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Application of Drones Technology in Agriculture: A Modern Approach

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Drone technology can be used for many applications for agricultural uses, including crop health monitoring and farm operations like weed management, Evapotranspiration estimation, spraying etc. For agricultural applications, regularized smart-farming solutions are being considered,

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including the use of unmanned aerial vehicles (UAVs). The agricultural UAVs are highly capable, and their use has expanded across all areas of agriculture, including pesticide and fertilizer spraying, seed sowing, and growth assessment and mapping. Accordingly, the market for agricultural UAVs is expected to continue growing with the related technologies. In this study, we consider the latest trends and applications of leading technologies related to agricultural UAVs, control technologies, equipment, and development. We discuss the use of UAVs in real agricultural environments. Furthermore, the future development of the agricultural UAVs and their challenges are presented. By flying safely and at relatively high speeds, drones can cover large and small properties quickly to manage assets, resources, and land. Many farms are now using drones to check and maintain water levels in dams and other resources previously inaccessible whilst removing any risk to the operator or surrounding area. In order to produce better crop quality and shield fields from harm, this study paper aims to emphasise the value of drones in agriculture and describe the best drones currently on the market for this purpose.

Keywords: Drone; UAV; smart farming; fertilizer spraying; seed sowing; growth assessment; mapping.

1. INTRODUCTION

"Drones are revolutionizing agriculture with their ability to gather vast amounts of data quickly and efficiently. Here's how drones are being applied in modern agriculture. Use of drones can be advantageous in the case of pesticide spraying, replacing labour intensive and hazardous conventional methods particularly in difficult areas such as hills. Artificial intelligence and machine learning can be combined with NDVI (Normalised Difference Vegetation Index) imaging technology-based high-resolution images captured by drones to develop understanding of soil conditions, plant health and crop yield prediction. Every individual plant can be located separately and analyzed using image processing algorithms, if it is stressed" [1,2]. "Using this result, farmers can take preventive action to cease the spread of diseases to other crops. Timely actions can be taken to prevent losses from biotic stresses such as insect pests and diseases, optimize fertilization, rationalize irrigation and reduce the impact of climate change and unpredictable weather using analyzed insights from data collected by drones and satellite-based remote sensing. The agricultural labour shortage in exceptional times of COVID 19 pandemic that has necessitated adoption of physical distancing measures has opened up several opportunities for the use of drones in agriculture. An attempt has been made in this article to assess the use of drones for facilitating farming activity amidst lockdown compliance and labour deficit. According to the 'Agriculture in 2050 Project,' the world population will reach about 10 billion by 2050. Consequently, food production will require a 70% boost [2a] Agriculture needs automation, robotics, information services, and intelligence- a combination of big data, the internet of things, robotics, artificial intelligence (AI), and information and communication technologies (ICT)- to increase the rate at which food is produced. Future prospects are created by the dynamic field of smart agriculture. At the centre of the smart agriculture expansion are agriculture robots, among which, unmanned aerial vehicles (UAV) have been extensively applied" [2b,3]. "UAVs have significantly reduced working hours, resulting in increased stability, measurement accuracy, and productivity. UAVs are not only less expensive than most other agricultural machines, but also, they are easily operated. Moreover, their applications have contributed to the expansion of many areas of agriculture, including insecticide and fertilizer prospecting and spraying, seed planting, weed recognition, fertility assessment, mapping, and crop forecasting" [4]. "Many different types of sensors and other data-gathering devices have been developed for agricultural applications, including yield sensors, weed sensors, aboveground and underground sensors that monitor temperature and humidity, and imaging sensors that are perhaps the most crucial in the field of precision agriculture. In the past, the only ways to obtain aerial photos were by aircraft or satellites, as those used in the Landsat programme. Images captured by satellites or aeroplanes equipped with multispectral and hyper- spectral cameras could be used to compute a variety of vegetation indices that can show variations in the field. The normalised difference vegetation index (NDVI), for example, is a vegetation index that compares the light intensities reflected from canopies in the near infrared (NIR) and visible ranges" [5,6]. "Precision positioning, navigation, controls, images, communications, sensors, materials, batteries, circuits, and motors are examples of cutting-edge technology. It is necessary to apply a variety of technologies (such as nozzle controls, big data, and equipment development) depending on how the UAV is used and the farming industry. Providing information on any UAV technology is difficult.Like other industries, the agricultural sector has sought innovation by utilizing convergence technologies. UAVs have proven to be highly utilized throughout the sector. However, agricultural UAVs face numerous technical limitations, such as battery efficiency, low flight time, communication distance, and payload" [7,8]. In order to develop the best strategy for the upcoming generation of agricultural solutions, technical constraints must be resolved. Therefore, it is important to first talk about the newest technologies, upgrades, precise instruments, and diversification before establishing a plan and a system for future development. This study looks at agricultural UAV trends, current state, emerging technologies, and application areas. It also offers future directions, opportunities, and problem-solving tasks. Overall, drones offer farmers a powerful tool for improving productivity, sustainability in farmer's income, and resilience in modern agriculture. As technology continues to advance, the applications of drones in agriculture are expected to expand further, driving innovation and efficiency in food production. In this review paper, we mainly discuss the value of deploying and utilising drones and UAVs in agriculture as well as the extra benefits that farmers can receive on crop productivity from using drones. The benefits and applications of drones in agriculture are covered in this review [9-13].

