



Review Article

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Precision Farming Drones: Advances and Future Directions

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Abstract

Agricultural drones are a disruptive technology in agriculture, the use of Unmanned Aerial Vehicles (UAVs) is as important as the change from animal traction to machinery in the agricultural field. They represent a different dynamic for many activities in the field, from a quick reconnaissance of the land of 80 hectares in an hour to zoning according to parameters that producers want to observe. In addition to the above, it is a technology that is easy to use and understand, accessible to all levels of farmers. In this review, we cover the latest drone advancements and tools, as well as a projection of the future of these technologies, without excluding the experience of producers who have adopted these technologies.

Highlights

- Drone technology has increased dramatically.
- Various tools have been developed that allow users to diversify functions, data collection and information processing.
- Increasingly autonomous equipment, RGB cameras with higher resolution, infrared cameras, crop condition measurement indices.
- By using these tools, analyzers integrate a multitude of data, which can provide information and help to know the current state of the land, the crop or the harvest, allowing decisions to be made practically now in which events occur.
- This technology can help measure water stress, crop health, pests, weed cover, meteorological events.

Keywords: Drone; Precision agriculture; Maneuverability

Introduction

Between 20,000 and 30,000 years ago, everything indicates that women from different parts of the world-responsible for food collection at that time-began to care for and then produce wild plants that were of special interest for food and health, or to obtain wood and fibers, to later select seeds from the best plants and thus begin the domestication process. 10,000-12,000 years ago, the cultivation of plants was the responsibility of domesticated women in at least four regions of the world [1]. However, it was not until 1892, when engineer John Froelich built the first tractor with an internal combustion engine, but only sold two. Despite this,

historians affirm that the inventor of the tractor is John Froelich in 1892 [2]. And it was not until the 80's when the use of agricultural drones in agriculture began mainly for mapping agricultural land and crops.

The world population, as projected, will reach 8.5 billion in 2030, 9.7 billion in 2050 and 10.4 billion in 2100 [3]. This implies a series of challenges for future generations, but one of these challenges is food production. Drones are a tool that has the potential to contribute to the food demands on the planet in the coming decades.

The world's farmers need to double their agricultural products by the year 2050, to feed a population of nine billion [4], or by 70% depending on the case [5], in an environment where the natural resources to achieve this are becoming increasingly scarce [6]. The Food and Agriculture Organization of the United Nations (FAO) considers that an increase of 70% in agricultural production compared to 2006 is necessary [7].

However, automation and robotics are altering agriculture. The benefits associated with farming automation are evident: cheaper cost of food for consumers, a far lesser pounding to the environment and well pretty much less labor costs all round. The farming sector is getting access to the modern era with technologies like self-driving tractor, weeding robots and a controlled Environment farming [8]. Additionally, information and communication is achieved with internet of things (IoT), aerial photography, smart greenhouses and many other modern farming methods [9].

The use of advanced drones, as technologies in agriculture, offers potential to address several challenges. The main use of drones in agriculture are monitoring the development of agricultural fields, determination of micro and macro elements of the soil, irrigation and bird monitoring [10]. This is part of precision agriculture.

Currently, agricultural activity demands the use of approximately 37.7% of the land [11]. The importance of agriculture in different countries is very diverse, but generally it is a source of jobs and the activity itself contributes to national income. In developed countries, this activity is a lever of development on a par with other economic activities. In developing countries, agricultural activity maintains a very vulnerable sector of society.

The new challenges facing the farmer is to ensure that the crops receive the right input, in the right amount, at the right place, at the right time and in the right way, known as the five R's. This is most easily achieved with precision farming [12-14].

Investment in the agricultural sector have increased by 80% in recent years. By 2050, productivity in the world faces the necessary increase of 70% in agricultural growth, and obtain enough to face the global growth that is expected, considering the cultivated area will decrease. This 70% increase is the objective to achieve [15,16].

The Massachusetts Institute of Technology conducted a ranking of the ten most cutting-edge technologies, ranking agricultural drones in first position [17]. Labor problems in the field are an increasingly recurrent issue, and the use of UAVs is reducing this problem both in terms of labor numbers and effort [18].

