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Unmanned Aerial Vehicles (UAV) in Precision Agriculture: Applications, challenges, and Future Perspectives

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ABSTRACT

Precision Agriculture (PA) is being revolutionized by unmanned aerial vehicles (UAVs), which enable for more effective resource utilization. PA will reach every corner of Sri Lanka in the next years. As a result, the purpose of this research is to (a) categorize UAVs in agriculture based on their performance characteristics, and (b) examine future challenges and research opportunities that will lead to the long-term deployment of UAVs in PA. The types, applications, advantages, disadvantages, opportunities, and potential dangers of using UAVs in PA were critically reviewed, examined, and evaluated using scholarly research articles, conference proceeding papers, and previously published literature from the past fifteen years, and information gaps were identified. UAVs have been classified based on their major performance parameters such as weight, endurance and range, altitude, wing loading, engine type, and power/thrust loading. UAVs are more appropriate in agricultural practices due to their high spatial resolution and fast turnaround capabilities, as well as their low operating costs and ease of use. Livestock and wildlife management, crop monitoring, chemical and fertilizer application, weed detection, field mapping, and soil condition assessment are the major applications of UAVs. Some of the primary constraints observed are the capture and availability of images on time, a lack of high spatial resolution images, challenges with image interpretation, and data extraction. Overall, UAVs are one of the most important technologies that transform traditional cultivation practices into a new perspective of intelligence in PA.

1. Introduction

Climate change has a severe influence on food security, with 815 million people suffering from chronic hunger, with Asia accounting for 64% of the total. To feed the growing population, food production must almost double by 2050. Nonetheless, land and water resources are becoming increasingly under threat [1]. As a result, farming communities and agricultural workers must respond to climate change and other challenges. In this regard, information and communication tools, as well as precision technologies, play a significant role in improving decision making through reliable, accurate, and fast information technologies [2].

Precision farming is now focused on developing smart applications for agricultural resource management. It seeks to boost production, profitability, and environmental preservation [3]. The primary steps of precision agriculture include data gathering, mapping of field variability, decision making, and management techniques [4]. Autonomous aircraft can be defined as an improved and cost-effective device for data collecting with real-time thermal pictures to the ground control station (GCS), as well as the quickest medium for rapid and important agricultural analysis [5].

Unmanned Aerial Vehicles (UAVs), particularly drones, can fly autonomously with dedicated software that allows creating a flight plan and deploying the system with Global Positioning System (GPS), as well as feeding in various parameters such as speed, altitude, Region of Interest (ROI), geo-fence, and fail-safe modes [6]. Currently, low altitude aerial imagery is used to determine soil and plant characteristics in agricultural fields [7]. Drones are preferable over fullsize aircraft and satellite images for a variety of reasons, including a combination of high spatial resolution and quick turnaround capabilities, as well as low operation costs and convenience of use [8].

Drones were permitted to observe a crop field throughout the growth stages. Satellites have one or two weeks of delay before the images are available for analysis. A drone operator may operate on his own timetable and is not reliant on satellite flight paths [9].

These characteristics are critical in precision agriculture, as significant areas of land are monitored and evaluations are made in a short period of time. Aerial vehicles can be used to carry out these activities. With the miniaturization of compact cameras and other sensors connected with aerial vehicles, such as infrared and sonar, the operation becomes more sophisticated [8].

Through remotely sensed images, precision agriculture may identify principally field variability of agricultural fields owing to soil conditions and variations in crop growth development. Variations within spectral responses can be used to generate remote sensing images [6]. Drones are now capable of controlling the spread of weeds and diseases in cultivations, identifying various soil characteristics, sensing vegetation variations, and producing accurate elevation models [7].

Healthy plants, in general, reflect both green and infrared light wavebands. Sensors can monitor and identify the behavior of the reflectance pattern when plants are stressed by pests, nutrients, water or soil [8].