2. AGRICULTURAL DRONE

"Drone technology uses tiny sensors (such as pressure, magnetometer, gyros, and accelerometers) whose sizes are getting smaller every day and whose performance is always improving" [14,15]. "Furthermore, drone technology is advancing due to the ongoing development of strong CPUs, GPS modules, and increased digital radio range. UAVs may now be smaller and carry more cargo because to advancements in embedded systems and motor technology. These further results in improved drone control for monitoring distant fields" [16,17]. Working of agriculture drones in field as seen in Fig. 1.

Fig. 1. Agriculture drone is being used in the field of agriculture

Fig. 2. Fixed-wing UAV drone is being used in the field

Fig. 3. A helicopter drone is being used in the field of agriculture

Fixed-wing UAV: "These UAVs are equipped with stationary wings in the form of aerofoils, which produce lift when the aircraft achieves a particular speed. Helicopters and fixed-wing aircraft have dominated the unmanned aerial vehicle (UAV) market during the last ten years. These days, the emphasis in precision agriculture has changed from small drones to multicopters, which currently account for about half of all UAV models on the market" [13]. Table 1 and Fig. 2 provides an overview of the benefits, drawbacks, and uses of fixed-wing drones, helicopters, and multicopters.

Helicopters: For lift and propulsion, it is equipped with a single set of horizontally revolving blades that are fixed to a central pole post. Fig. 3 depicts this kind of UAV. Helicopters can fly forward, backward, take off and land vertically, and hover over an object. These characteristics enable the employment of helicopters in crowded and isolated locations where fixed-wing aircraft cannot function.

