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Drones in Agriculture: Real-World Applications and Impactful Case Studies

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ABSTRACT

Uncrewed aircraft, commonly known as drones, are deployed manually by a ground-based pilot through remote control or autonomously through pre-programmed flight sequences. This paper explores the multifaceted applications of drone technology within agriculture. The scope of this technology extends to various crucial facets, including managing water resources in agricultural systems, detecting water stress, identifying diseases and pests, estimating crop yield and maturity, detecting weed flora, workforce monitoring, livestock maintenance, and logistical concerns. Integrating drone technology in agriculture yields notable benefits, enhancing operational efficiency, task precision, and cost-effectiveness by reducing inputs such as land, water, seeds, agro-chemicals, and manual labor.

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Introduction

Drones are a remarkable innovation with profound implications across diverse sectors, including defense, industry, and agriculture. Presently, a substantial 85% of drone technology is predominantly harnessed by military applications, leaving a 15% share for civilian use in various contexts. However, many countries impose restrictions on drone flights over public spaces and government structures (Aguilar et al., 2018). The Association of Unmanned Aerial Systems International (2016) highlights an annual growth rate of 85-92%, primarily driven by the burgeoning agricultural market.

The World Health Organization (WHO) estimates that pesticide poisoning affects approximately 3 million workers annually, resulting in approximately 18,000 fatalities (Ahirwar et al., 2019). Drones offer a transformative solution in agriculture, addressing critical aspects like water management, weather phenomena, crop disease and pest infestations, and land fertility. Recent observations indicate that drone technology can cover 10 to 15 times more area than traditional land-based techniques (Bujang et al., 2019).

Given that the irrigation sector consumes approximately 80% of available water resources globally, with water use efficiency ranging from 25 to 40%, there is an urgent need to enhance Water Use Efficiency (WUE) to achieve maximum yield. Advanced Information and Communication Technologies (ICTs) play a pivotal role in this regard, offering applications such as precision farming, soil nutrient mapping, land leveling, variable-rate technology for seeding and fertilization, early warning systems for pests and diseases, agro-chemical spraying, and yield monitoring (Călina et al., 2020).

Drones, equipped with diverse sensors, have emerged as integral components in modern agriculture (Celen et al., 2020). They facilitate tasks such as monitoring rice field productivity, assessing wheat production, for example, with various fertilizers, and distinguishing healthy and diseased areas (Daponte et al., 2019). Sensors measuring soil moisture, electrical conductivity, pH, surface temperature, weed or pest infestations, and photosynthesis activity reduce overall agricultural production costs, enhance production efficiency, provide precise crop harvest estimations, and address climate change impacts.

The extensive use of drone technology in addressing water management challenges within agriculture and the irrigation sector is notable. Moreover, in the face of critical challenges arising from climate change, adopting advanced technologies, including drones and image processing, becomes imperative (Daponte., 2019). This transition can mitigate agricultural management issues and increase crop production, productivity, and quality (Dileep., 2020).

DRONES

Dynamic Remotely Operated Navigation Equipment, or simply DRONE, is also recognized by other terms such as Unmanned Aerial Vehicle (UAV) or Remotely Piloted Aircraft (RPA). These aerial vehicles are capable of autonomous navigation, guided by GPS control, eliminating the need for onboard pilots (Erena et al., 2019; Filho., 2020). Referred to as Unmanned Aircraft Systems (UAS), colloquially known as drones, they represent a modern paradigm where aircraft are either manually operated by a ground-based pilot using remote control or autonomously flown by executing pre-programmed flight sequences. This flexibility in operation has propelled drones into various applications, making them instrumental in performing tasks efficiently.

Classification of Drones Based on Rotors

Drones can be broadly categorized into two primary types: fixed-wing airplanes and rotary motor helicopters, commonly called quadcopters. This classification encompasses various uncrewed aerial vehicles designed with specific features and capabilities.

Fixed-Wing Drones. It can achieve higher speeds, typically ranging between 25-45 miles per hour (mph), enabling them to cover expansive areas at an impressive rate. With the potential to cover a range of 500 to 750 acres per hour, the actual coverage is contingent upon the battery fly time (Aguilar., 2018). Notably, fixed-wing drones surpass their rotor-based counterparts in speed and size. Their larger dimensions accommodate higher payloads, increasing versatility and efficiency in various applications (Gao et al., 2019).

