

AGRICULTURE FORUM FOR TECHNICAL EDUCATION OF FARMING SOCIETY

Kota, Rajasthan



Drone Technology in Crop Management

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INTRODUCTION

The rapid development of technologies in agriculture has been driven by the necessity to produce more food using fewer resources and guaranteeing the sustainability of the environment. Conventional approaches to crop monitoring are associated with heavy labor needs, time-consuming processes, and significant expenses, making them unsuitable for large-scale farming operations. Digital agriculture has brought about such devices as unmanned aerial vehicles, also called drones, which have become efficient means of boosting agricultural productivity.

Agricultural drones are capable of collecting highly detailed images, monitoring crops, detecting areas that are under stress, and spraying fertilizers, pesticides, and other crop protection materials. These technologies enable farmers to make informed decisions based on real-time field data rather than relying solely on visual observations. Consequently, drone-assisted farming contributes significantly to precision agriculture by improving efficiency, profitability, and sustainability.

Drones have been identified among the most important developments of modern agriculture, providing effective, accurate, and cost-efficient means of crop management. Armed with sophisticated sensors, cameras, and GPS technology, drones deliver immediate information about crop health, variations within a field, irrigation needs, pest outbreaks, and nutrient shortages. Drones facilitate the adoption of precision agriculture, optimizing inputs, increasing crop yield, minimizing costs of production, and reducing the impact on the environment. This paper explores the principles, applications, benefits, limitations, and prospects of drones in crop management.



2. Types of Agricultural Drones

Agricultural drones are made in various designs to accommodate the needs of crop management, field monitoring, and precision agriculture. Depending on their design and performance, agricultural drones can be categorized into fixed-wing drones, multi-rotor drones, and hybrid drones.

1. Fixed-Wing Drones

Fixed-wing drones are similar to traditional aircraft since they utilize lift generated by wings instead of using only rotor blades. These types of drones are very appropriate for the surveying of vast agricultural landscapes since they can manage a large area in a single flight. Since they have an aerodynamic design, fixed-wing drones use minimal amounts of energy and give a longer duration of flight compared to rotary-wing drones. They are extensively used for mapping, crop surveillance, vegetation monitoring, and creating high-resolution orthomosaic maps. However, these types of drones do not offer hovering capability and hence are more efficient in covering large farms.

Therefore, they are the best choice for commercial agriculture and plantation management.

2. Multi-Rotor Drones

Multi-rotor drones are the most popular agricultural drones due to their flexibility, simplicity in use, and hovering capability. They are capable of vertical take-off and landing (VTOL), allowing them to operate in fields with limited open space. Multi-rotor drones are extensively used for pesticide spraying, fertilizer application, crop monitoring, weed detection, and field inspection. Their precision and ability to fly at low altitudes make them highly suitable for small and medium-sized farms where targeted interventions are required.

3. Hybrid Drones

Hybrid drones make use of the best attributes of fixed-wing and multi-rotor technology. They have the long-range flying capacity of the fixed-wing drones but also maintain the hovering ability and the vertical take-off capacity of the multi-rotor drones. Due to the mentioned capabilities, hybrid drones can effectively perform the mapping and precision spraying missions during the single mission. Hybrid drones have started to become more popular in the precision agriculture market since they provide better endurance, greater versatility, and better efficiency in dealing with large agricultural estates.

3. Components of Agricultural Drones

Agricultural drones are made up of a number of advanced hardware and software components that allow collecting precise information from the fields

and performing agricultural tasks in an efficient way. GPS allows for precise location determination and the flight following the pre-programmed course. The flight controller is the brain of the drone controlling its stability, navigation, altitude, and flight operations. Electric motors and propellers provide lift for the flight, while lithium-ion batteries supply energy.

The agricultural drone is fitted with high resolution RGB cameras to capture detailed images for crop monitoring and field mapping purposes. The multispectral and hyperspectral cameras capture reflected light at various wavelengths and help farmers monitor nutrient deficiencies, diseases, and crop stresses even before these become visibly apparent to the naked eye. The thermal imaging camera measures the canopy temperature of the crops in order to identify crop stresses caused by lack of irrigation, diseases, and other causes.