There is an accelerated growth in the use of UAVs in civilian applications [19], which include monitoring the crop at any stage of development, sensors, precision agriculture and civil activities in case of missing people and inspection of civilian infrastructure.

To increase crop yields the drones have been one of the best

innovations [20].

Drones are not a new technology. But there are one of the most promise areas is agriculture where drone have the potential to address major challenges [5].

In agriculture, two drones can be identified according to their characteristics, fixed-wing and rotor or multirotor. Its applications are very diverse: to obtain information about land or crops used to know the conditions of the land. And rotor ones are mainly used, for the application of the different inputs that are prescribed for crops [21].

This review article provides an overview of useful tools for researchers, users, and producers. Our understanding and interpretation of the information generated by these tools allows us to know the types of drones, their most important uses and the scope of this technology in agriculture. Future applications and their importance for agricultural producers. In addition, the use of Artificial Intelligence (AI) and Deep Learning are mentioned as new trends in modern agriculture.

Classification of Agricultural Drones

Unmanned Aircraft Vehicles (UAVs) are normally composed of a Fuselage (normally made of polystyrene), Telemetry (controlled by radio at the frequencies of 2.4 GHz and 5.8 GHz, through which the drone communicates [22], and the transmission of videos and images is possible if used a first-person view system [23]. Receiver or remote control (with 2 to 8 channels for aileron, elevator, and camera control), On-board computer (includes GPS and inertial measurement unit device which measures reports data such as speed, orientation, and gravitational forces, using a combination of accelerometers and gyroscopes) Bustamante et al. [24], pressure sensor and flight data log (whose software is installed in the ground control station), Ground control station (PC with software that transmits coordinates and receives flight information), battery (generally made of lithium polymer (LiPo) with varied number of cells and capacities) and camera (which can operate from the visible to the near infrared of the electromagnetic spectrum) [25].

The advantages of using drones are related to aspects such as ease of operation, versatility for monitoring difficult access, monitoring forest fires and monitoring crop yield over large areas. Drones are classified into two types: fixed-wing aircraft and rotary-engine helicopters [26].

UAVs are commonly called drones, and also referred to as a drone aircraft by the International Civil Aviation Organization (ICAO), or an unmanned aerial vehicle (UAVs). Drones are as they can fly without any human intervention or pilot, or a device used for identifying different types of objects via some kind of authentication mechanism. In this case, the term is intentionally changed from a UAVs to UAS as complex systems are called in drone operation [27,28].

The operation of drone is possible thanks to sensors. To talk

of specific instruments (sensors) and techniques of capturing information at a distance (remotely) is to talk about remote sensors [15]. Agricultural drones are divided into fixed wings, multi rotors and single rotors [29]. The generally accepted nomenclature for drones is: “MAV (Micro (or Miniature) or NAV (Nano) Air Vehicles): they are named because of their size; VTOL (Vertical Take-Off & Landing): These aircraft require no takeoff or landing run” [30]; “LASE (Low Altitude, Short-Endurance) [31]: systems, also known as sUAS, small, UA systems, also obviate the need for runways with aircraft optimized for easy field deployment/recovery and transport”; “LASE Close [32]. This category describes small UAS whose aircraft do require runways”; “LALE (Low Altitude, Long Endurance): Typically at the upper end of the “sUAS” weight designation by the United States Federal Aviation Administration (FAA; see below); [33] “MALE (Medium Altitude, Long Endurance): aircraft are typically much larger than low-altitude classes of UAVs”; “HALE (High Altitude, Long Endurance): These are the largest and most complex of the UAS, with aircraft larger than many general-aviation manned aircraft”

[34].

Another well-known name for drones is according to their weight, distance from the remote control, durability, load they support, height they can reach and type of motor used for their operation [35].

Three main types of drones have been considered: micro and mini-UAVs, tactical UAVs and strategic UAVs [36]. We have divided UAVs into five subcategories: Short, Medium and Long Range, Endurance, and Medium Altitude Long Endurance (MALE) UAVs.