Rotary Motor Drones. It operates with a constant speed, providing a stable and controlled flight experience. While they may have limited battery life, their ability to take off and land safely in small, confined areas makes them particularly suitable for beginners learning the intricacies of drone flying (Gao et al., 2019). Multi-rotor and single-rotor drones, in this category, offer the advantage of not requiring specific structures for take-off and landing.

Within multi-rotor drones, various configurations exist based on the number of rotors (Ghazali et al., 2022). These include three-rotor drones, known as tricopters; four-rotor drones, commonly called quadcopters; six-rotor drones, identified as hexacopters; and eight-rotor drones, designated octocopters. Tricopter drones, with their three rotors, boast a cost advantage despite limited weight-carrying capacity and mobility. Quadcopters featuring four rotors are highly favored due to their cost-effectiveness and functional versatility. Thanks to their additional rotors, hexacopters share similar advantages with quadcopters but can carry heavier loads and fly to higher altitudes. Achieving balanced and stable flight in hexacopters is ensured by having three of the six rotors rotate clockwise while the remaining three rotate anticlockwise. Table 1 summarizes the specifications of fixed-wing and rotary-motor drone types.

Table 1: Specifications of drone types

Item	Fixed wing drone	Quad-copter
Weight (kg)	2.5-6	1.5-5
Speed (m/s)	11-17	8-10
Battery type	Lithium polymer	Lithium polymer
Photo capture capacity	3 photos per second	3 photos per second
Flight altitude (m)	150	90
Flight duration (min)	90	45
Area covered in single flight (Km^2)	4-5	2-4
Type of terrain	Plain area	Hilly area

Classification of Drones Based on All-Up Weight

Drones are systematically categorized into various classes based on their all-up weight, including the drone's weight and any payload it carries. This classification spans nano, micro, small, medium, and large drones, each exhibiting distinct characteristics and applications.

Globally, individuals intending to operate drones weighing more than 250 grams are mandated to obtain a remote pilot license. However, a remote pilot license may not be obligatory for micro drones intended for non-commercial use. Nevertheless, operators of other categories of drones are required to possess a remote pilot license as stipulated by regulatory authorities. These regulations underscore the importance of licensing in ensuring the responsible and safe operation of drones, aligning with the evolving landscape of uncrewed aerial systems. Table 2 summarizes the weight specifications and pilot requirements for different types of drones.

Table 2: Drone classification based on all-up weight

Types of drone	Weight	Remote Pilot Licence
Nano	= 250 g	Not required
Micro	More than 250 g and upto 2 kg	Not required for non-commerical and required for commercial use
Small	More than 2kg &upto 25 kg	Required
Medium	More than 25 kg upto 150 kg	Required
Large	More than 150 kg	Required

Benefits of Drone Technology

Drone technology brings forth many advantages, especially in spatial data collection at both local and regional scales. In contrast to traditional methods involving crewed aircraft or satellites, drones offer a range of compelling benefits. Firstly, drones are a cost-effective solution for gathering high-quality data with survey precision, presenting an economical alternative to conventional data collection approaches. Additionally, when deployed by in-house staff, drones operate independently, eliminating the constraints associated with third-party relations, such as contracting, scheduling, and purchasing. This autonomy streamlines the data collection process.

Drones also exhibit a rapid response capability, excelling in swiftly addressing emergent issues like flood or pollution events and providing a nimble and efficient approach to data acquisition in critical situations. With their high maneuverability, drones can navigate challenging and difficult-to-access terrain, proving indispensable for acquiring data in otherwise inaccessible locations. Furthermore, drones can fly at lower altitudes, minimizing the impact of weather effects like cloud cover and ensuring optimal data collection conditions.

Using drones also ensures data security, which is particularly advantageous when the capacity to collect and process the data is managed in-house, enhancing overall data security and control. Drones offer continuous monitoring capabilities, enabling consistent field surveillance throughout the crop-growing season. This continuous monitoring contributes to more informed decision-making in precision agriculture practices, allowing for timely adjustments based on dynamic agricultural processes.