Multi-copters: "Rotorcraft with numerous sets of horizontally rotating blades (usually 4-8) has the capacity to lift and regulate UAV motions. The usage of semi-controlled drones for farm surveillance has been transformed by the integration of artificial intelligence (AI)" [18,19]. A semi-controlled drone made decisions solely based on the output from its sensors. Because AI systems are capable of making decisions on their own, they are a valuable tool for real-time data processing. AI's ability to make decisions is predicated on prior training. Real-time data analysis that maps the spatial variability of the field has enhanced farm output. In agricultural settings, drones are utilised to collect basic crop data that is incorporated into analytical models for further analysis and remedial action to boost productivity. Drones can assist with crop health monitoring, irrigation, fertiliser application, and soil health evaluations. It also provides useful data analysis for farming estimates. "These days, the use of small unmanned aerial vehicles (UAVs) in agriculture is expanding quickly" [9,10]. "Drones are semiautomated machines that are moving closer to being fully automated. The potential for agricultural planning and related spatial information collecting with these devices is immense. Despite certain inherent obstacles, this technology can be applied to useful data analysis" [11]. "In the past, unmanned aerial vehicles (UAVs) were piloted by a pilot via a radio; however, contemporary drones are GPS-based autonomous aerial vehicles. Depending on how a drone will be used, different cameras, sensors, and control devices will be used. Fixed-wing, Helicopter, and Multi-copter are the three primary categories of UAV platforms" [12]. The usage of semi-controlled drones for farm surveillance has been transformed by the integration of artificial intelligence (AI) [18,19]. A semi-controlled drone made decisions solely based on the output from its sensors. Because AI systems are capable of making decisions on their own, they are a valuable tool for real-time data processing. AI's ability to make decisions is predicated on prior training. The productivity of farms has increased because of real-time data processing that maps the field's spatial variability. Drones are used in agricultural settings to gather basic crop data, which is subsequently entered into analytical models for additional analysis and corrective action to increase output. Drones can help with irrigation, fertiliser application, crop health monitoring, and soil health assessments. It offers helpful data analysis for farming predictions as well [20,21].

Table 1. Different Types of aerial imaging system used in precision agriculture

Types of Aerial platform	Commercial agriculture drones	Price range	Applications in agriculture	Advantage	Disadvantage
Pilot aircraft (40)	M-18 Dromader PZL-106AR Kruk	Very high	Crop scouting Fertilizer and pesticide spraying for larger area Drought monitoring Security, and surveillance	1-High speed 2-High Flight Time 3-Higher payload Weight 4-Can cover well over hundreds of hectares of crop fields in a short period	1-High operating cost 2-High altitude Flight 3- Problem in inspection of isolated small fields
Single Rotor Helicopter (UAV) (53)	Yamaha RMAXR22-UVR66 spray systemAlign Demeter E1SR20 and SR200 of Rotary motion	High	Large area pesticide spraying in remote area where high payload capability is needed Crop height estimations Soil and field analysis Crop classification	1-High Payload Capacity 2-Higher flight time 3-Higher speed 4-Strong and durable	1-Heavier 2-Costly setup 3-High altitude flight 4-Noise and vibration 5-Stability problem
Fixed Wing (12,23,31)	1-AgEagle RX60 2-eBee Ag 3- Precision Hawk Lancaster 4-Sentera Phoenix 2Trimble UX5	Medium-High	Large area monitoring large area crop growth monitoring Crop health status monitoring Fertilizer and pesticide spraying	1-Simpler architecture 2-Easier maintenance process 3-Long endurance and range 4-Higher flight speed	1-Limited accessibility 2-Less wind resistance 3-Difficulties in launching 4-Difficulties in landing
Multi-copter	1-DJI Phantom 4 PRO 2-AGCO Solo	Low - Medium	Nutrition, and crop stress considering local field needs Spot pesticide spraying small field	1-Site-specific management 2-Low altitude flight capability 3-Better stability 4-Stable fixed flight capability	1-low speed 2-low payload weight 3-capability Complex 4-architecture Difficult maintenance process Limited flying time and range Lower flight speed