Other researchers have classified drones into heavy, medium and high altitude, micro, mini and tactical [37].

Five potential sectors of drones are recognized: environmental aspect, which includes soil moisture, agricultural studies and crop monitoring, emergencies, earth observation, infrastructure surveillance and inspection, environment, defense and security [38].



Figure 1: (a) Multirotor for scanning; (b) Multirotor for product application, Hexacopter; (c) Fixed Wing, Fixed-wing (eBee); (d) Multirotors.

There are two types of agricultural drones: to scan plantations Figure 1(a) and to apply the necessary treatment Figure 1(b). Furthermore, we can differentiate them into fixed-wing aircraft Figure 1(c), used to cover large areas, and Multirotors Figure 1(d), used when the field is smaller or more abrupt.

i. The drones are equipped with at least one of three types of sensors to carry out the different monitors, RGB, thermal and multispectral. The RGB camera [22] captures the observable radiation or spectrum, or simply light; Its wavelength is between 380 and 780 nm. The acronym RGB stands for Red, Green, and

Blue. Its main applications are: Generation of aerial photos to detect problems in crops, areas with little vegetation, damage to plants, waterlogging areas, etc. [39]

ii. Topography: topographic surveys for planning new irrigation sectors, perimeter, and area measurements, etc. [40]

iii. Damage assessment: determination and quantification of damage to crops due to pests, diseases, or inclement weather [41].

iv. Generation of the digital model of the terrain: generation models of the farm, counting of trees, exact location of these [42].

Most used sensors

RGB sensor. Visible light imaging is ideal for many applications in agriculture, as we have for example crop zoning, measurement of crop heights, estimation of crop volume, monitoring of differential growth, inventories, infrastructure inspection, among others [43].

Multispectral Sensor. Multispectral images allow vegetation to be monitored at wavelengths not visible to the human eye. Among others: crop zoning, detection of nutritional stress, early detection of pests and diseases [44].

Thermal Sensor. Crop images in the thermal spectrum, with high precision and resolution sensors, allow us to obtain the temperature of pure pixels of vegetation and its correlation with different aspects of the plant. They allow us, among other things: monitoring of water stress, analysis of effectiveness and homogeneity in irrigation sectors, detection of leaks in irrigation systems, early detection of pests and diseases [45,46].

The first drones used in precision agriculture have scientific sensors to identify the needs of the crop, the optimal harvest point, create GPS maps, count trees or monitor livestock: The most used are multispectral sensors, they measure the amount of light that plants receive and reflect, with this information they color a map (reflectance map) with NVDI indicators of the state of chlorophyll, the wavelength indicates the health of the crop or the optimal harvest time. And they do all this automatically, like the Parrot BlueGrass Fields drone, which collects the necessary information with its Sequoia multispectral camera to generate these maps with NVDI indexes [40].

Multispectral cameras collect information that is not perceptible to the human eye, however, if position information, dimensions of the affected area or other visual data are required, a professional drone with an RGB camera (real image) or at most combined with a thermal camera (Dron Multiespectral - Greendrone.Mx, n.d.) This information allows us to plan crops or count trees, even livestock, if it is also thermographic, as in the case of the Parrot Thermal quadcopter [47].

Agricultural technologies cannot be fully improved by using modern approaches. When selecting new technologies, the criteria that must be taken into account is the reduction of unit costs [48].

To supply the demand for agricultural products from the increase in population on earth, among other factors, the improvement of agricultural technologies must be considered [49].

The frame is one of the important element of a drone, which must be resistant and as light as possible [50], in many cases, drones are known by their number of arms, which are what make up the structure of the drone or frame, hence the drones with two, three, four arms, etc. [51]. Based in this classification can be: Bicopters - two engines, Tricopters - three engines, Quadcopters - four engines, Hexacopters - six engines and Octocopters - eight engines.

The use of drones in agricultura is very broad, we can mention among others, crop monitoring, detection of water stress [52]; soil moisture analysis, pest detection, among others, where different types of cameras or sensors are used, such as those that capture the visible range, multispectral or thermal [45].