The benefits of drone technology in agriculture can be summarized as shown in Figure 1.

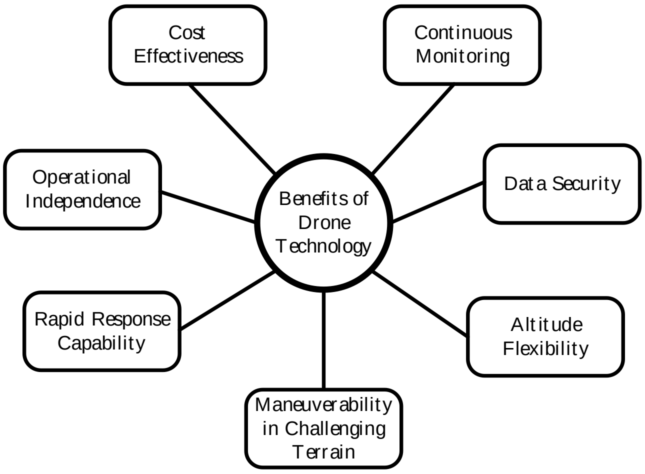

Figure 1: Benefits of drone technology in agriculture

Required Steps for Improving Agriculture Production Using Drones

To enhance agricultural production through the utilization of drone technology, several imperative steps can be undertaken. These steps underscore drone technology's transformative potential in revolutionizing agricultural practices, promoting sustainability, and maximizing productivity.

Optimized Fertilizer Application. Employing drones facilitates the precise application of fertilizers, ensuring they are distributed where and when needed. This targeted approach has the potential to significantly reduce fertilizer usage by 20–40%, optimizing resource utilization.

Enhanced Water Management. Drones are crucial in optimizing water usage and irrigation scheduling. By providing real-time data and insights, farmers can make informed decisions, leading to more efficient water utilization in agricultural practices.

Mitigation of Postharvest Losses. Drones contribute to reducing and preventing agricultural waste and postharvest losses through early detection of issues such as diseases, pests, and suboptimal crop conditions. Timely intervention based on drone-collected data aids in preserving crop quality and quantity.

Resource and Labor Efficiency. Leveraging drone technology results in the reduction of workforce and input costs. Drones streamline various processes, minimizing the need for manual labor and enhancing overall operational efficiency.

Environmental Risk Reduction. Drones assist in identifying and mitigating environmental risks by providing real-time monitoring of field conditions. Early detection of potential issues, such as soil degradation or pest infestations, allows for proactive measures to reduce environmental impact.

Continuous Process Analysis. Drones enable automatic and continuous analysis of agricultural processes and field status. This ongoing monitoring provides farmers with up-to-date information, empowering them to make data-driven decisions for optimal crop management.

Emerging Applications of Drone Technology in Agriculture

Using drone technology in agriculture brings many advantages compared to traditional methods involving satellite high-resolution images and airborne sensors. These advantages encompass improved performance, enhanced efficiency, increased productivity, reduced environmental impact, and the availability of computable data from large farms (Kolhe., 2019).

Despite the transformative potential of drones, agriculture globally continues to grapple with challenges such as unpredictable weather patterns, small and scattered landholdings, non-scientific farming practices, and slow technological adoption (Koparan., 2018). Recognizing this, drone technology is a pivotal tool for optimizing agricultural practices and addressing these challenges.

Numerous reports underscore the transformative impact of drone technology in agriculture. Drones have the potential to assist farmers in optimizing the use of inputs such as seeds, fertilizers, pesticides, and water, allowing for quick responses to threats like weeds, diseases, and pests (Dileep et al., 2020). They also contribute to time-saving on-the-spot surveillance. Drone technology aids in disease and pest detection, water stress assessment, yield estimation, weed identification, and the monitoring of workers through remote sensing and plant monitoring techniques.

The applications of drone technology in agriculture are vast and varied. Some key areas of focus include:

Efficient Water Management. Drones employ ultra-low volume (ULV) spraying technology, enabling economical water usage.

Assessment of Temporal Land Use Changes. Drone-based remote sensing facilitates the assessment of changes in land use over time, particularly in regions experiencing rapid transformations.