Some advanced agricultural drones can even have LiDAR (Light Detection and Ranging) sensors to generate accurate 3D models of the crop canopies and field topography. The drones used for spraying applications have tanks and pumps to hold the chemicals, and are fitted with nozzles to ensure effective delivery of pesticides and fertilizers. The captured data is processed using ground control software, cloud computing technologies, and AI image analysis systems.

4. Applications of Drone Technology in Crop Management

1. Crop Monitoring

Crop monitoring is the key area of application for agricultural drones. Regular aerial surveys allow

farmers to obtain high-quality images which make it possible to monitor crops constantly during the growing season. In contrast to conventional scouting, drones have an ability to scan large fields very quickly and determine the crop variation.

Drones can help in the detection of the stress in crops because of nutrient deficiencies, water deficit, pests, plant diseases, adverse weather conditions and others before these issues become obvious to a farmer. It is also possible to assess plant density, canopy development, crop vitality, emergence evenness and growth patterns through vegetation maps obtained from drones.

2. Precision Spraying

Precision spraying is a new era in crop protection when drones can spray the pesticide, herbicide, fungicide, bio-pesticide, and liquid fertilizer only on those places where it is necessary. Drone spraying system works on GPS guided flight planning.

As compared to conventional sprayers, drone spraying greatly helps to reduce chemical wastage, reduce the number of laborers, cut down on cost, and protect operators from exposure to harmful chemicals. Due to the ability of drones to operate in difficult terrains and waterlogged areas, it becomes possible to provide timely crop protection under field conditions.

3. Nutrient Management

Efficient nutrient management is highly necessary to increase the efficiency of crop production while reducing the fertilizer loss. Agricultural drones with multispectral sensors calculate the NDVI (Normalized Difference Vegetation Index) to determine the nutrient-deficient parts of the field.

Using nutrient maps generated by agricultural drones, it is possible to adopt site-specific nutrient management techniques with variable rates of fertilization to reduce costs and environmental pollution.

4. Irrigation Management

Due to water scarcity in modern agricultural practices, irrigation management has acquired special significance in agricultural practices. Using agricultural drones with thermal and multispectral sensors makes it possible to identify water-stressed plants based on their canopy temperature and reflectance.

Irrigation maps generated by the drones will help farmers manage irrigation scheduling, irrigation system troubleshooting, and avoid over-irrigation/under-irrigation. In this way, water use efficiency will be greatly increased.

5. Detecting Pests and Diseases

The early discovery of pests and diseases is highly essential to reduce the yield losses and increase the economic profitability of farms. Drones coupled with AI allow for quick recognition of the symptoms of disease and insect infestation.

With the help of agricultural drones, farmers can recognize such diseases as leaf spot, rust, blight, powdery mildew, bacterial infection, viral disease, as well as the damage that insects cause such as stem borers, leaf folders, caterpillars, aphids, and other pests. The early detection of pests and diseases allows farmers to take preventive actions to avoid yield losses.

6. Detecting Weeds

Weed detection is one more area where drones become helpful. By analyzing high-resolution images, drones can easily recognize weeds by their spectral features, shapes, and other parameters. Rather than spraying herbicides evenly over all the field, farmers will be able to apply the herbicides only to the places where they are needed thanks to the weed map created with the help of drones. Thus, farmers will save money, prevent the pollution of the environment, and delay the development of herbicide-resistant weeds.

7. Yield Estimation

Drones are very important in yield estimation. By measuring canopy coverage, plant density, biomass production, flowering intensity, and crop growth trends, drones can easily produce accurate predictions on crop yield. Yield prediction enables farmers to plan for their harvesting, labor management, storage facility management, market supplies, and marketing decisions. Governments, insurance companies, and agribusiness organizations also make use of yield predictions made by drones in their agricultural planning processes.