Agricultural Drone Maneuverability

The Industry 5.0 officially recognized by the European Commission began in 2021 [53] with its consequent application in the agricultural industry by a) making available to the agricultural sector; b) enable the efficiency of agricultural activities. The technological advances in each of these eras have been adapted and applied to the agricultural sector. The innovations developed have managed to reduce the number of resources in production and less effort to carry out agricultural tasks. Drones are the greatest invention of mankind. There are many different activities in which they can be used. In agriculture, their possible functions are very wide. For many years, crop monitoring was done whit ground vehicles, which consumed a lot of time and effort, drones are facilitating these activities [54]. The use of those technologies reduces problems related to agricultural production and improves crop performance [20]. The use and control of UAVs can be done from a distance that is safe for the person when applying any product (insecticide, herbicide) that could put their health at risk [55].

Unmanned aerial vehicles are equipment that has the potential to contribute to the production of food required by the coming generations, which are increasingly more demanding. Agricultural drones help farmers optimize the agriculture operations that are carried out [56]. Drones make it possible for farmer to view their crops from multiple perspectives. Drones, or UAVs, collect information that allows communication whit robots, artificial intelligent, big data and IoT. [57].

Autonomous drones have wireless sensors; therefore, they are considered an effective means of capturing large-scale data even with limited or no cellular infrastructure thanks to their flexibility and excellent maneuverability, for example, they make them smart agriculture even in remote areas [58].

With drone technology, precision agriculture is without a doubt the most relevant areas that can be studied and examine

[59]. This combination of information systems, sensors, machinery modernization and administrative activities to achieve efficient performance considering the variations that exist in agricultural systems today is possible.

The maneuverability of drones also lies in the possibility of using different devices (multispectral, thermal and visible cameras), software, sensors, and platforms that make it possible to obtain different vegetation indices, pest and disease control, ingathering, irrigation, and fertilization [60], which are frequently used to guarantee precision agriculture through crop monitoring [61].

Together, these tools allow the process of collecting information, which is finally captured in digital maps, from which crop management decisions are made [62].

The increasing global population is driving a shift towards smart agricultural practices [63]. For many countries, the issue of food security is of utmost importance, even these days, even more so today with less agricultural land, climate change and fewer natural resources. Technologies such as IoT and DA are being used to cope with the current agricultural environment [64].

The scope and importance of UAVs in the precision agriculture sector becomes more relevant every day. Incorporating AI, microcontrollers, sensors and IoT in drones enables them to address the main issues that agricultural workers have to face, such as monitoring different species of livestock, land extension, application of chemicals to crops, including in-depth analysis of the state of crops [65].

The industrial sector, considering agriculture and food, is using IoT to transform these areas of production [66,67]. The process of adoption of new technologies in the agri-food sector is, in many cases, long and complicated, mainly due to cultural issues and high adoption costs. IoT technology considers sensors, actuators, drones, navigation systems, data services stored in the cloud and analysis, which for the livestock industry is facing a paradigm shift in terms of elements and information available for decision-making [68].

Application of fertilizers, pesticides, and irrigation with use of drones.

The application of chemicals such as pesticides and fertilizers in agricultural areas is of primary importance for crop yields [69].

The wireless sensors, through data feedback, enable the chemical application process. The intention of this system is to provide variations in the controls and in turn, UAVs sprayers can interpret the information from the sensors [70].

The use of agricultural drones has contributed to great benefits in agriculture [49], reducing production costs, reducing losses during crop development, increasing yields, and minimizing the passage of tractors during the crop cycle.

Drones can be advantageous in the case of pesticide spraying [71], replacing dangerous and labor-intensive conventional methods, especially in difficult areas or activities. Artificial intelligence and machine learning is use to study high-resolution images based on NDVI (normalized difference vegetation index) imaging technology captured by drones to develop understanding of soil conditions, plant health and prediction of crop yields [72].

Unmanned aerial vehicles have different accessories and technology for different tasks in agricultural fields, such as cameras and sensors that make it possible to apply different agricultural products. The World Health Organization (WHO) estimates that there are one million cases of harmful effects from manual spraying of pesticides on planted crops [73].