Crop Monitoring and Stress Diagnosis. Drones contribute to timely and precise farm operations by monitoring crops, diagnosing abiotic and biotic stresses, and assessing the impact of weather conditions.

Precision Application of Agro-Chemicals. Drones enable the judicious and precise application of agro-chemicals, avoiding overuse and ensuring effective foliar application on tall trees and various crops. Fig. 2 shows an example of using drones for precise agro-chemical spraying applications.

Crop and Weed Species Mapping. Equipped with advanced cameras and sensors, drones can map the distribution of crop and weed species, enhancing weed management planning and potentially delaying the emergence of weed resistance.

Agro-Forestry Management. Drones collect data for predictive planning and analysis in agricultural crop planting with trees.

Horticulture and Plantation Crop Management. Drones with multi-spectral sensors and satellite-based remote sensing platforms estimate the area under different horticultural crops.

Water Body Surveillance. Drones assist in mapping water bodies and the spread of water-loving crops and conducting water resource mapping at various scales.

Figure 2. Precise agro-chemicals spaying by drones

Monitoring Crop Growth and Development. Drones utilize infrared mapping to gather information about soil and crop health, facilitating timely farm operations. Fig. 2 shows an example of using multi-spectral imaging/mapping for crops' health and growth.

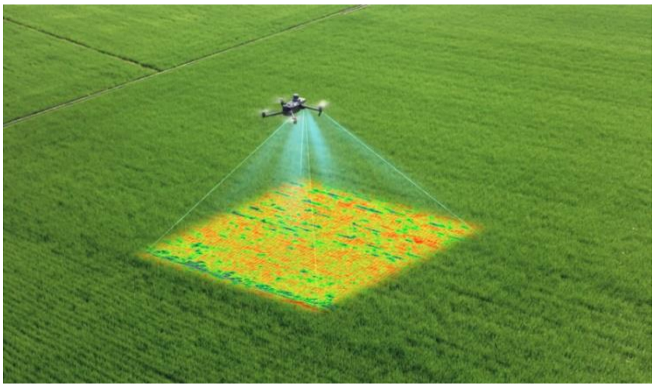

Fig3. Drone's application for crops' health and growth

Geo-Fencing. Thermal cameras mounted on drones can detect animals, birds, and humans, protecting fields from external damage.

Livestock Management. Drones with high-resolution infrared cameras can monitor and manage livestock, identifying sick animals for prompt intervention.

Fisheries Management. Unmanned aircraft systems provide opportunities for real-time survey data, aiding fisheries managers in monitoring resources and combating illegal fishing practices.

These applications underscore the versatility of drone technology, offering innovative solutions to address challenges in agriculture while promoting sustainability and efficiency.

Case Study: Drones in Agricultural Applications

This section explores case studies to demonstrate the application of drones in agriculture. The diverse applications of drone technology in agriculture are showcased, emphasizing its transformative impact on various aspects of crop management and resource optimization.

1. *Efficient Water Management*: In the Pune region of Maharashtra, India, a case study focused on the application of drones for mapping the command area of an irrigation project covering approximately 5 lakh hectares. The primary objective was to identify crop-wise areas, utilizing this information to prepare water charges. The drone survey yielded accurate estimations of irrigated areas and precise identification of crops, resulting in significant time savings and increased departmental revenue.
2. *Characterizing Water Bodies*: Aerial, floating, and underwater drones based on open-source technology were employed to acquire data in water reservoirs in the Segura River Basin, Southeast Spain (Kurkute., 2018). These drones performed bathymetric surveys, surface water vehicle assessments, and underwater remote-operated vehicle measurements. The results revealed an average annual water storage capacity loss rate of 0.33% (Kurt et al., 2021). Other studies demonstrated drone-based systems for on-site water quality measurements, proving accurate and providing spatial distribution maps of measured parameters (Press Information Bureau., 2021).
3. *Assessing Crop Water Requirements*: Evaluation and validation of the MOD16 algorithm, utilizing satellite information, were conducted in five Northwestern Mexico locations (Puri et al., 2017). The algorithm's performance in estimating crop water needs varied among sites. Another study integrated into ArcGIS demonstrated a user-friendly tool for estimating crop water needs from satellite images, showcasing good adjustments but with certain underestimations (Ram Kumar et al., 208).
4. *Characterizing Crop Water Status*: A five-step algorithm for assessing apple crops under varying light intensities achieved an accuracy exceeding 99%, outperforming existing methods (Ramírez-Cuesta et al., 2018).
5. *Crop Monitoring*: Sensor-equipped drones were employed to collect spectral data, creating maps illustrating changes in crop health (Verma et al., 2022). Multi-spectral and RGB cameras allow for imaging of the near-infrared spectrum, enhancing crop health assessment (Rani et al., 2019). Using vegetation indices and color space analysis proved highly accurate, increasing consistency efficiency and reducing costs (Ren et al., 2020).
6. *Variable Rate Fertility*: Drone technology facilitated the creation of variable-rate application (VRA) maps, optimizing nutrient uptake in different field areas (Sabzi et al., 2018). This approach allowed farmers to apply fertilizers judiciously, reducing costs and increasing yields.
7. *Cattle Herd Monitoring*: Drones emerged as a reliable tool for monitoring herds from overhead and tracking animal quantity and activity levels. In protected areas like the