3. POTENTIALS AND PROBLEMS OF USING DRONES IN AGRICULTURE

1) **Soil Analysis for field planning:** Drones can be used to analyze soil and fields for planting schedules, irrigation, and soil nitrogen levels. Drones are also useful for creating precise 3-D maps that can be utilized for soil analysis, including measurements of moisture content, soil erosion, and soil characteristics [22].
2) **Seed Pod Planting:** Some businesses have developed an additional attachment underneath drone systems that can shoot pods holding seed and plant nutrients into the prepared soil. These pods are invented, but they are not widely used just yet. This lowers the cost of planting.
3) **Crop Monitoring:** Crop monitoring is the biggest headache not only for farmers, but also various other stakeholders associated in agriculture operations. This challenge has got worse also with rise of unpredictable weather patterns, which lead to rising crop loss risks and maintenance costs. Drones can be used to set its monitoring routes by gathering multispectral geospatial and temporal datasets at pre-defined scales that relate to crop development and health. Data analytics help in getting insights on crop health much before being visible by manual field scouting [22].
4) **Crop Spraying:** Drones are able to carry appropriately sized reservoirs that can be loaded with insecticides, herbicides, or fertilizers to quickly and efficiently spray agricultural products across wide areas. Due to its autonomous and pre-programmed operation on precise times and routes, crop spraying is far safer and more economical. In order to obtain consistent and ideal spraying outcomes over a variety of topographies, drones are also programmed to self-adjust their height and speed using ultrasonic echoes, TOF lasers, and GNSS signals. Drone spraying is a smart farm's way of reducing human exposure to pesticides, fertilizers, and other hazardous substances. Pesticides that prevent crop diseases from spreading are sprayed by drones [23]. In less than 30 minutes, pesticides and insecticides can be sprayed on the farm with the help of a drone. Drone cameras can be used for data collecting, research, land photogrammetry, agricultural mapping, and crop monitoring [24]. Drones make it simple to maintain the plant at all times on such a vast area of land, which aids in accurate data collection and global mapping. It is possible to irrigate little areas. Plants require a variety of conditions in order to grow. Today, one of the most crucial parts of agriculture is irrigation management. It can be quite challenging to irrigate plants without irrigation solutions.

Drones also outperform other methods when it comes to automated spot therapy using stress detection technology, which employs cameras and sensors to target unhealthy areas while sparing healthy areas. Drones increase the spraying capacity to five times faster than with traditional machinery [25].

5) **Irrigation:** Drones equipped with thermal, multispectral, or hyperspectral sensors can use multispectral indices to pinpoint the areas of the field that lack moisture. This facilitates the precise and timely planning of irrigation to the designated locations [26].
6) **Crop health assessment:** The amount of visible and near-infrared light that plants reflect depends on their health and stress tolerance. Drones equipped with sensors that can detect visible and near-infrared light from crops can be used to follow the health of the crop over time and to see how it responds to corrective action [27].
7) **Crop surveillance:** In huge fields, estimating the general condition of the crops is very impossible. Farmers may identify which field regions need attention and stay up to speed on plant status by using drones to map agricultural landscapes. Using infrared cameras, drones scan the area and calculate light absorption rates to assess the condition of the crops. Farmers can take action to enhance the condition of plants in any area of the field based on accurate and up-to-date information. The use of drones to improve agricultural insurance instruments for cross-verifying farmers' insurance claims is based on this aspect of crop surveillance and crop health assessment. The possible application in the future will be determined by practical considerations and the financial implications of the insurance model that is implemented [28].
8) **Controlling weed, insect, pest and diseases:** Drones are able to identify and notify farmers about field regions affected by disease, weeds, and insect pests in addition to soil conditions. With the

application of this knowledge, farmers can minimize the amount of insecticides used to combat infestations, saving costs and improving the health of their fields.

9) **Tree/crop biomass estimation:** Drones equipped with ultra tiny LiDAR sensors can be used to determine the distance from the ground surface and the density of crop and tree canopy. This makes it possible to determine the change in biomass of trees and crops based on differential height measurements, which is the foundation for measuring the output of crops like sugarcane and lumber in forests. Following the distribution of numerous crop seeds, birds pose a significant threat. Labor is needed for this to keep the field safe. The birds might be scared off from the field by a few drone flights [29].

Benefits, Costs and Saving in Using Drone:

Security: Pilots with training operate the drones that spray crops from a distance. Through this method, farmers and farm labourers are kept out of direct contact with hazardous chemicals and unfavourable working circumstances.