A detailed review of UAVs in precision agriculture is to assess the usefulness in field tasks that include the review of plants throughout their development [74], estimations of yield and growth [75], quality in the application of pesticides [31], determination of soil parameters [76].

Experts in the UAVs sector see agriculture as an important potential for UAVs in use different. Farmers that use can benefit in the subsequent means [77]. In the case of stables or beef farms, there are many applications for drones, observing animals and gathering enough information to make decisions regarding their health and development.

This can lead to significant cost savings for UAVs, for example for monitoring hard-to-reach infrastructure, application of chemical products necessary for the proper development of agricultural fields and observation of their growth process, without leaving aside activities such as parcel service [78]. New advances in remote sensing systems and small UAVs technology offer a very efficient way for the early determination of water deficit in grass management [79].

Drones Crop Surveying and Mapping

The most important thing for the media and scientists around the world in the agricultural sector are UAVs, whose main function is to monitor agricultural crops [80]. Since the drone industry started, agriculture has taken advantage of its versatility and ease of use in its use, the analytics and software used are complemented by drone solutions that allow for practical and fast solutions [81].

There are many types of drones available today, but not all of them are good candidates for agriculture [82]. Those suitable for agricultural applications are divided into two categories: fix-wing drones and multirotor drones [83]. The cost and payload capacity of both types is similar, and the hardware is quickly becoming a commodity [43].

The studies necessary today to care for natural resources require important tools such as sensors, satellite images, real-time data measurement, among others [84], other authors highlight their use in precision agriculture, forestry, biodiversity,

meteorology, emergencies. Aerial remote sensing and cartography are derived from the development of robotics, computer vision and geomatics technologies [85].

This technology allows obtaining information in multiple applications thanks to the wide range of existing equipment, which can be classified according to their size into micro and mini UAVs: multirotor or fixed wing, which present different execution advantages in different environments or defined tasks [86].

Some of the advantages that UAVs offer is high temporal resolution being able to fly multiple flights over a same property in relatively short time frames, reduced operating costs for small projects versus conventional manned aircraft surveys and are now known as environmental friendly tools; other spatial resolutions translate into fine detail data very close from imaging targets (low altitudes) regarding ground conditions approaching to 2.5 - 15 m depending on type of sensors mounted and missions strategies used also mitigated atmospheric interferences or even eliminated flying above meteorological clouds. The ease of use for even the newest workers showcases that this type of technology poses no human risks to a crew [25,87-89].

Additionally, drones are used in different agricultural activities, terrain reconnaissance, agricultural fields with monitoring at different stages of growth, which facilitates a planning program and better use of resources [90].

Machine and deep learning in the drone's precision agriculture

Emerging technologies such as the IoT, offer both smart agriculture and precision agriculture significant potential in applications, allowing the acquisition of environmental data in real time [91]. Currently, images of very high quality and resolution can be obtained through devices such as IoT and UAVs and used in a large number of studies on crop monitoring [42].

In recent years, smart agriculture and information technologies and primitive agriculture, have evolved greatly towards bridging these two separate worlds [92]. In this sense, smart agriculture it has positioned itself in part of what is now known as digital evolution, using numerous digitization, and therefore generation of information, together with activities to update the content of various media available in existing formats [93].

Agriculture actually plays a fundamental role in the world's economy. The digital agriculture, composing agrotechnology and precision agriculture, have emerged to become scientific areas that employ big data approaches to boost agricultural productivity and minimize the impacts of climate change [94]. Pressure on the agricultural system will increase as the human population continues to expand.

Every farmer has a lot at stake when it comes to crops, their yield, and their quality. In the current era, technological advances are key to better performance and sustainability in an environment

of high competition and current difficulties in markets [95]. The growing water problems and the appropriate methodological procedures for the administration of agricultural properties is a debate that must be addressed with great responsibility [96].

Knowledge of machine learning through IoT analysis in the agricultural sector will generate many procedures to obtain high yields of agricultural products that at the same time guarantee better quality and increase in quantity to contribute to the growing need for agricultural products [97].