Kaziranga National Park in India, drones were employed to track herds and human poachers.

8. *Disease Surveillance*: Drones were utilized for pathogen surveillance by capturing air spores, enabling the detection of diseases such as Fusarium graminearum, and contributing to early intervention (Stehr., 2015).
9. *Mechanical Pollinator*: Innovative drone-based solutions, such as pollen dump drones, were developed to aid pollination, particularly in fruit crops (Stehr., 2015). These solutions demonstrated a significant increase in pollination rates.
10. *Agricultural Insurance Investigation*: Drones showcased their capabilities in disaster damage assessment, providing high-resolution images and precise positioning data. Insurance companies leveraged drones to determine disaster areas accurately, facilitating efficient claims processing (Verma et al., 2022).
11. *Planting*: Drones equipped with seed-dropping mechanisms demonstrated efficient seed dispersal, achieving high planting rates and significant cost reductions (Rani et al., 2019). Start-ups developed drone planting systems with high uptake rates, revolutionizing traditional planting methods (Veroustraete., 2015).
12. *Crop Spraying*: Drones outperformed traditional machinery in aerial spraying, completing tasks up to five times faster (Veroustraete., 2015). The use of drones for pesticide spraying demonstrated significant savings in operating time, water consumption, and pesticide use (Aguilar et al., 2018; Călina et al., 2020; Filho et al., 2020; Rani et al., 2019).
13. *Mapping and Soil Analysis*: Comparing drone mapping to terrestrial methods, drones exhibited lower implementation costs, significantly faster data acquisition, and reduced workforce requirements. Drones effectively acquire soil information, including pH levels, soil types, and chemical contents, contributing to precise soil analysis (Rani et al., 2019).

Ongoing Project: Development of Smart Agricultural Technologies to Optimize Resource Allocation to Ensure Food Security in Qatar

The University of Doha for Science and Technology (UDST) has recently secured a local grant from the Qatar Research, Development, and Innovation (QRDI) Council for an innovative project focusing on food security. Titled "Development of Smart Agricultural Technologies to Optimize Resource Allocation to Ensure Food Security – A Pathway Towards Sustainable Vegetables and Date Palm Production in Qatar," the $500,000 project is geared towards leveraging cutting-edge technologies to enhance soil quality, increase crop yields, and optimize water and resource usage. The project will harness various advanced technologies, including Internet-of-Things (IoT), Wireless Sensor Networks (WSN), Machine Learning (ML), Machine Vision (MV), robotics, and drone technology, with the overarching goal of advancing sustainable practices in vegetable and date palm production in Qatar.

Project Overview

The role of agriculture in sustaining societies globally has been paramount, and its significance has become even more pronounced in hot, arid regions. In response to increased food demands driven by rapid population growth and economic development, Qatar has demonstrated noteworthy efforts to ensure food security. As part of the National Food Security Program and Qatar's National Vision 2030, this study proposes a comprehensive exploration of climate-smart farming options in Qatar.

