomous artificial intelligence-operated drones that can independently make decisions are going to enhance the efficiency of operations. Drone swarms executing coordinated agricultural tasks will ensure higher field coverage and shorter operation times. Analytical processing of the state of crops in real time and the ability of automatic application of inputs at varying rates will enhance the efficient use of resources. The implementation of 5G communication technology will facilitate fast data transfer and control of drones in real time. Blockchain technology will be used in order to increase the security and transparency of agricultural data management. The future integration of agricultural robots, autonomous farm machines, digital twins, and smart decision-support systems will lead to full automation of the entire process.

10. Recommendations

For faster adoption of drones in precision farming, cheap drone services can be provided through Custom Hiring Centres (CHCs), Farmer Producer Organizations (FPOs), and agricultural cooperatives. Proper training sessions should be conducted to ensure that skilled drone pilots, agricultural extension workers, and farmers are produced. Partnerships between the public and private sectors should be encouraged for fostering innovation, research, and commercialization of agricultural drones. Adequate investments need to be made in order to enhance digital connectivity in rural areas. Drones' analytics should be made easy through proper development of user-friendly platforms. Incentives in terms of subsidies, financial help, and credit facilities need to be offered to ensure faster adoption of drones, particularly by small and marginal farmers. Lastly, drones

need to be combined with precision farming, climate-smart agriculture, digital agriculture, and sustainable resource management programs.

CONCLUSION

Agricultural drones have proven themselves to be one of the most revolutionary developments in precision crop management through their ability to provide crop monitoring, application of inputs with accuracy, pest/disease detection, irrigation management, and data-driven decision-making. Using drones in conjunction with Artificial Intelligence, remote sensing, GIS, Internet-of-Things (IoT), and cloud computing, farmers can effectively utilize resources, cut down on production costs, enhance crop productivity, and ensure environmental sustainability. Even though there are still many challenges associated with investment, technology use, policy issues, and digital infrastructures, technological innovations, favorable governmental policies, active private sector involvement, and skill development programs will contribute to the increased deployment of agricultural drones. Precision agriculture is rapidly developing and the drones will certainly make an important contribution in establishing sustainable,

resilient, climate-smart, and profitable agricultural production systems.

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