Agricultural activities have evolved thanks to recent advances in communication technologies, which have made intercommunication between equipment possible. In the innovation era, the advancement in artificial intelligence (AI), mainly deep learning [98], has improved the processing and speed of data obtained in the field [99]. Recent research suggests that the digitalization of agricultural areas with current technologies surpasses standard image processing techniques.

Farmers need to know several parameters for decision making and protecting their crops: temperature changes, rainfall, prevailing winds and their speed, and changes and duration of radiation. The AI provides this information in a timely fashion (Gupta 2019). Analysis of historic data and yield allows for more comparable desired outcome streams. AI in agriculture will be useful in such a way that traditional farmers' jobs will continue to exist, but it will improve their processes.

These new technologies provide: to be used modern equipment is aimed at reducing the cost for farmers [100], less time spent on agricultural activities, everything will grow much faster and easier irrigation problems terminate without exception due activated is performed in a timely, chemical control administered fertilize the ground fewer chemicals are being released and all that let decreased prices of products, and waste materials are more controlled [9].

There are many challenges that farmers face: monitoring livestock, large areas of land, crop fumigation and timely analysis of crop health, with the incorporation of AI, sensors, microcontrollers and IoT in UAVs, it is easier to track them [65].

Future directions of drones in precision agriculture

Precision agriculture using agricultural drones considers low-altitude Remote Sensing (RS) as new technologies for crop development [101]. In this context, thermal remote sensing has many applications, for example, the external temperature of plants changes rapidly depending on their condition, these changes can be detected with this technology and detect in real time the crop conditions [102].

The phenomenon under investigation, using RS is the science of obtaining information about, objects, crops, livestock, forest with equipment whose technology allows collecting data without having direct contact with the study objects [103].

The application of UAVs with RS thermal sensor allows the survey of maps and monitoring, yield estimation, plant phenotyping and others topics [104,105] plant moisture deficit detection [106,107], and plant disease detection [108]. When considering these latter applications, the ability to identify crop stress and health using unmanned aerial vehicles with sensors before they suffer significant damage could be a real goal [109].

UAVs are a very versatile tool. Their use ranges from support to civil society, agriculture, environmental care and rescue services. They will play a very convenient role in the vision of the Internet of Things (IoT) and can contribute with information for decision making [110].

Acquiring real-time environmental data was a dream, emerging technologies such as IoT make this possible and offer substantial potential in precision agriculture. UAVs provided with different types of cameras, various sensors and GPS attachments, which are part of the IoT, provide a series of benefits and applications related to crop monitoring by taking photographs and processing them practically in the field [111].

Smart farming and precision agriculture, using IoT and AI technologies, have the potential to make better, faster, and lower-cost decisions for crop production using data and images from UAVs [112]. The use of innovative systems (robots) is associated with a significant increase in costs for horticultural producers compared to the increase in income. However, the development of the horticultural sector must improve in all areas of production [113].

Given recent advances in unmanned aerial vehicles, the photographs taken with thermal cameras with high spatial and temporal resolution are at affordable prices, improving the opportunities to understand the field situation, soil and crop conditions, useful for making appropriate agronomic decisions [102].

Current information allows the use and development of remote sensing methods for non-destructive monitoring of crop growth and development and for measuring environmental stress elements that decrease plant productivity [114]. With advances in computing and location technologies, remote sensing on ground, airborne and space platforms provide detailed spatial and temporal information on the response of plants to their local environment, necessary for in-situ agricultural management tactics [115].

In thermal imaging, the invisible radiation shape of an object is transformed into a visible image. This two-dimensional temperature mapping technique in the agricultural and food industries enables the monitoring and characterization of products in various operations [116,117].

Conclusion

UAVs, used by agricultural producers, are a very dynamic and powerful tool. Which have the potential to improve the conditions

of plants, soil, and livestock. Parameters such as water stress, presence of pests, crop health, general conditions of the land can be known practically in real time. The versatility of drones gives them the ability to equip them with different types of cameras, whose images are processed with different software and used through different indices, terrain conditions. They can be used in activities of certain risk, such as application of chemical products, planting.

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