Project Objectives

The project aims to contribute to the country's self-sufficiency goals by developing innovative, smart agricultural practices focused on expanding the acreage and productivity of date palms and vegetables, specifically tomatoes and eggplants. Through a multidisciplinary approach, the project outlines five scientific objectives to foster sustainable date palm and vegetable production in Qatar:

- Precision soil conservation to enhance soil health by introducing bio-solids and organic amendments.
- Development and application of artificial intelligence-based machine vision technologies for real-time identification of plant pests (diseases), enabling targeted agro-chemical applications.
- Introduction of sustainable sensor-based smart irrigation systems to optimize the quantity and timing of water allocation for crop production.
- Drones-assisted monitoring and mapping of plants and soil health for early warning and field terrain assessment, facilitating sustainable resource allocation.
- Promotion of circular bio-economy and the performance of life cycle analysis of wastes to enhance current agricultural management practices.

This research project focuses on developing novel, innovative, and cost-effective technologies capable of addressing spatial and temporal variability in soil and crop characteristics, aiming to enhance yield and quality in both open-field and greenhouse-grown crops. The technologies emerging from this research are anticipated to be economically viable and environmentally efficient, holding significant potential to contribute to self-sufficiency in Qatar's agriculture sector by judiciously allocating resources for sustainable practices. The objectives outlined in the proposal are in close alignment with the National Food Security Program and Qatar's National Vision 2030, emphasizing the promotion of local agricultural production technologies, resource conservation, and optimization, and the reduction of the state's dependence on food imports through enhanced self-sufficiency and food security measures. The incorporation of smart technologies such as machine vision, artificial intelligence, deep learning, precision soil conservation, sensor-based sustainable irrigation, and bio-circular economy into the cultivation of vegetables and date palms introduces a novel and innovative dimension to the project, furthering its potential to revolutionize sustainable food production practices.

Expected Outcomes

This research endeavors to provide farmers and stakeholders in Qatar with tools to optimize crop productivity, enhance soil health, mitigate environmental risks, and reduce production costs through precision application of agricultural inputs. The introduction of the circular bio-economy concept, aiming to convert waste into value-added products usable as soil amendments, holds promising potential for enhancing soil health and overall productivity. The development of innovative systems, grounded in scientific investigations, engineering expertise, and thorough lab/field evaluations, will contribute to the research objectives and serve as a valuable training ground for early career researchers and students. Equipping them with expertise in climate-smart agriculture production technologies, this initiative will prepare them for successful careers in industry, government, and academia. As the research delves into emerging areas of climate-smart agriculture practices, it positions Qatar on the global stage as a leader in technology development, emphasizing its commitment to utilizing advanced solutions for ensuring food security.

Expected Impact of the Project

The anticipated impact of this project is threefold—social, economic, and environmental—charting a course towards sustainable agriculture. Socially, the project aims to empower local farmers with knowledge and tools to enhance productivity, fostering a resilient agricultural community. Economically, optimizing resource utilization and reducing production costs are poised to influence the agricultural sector, contributing to economic sustainability positively. Environmentally, the adoption of climate-smart agriculture practices and the incorporation of circular bio-economy principles have the potential to minimize environmental risks and promote ecological balance. In essence, the project aspires to create a lasting impact, harmonizing social progress, economic viability, and environmental sustainability in Qatar's agriculture realm.

Conclusions

Undoubtedly, the integration of drones into agriculture has the potential to revolutionize traditional farming practices into a realm of smart farming. The implications of drone technology in agriculture extend beyond mere enhancement of crop production; they redefine the farming landscape, providing protection for farmers.

Despite the limited current applications of these technologies in the Indian context, there is a growing adoption trajectory. The diverse applications span efficient water management, characterizing water bodies, planting, livestock monitoring, soil health monitoring, and disease and pest control. This trend is expected to expand gradually, bridging the gap from farm to household for multifaceted uses.

The advantages of drone technology in agriculture are significant, offering substantial savings in operating time, water consumption, and pesticide use. The technology contributes to a 50% reduction in fertilizer costs and a simultaneous increase in yield. Moreover, the potential to decrease planting costs by an impressive 85% underscores the transformative impact of drones on the entire agricultural ecosystem. As technology continues to evolve, its integration promises a future where agriculture is productive, sustainable, efficient, and technologically advanced.

Conflict of Interest: The author(s) have declared no conflict of interest.

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