High field capacity and efficiency: Drones operate in the field with extremely little delay and turnaround time. Depending on its capacity, the drone may spray between 50 and 100 acres every day, which is thirty times more than a standard knapsack sprayer**.**

Wastage reduction: The high degree of atomization during spraying conserves 30% of the insecticide. Pesticides such as chemical fog can be sprayed on crops at any point in their growth cycle.

Water saving: Drones save 90% of the water used in traditional spraying methods by utilizing ultra-low volume spraying technology. Lower cost: Drone spaying is 97% less expensive than traditional spraying techniques.

Easy to use and maintain: The drones for agriculture are built tough. It requires little upkeep, has a lengthy productive lifespan, and is easy to replace its parts as needed by the drone service provider [30].

Problems and bottlenecks:

1) Flight Time and Range: Drones for agricultural usage have advantages, but they also have certain drawbacks. Drones used in agriculture have short flight durations (20–60 minutes) because of their relatively larger payloads. As a result, the land is only partially covered by each charge. Longer flight times result in a large increase in drone costs [31].

2) Initial Cost: Most agricultural drones used for surveying have fixed wings, and depending on the features and sensors required to carry out their intended purpose, they can cost as much as $25000 ex. Precision Hawk's Lancaster. Certain drones are more expensive than others because they require additional hardware, software, sensors, and equipment. Aside from sensors and features, the starting cost is also correlated with the payload and flight duration capacities.

3) National Laws: The first Civil Aviation Regulations (CAR) for drones in India were issued by the Directorate General of Civil Aviation on August 27, 2018, and they will take effect on December 1st, 2018. The Unmanned Aircraft System (UAS) Rules18-Part VI, which were published in the Indian Gazette on June 2, 2020, regulate the operation of drones in India. These regulations stipulate that in order to operate a UAS, an operator must obtain an Unmanned Aircraft Operator's Permit (UAOP) and obtain permission for each flight via the Online Digital Sky platform in order to comply with the No Permission No Takeoff (NPNT) policy [32].

4) Connectivity: In most arable farms, internet access is not available. Any farmer who wants to employ drones in this scenario needs to make an investment in connectivity or purchase a drone that can store data locally in a format that can be processed and transferred later.

5) Weather Dependent: Drones are more difficult to fly in windy or wet weather than traditional aircraft. Drones rely on the weather [33,34].

6) Knowledge and Skill: A typical farmer is unable to analyze drone photos since doing so calls for specific knowledge and abilities that cannot be obtained from them. In these situations, the farmer must either recruit knowledgeable staff who are familiar with the analysis program or develop the necessary skills and knowledge of image processing software.

7) **Misuse:** There is a potential for abuse to result in unauthorized information transmission and privacy violations.

These methods are easy to use and call for little data. However, due of their weak theoretical foundation, they are challenging to implement in complicated disciplines.

4. CONCLUSIONS AND FUTURE CHALLENGES

This review paper presents the state-of-the-art development of drone technology for precision farming. The Paper covers two main fields of drone applications in the area of Precision agriculture: crop monitoring, and pesticide spraying. In particular, change in drone structures, development of sensors for data collection, innovation in pesticide spraying drone, implementation of deep learning. The application of sensors, IoT, mechatronics, and other technologies in agriculture has become inevitable in recent years. Drones can be a practical tool for mapping variability across agricultural fields and applying agricultural inputs efficiently. Drones are very useful in agricultural and related fields like horticulture, fishing, forestry, and livestock management. It is applicable to all phases of plant development, from seed germination to harvesting. A farmer can use a drone to watch his field from above and spot any particular plant stand that isn't growing properly. It gives the farmer a clearer picture and enables them to make better judgments on a range of agricultural duties. Over the past two decades, the market for drones has grown significantly, and they have revolutionised a number of industries, including agriculture, industry, and the military. This study looked into the value of drones in agriculture and emphasised the several drones that are available for different uses in the field, along with their technical details. The study is seen as an alert for the agricultural and industrial sectors regarding the development and integration of more drones to improve agricultural activities and, ultimately, produce the highest-quality crops in the near future.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Generative AI technologies, including Large Language Models (LLMs), are transforming various industries, including agriculture. These advancements can help farmers and agribusinesses improve efficiency, sustainability, and productivity. Here's a detailed look at how generative AI, particularly LLMs, are impacting agriculture:

1. Precision Agriculture
   - Data Analysis and Prediction: LLMs can analyze large datasets from various sources such as soil sensors, weather stations, and satellite imagery. This helps in predicting crop yields, identifying pest infestations, and optimizing irrigation schedules.
   - Soil Health Monitoring: By processing data from soil samples, LLMs can provide insights into nutrient deficiencies and recommend appropriate fertilizers or soil amendments.
2. Crop Management
   - Disease Detection: Generative AI can analyze images of plants to detect diseases at an early stage. This is done through computer vision models trained on large datasets of healthy and diseased plants.
   - Pest Control: AI models can predict pest outbreaks by analyzing weather patterns, crop data, and historical pest activity, allowing for timely interventions.
3. Supply Chain Optimization
   - Demand Forecasting: LLMs can predict market demand for various crops by analyzing historical data, market trends, and external factors such as economic indicators and climate conditions.
   - Logistics and Distribution: Generative AI can optimize the supply chain by predicting the best routes and times for transporting goods, reducing waste and costs.
4. Farm Management Systems
   - Decision Support Systems: AI-powered platforms can assist farmers in making data-driven decisions about planting, harvesting, and resource management.
   - Automation and Robotics: LLMs and other AI technologies power autonomous tractors, drones, and robotic harvesters, increasing efficiency and reducing labor costs.
5. Sustainability and Environmental Impact
   - Resource Management: Generative AI helps in optimizing the use of water, fertilizers, and pesticides, reducing environmental impact and promoting sustainable farming practices.
   - Carbon Footprint Reduction: AI models can suggest practices that reduce

carbon emissions and enhance carbon sequestration in soil.

6. Personalized Farming Assistance

- Chatbots and Virtual Assistants: LLMs can power chatbots that provide personalized advice to farmers, answering questions about crop management, pest control, and weather forecasts in real-time.
- Education and Training: AI-powered platforms can offer customized training programs for farmers, helping them adopt new technologies and practices more effectively.

Challenges and Considerations

- Data Privacy: Ensuring the privacy and security of farmers' data is crucial as more information is collected and analyzed.
- Adoption Barriers: Small-scale farmers may face challenges in adopting these technologies due to cost, lack of technical knowledge, or infrastructure limitations.
- Bias and Fairness: AI models must be trained on diverse datasets to avoid biases that could disadvantage certain groups of farmers or regions.

Case Studies and Examples

- IBM's Watson Decision Platform for Agriculture: Uses AI to analyze data from multiple sources and provide actionable insights to farmers.
- Microsoft's AI for Earth: Supports projects that use AI to tackle environmental challenges, including those in agriculture.
- Blue River Technology: Acquired by John Deere, uses computer vision and machine learning to create smart agricultural equipment that can identify and manage individual plants.

Generative AI and LLMs are ushering in a new era of smart farming, where data-driven decisions and automation can lead to increased productivity, sustainability, and profitability in agriculture. As these technologies continue to evolve, their integration into agriculture will likely deepen, offering even more innovative solutions to the challenges faced by the industry.

Usages of AI are given below:

Artificial intelligence is transforming agriculture by enabling precision farming, early pest and disease detection, enhanced crop and soil health monitoring, informed decision-making, and automation of farming operations. These advancements lead to increased productivity, sustainability, and profitability in the agricultural sector.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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