8. Crop Insurance Assessment

Drones have helped to make crop insurance assessment process more effective. Once natural calamities like floods, droughts, hail storms, cyclones, and pest attacks occur, drones help take aerial images of the affected farm areas. The collected data makes it easier to estimate the extent of damage, enabling faster processing of insurance claims. It also reduces conflicts between farmers and insurance companies regarding claims settlement.

9. Sensors used in agricultural drones

Different types of sophisticated sensors are used in agricultural drones depending on their application. RGB sensors provide high resolution pictures for mapping and crop monitoring. Multispectral sensors detect crop reflection in particular spectral regions and help to calculate vegetation indices like NDVI and assess the state of crops. Thermal sensors detect temperature variations in canopies and are helpful in assessing irrigation status and presence of diseases. Hyperspectral sensors collect highly resolved spectral data and enable detection of nutritional and disease problems at early stages. LiDAR sensors create precise three-dimensional models of crop canopies and field terrain.

10. Advantages of drone technology

There are many benefits provided by drone technology that make it an integral part of precision agriculture of today. It allows monitoring crop growth in real time, improving efficiency, decreasing dependence on workforce and enabling precise application of agricultural inputs. Using drones increases crop yields while reducing pesticide exposure of farmers and environmental pollution.

It also enables effective monitoring of diseases, creation of accurate field maps, helps in decision making based on data, saves a lot of time during field operations and makes monitoring of inaccessible or dangerous zones possible. Overall, drones contribute significantly to increasing farm profitability while promoting sustainable agricultural practices.

11. Limitations

Although there are many advantages associated with drone technology, some limitations prevent the use of drones in farming on a larger scale. The expensive cost of buying drones and sensors is one limitation that poses challenges especially to small-scale farmers. In addition, limited battery life reduces the time and range of the flights while harsh weather like windy and rainy conditions affect flights. Effective drone use calls for the availability of skilled people who can plan for flights and interpret the collected data. Besides, handling large quantities of data generated by drones requires sophisticated computer programs and experts.

Role of Artificial Intelligence

Artificial Intelligence (AI) has tremendously improved drone technology in agriculture through automatic analysis of the imagery captured by the drones to diagnose diseases, detect weed, classify plants, calculate yields, and assess growth of crops accurately.

The machine learning algorithms are constantly improving their performances by learning from large amounts of agricultural data. AI technology is very crucial for implementing variable rate application techniques, planning flights, and decision support systems.

Economic Benefits

Drone technology contributes significantly to improving farm profitability. Precision application of fertilizers and pesticides reduces input costs while maintaining high crop productivity. Improved

irrigation scheduling decreases water consumption and energy costs. Reduced labor requirements further lower production expenses, particularly in regions experiencing labor shortages.

Early detection of crop stress minimizes yield losses and enhances produce quality, resulting in better market prices. Overall, drone-assisted precision farming increases resource-use efficiency, improves net farm income, and enhances long-term economic sustainability.

Environmental Advantages

The environmentally sustainable farming through drone-enabled precision agriculture occurs because there is no excessive use of fertilizer and pesticides on the site. It ensures that there is no chemical runoff from the site, no harm to the soil, water conservation, and minimization of the release of greenhouse gases by agricultural processes.

Moreover, precision agriculture enables the preservation of useful insects, minimizes ecosystem contamination, prevents soil degradation, and ensures efficient resource use. The environmental advantages mentioned above greatly enhance the sustainability of agricultural production.

12. Prospects for the Future

The future of drone technology in agricultural applications looks very promising. Drone integration with AI, IoT, cloud computing, robotics, big data analysis, and satellite imagery will further develop the field of precision agriculture. Swarms of autonomous drones capable of performing monitoring and spraying tasks are likely to appear in the near future.

New technologies such as digital twin technology, predictive analysis, blockchain traceability, and real-time farm decision support systems will revolutionize data collection and processing in the field of agriculture. Driven by decreasing cost of manufacturing drones and governmental incentives, the future of drone technology looks promising in the context of sustainable agriculture.