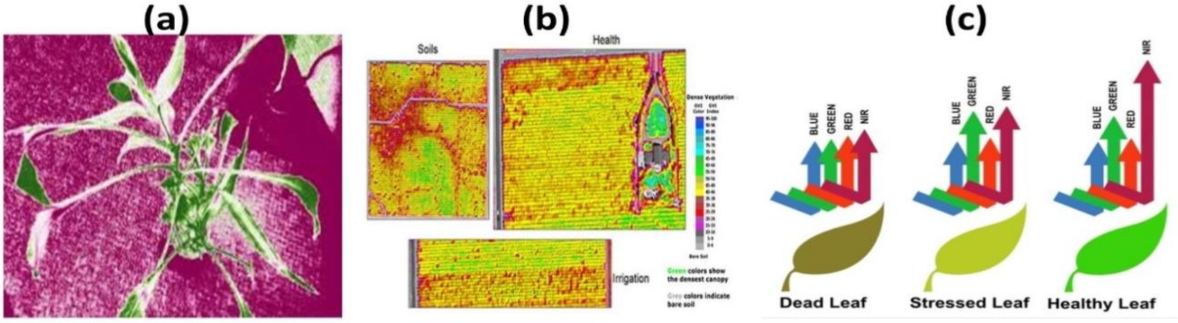

Figure 1: (a) Output of the modified camera of a drone (NDVI image); (b) NDVI image of Sugarcane Field; and (c) NIR analysis of Leaf Area Index [23]

Agriculturalists would monitor crops in flight and visualize patterns of irrigation-related issues, soil variance, and fungal influxes. Furthermore, crop development may be determined by comparing multiple images acquired by satellite as drones' which employ satellite remote sensing technology [10]. Aerial cameras may also be used to discover variations between distressed and healthy plants that are not visible with the human eye by collecting multispectral pictures and gathering data utilizing the optical spectrum as well as infrared [11].

Taking all of these perspectives into account, the purpose of this research is to investigate the advantages, disadvantages, possibilities, and potential implications of UAV usage in precision farming, as well as to identify future knowledge gaps. This study's specific aims were to (a) classify UAVs in agriculture based on performance characteristics, and (b) critically examine future obstacles and research possibilities that would lead to the sustainable deployment of UAVs in PA.

2. Methodology

According to [12], a systematic literature review procedure was used to accomplish the study's objectives since it is an accurate and reliable method. The review was conducted in 5 steps (Figure 2).

The review's key objective was to categorize UAVs in agriculture based on performance parameters utilized in recent scholarly articles, and to critically examine future obstacles and research possibilities that would lead to the sustainable deployment of UAVs in PA. We reviewed 100 publications published between 2005 and 2022 and confined our search to high-ranking journals published in English. Then, in two steps, keywords were identified: first, only the term "Unmanned Aerial Vehicles" was searched for, which should appear in titles, keywords, and/or abstracts; then, to test the search's robustness, we conducted another new search in the "Science Direct" database using the Boolean operation ("drones" OR "image processing" OR "remote sensing"; AND "agriculture"), searching in "all fields." "Articles," published between 2005 and 2022, were the category of article included in the search.

Following the elimination of duplicates in both searches, the article selection process began with multiple researchers independently reading the abstracts of the remaining articles, with the goal of only selecting articles with research questions and results directly related to the study objectives. The researchers then conducted a rigorous evaluation of the database of papers. The study focused on identifying unmanned aerial vehicles (UAVs) in precision agriculture concepts, advantages, obstacles, and critical success determinants.

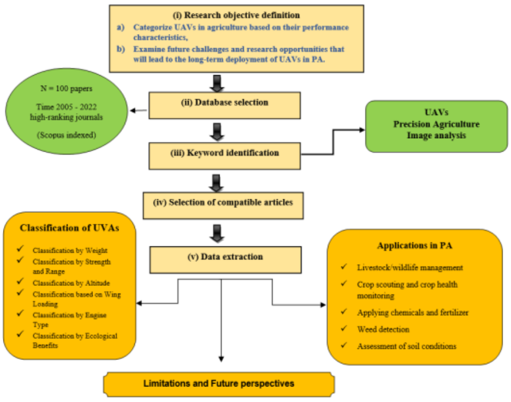

Figure 2: Study Methodology

3. Classification of UVAs

UAVs have been classified based on their various performance parameters. UAVs' major performance parameters are weight, endurance and range, altitude, wing loading, engine type, and power/thrust loading [15].

3.1. Classification by Weight

UAVs are available in a multitude of weights (Table 1). UAVs are classified as micro-UAVs, which weigh only a few grams, and super heavy UAVs, which weigh more than 11 tons [16].

Table1: Classification of Unmanned Arial Vehicles (UAV) by Weight [16].

Type of UAV	Range of weight (kg)	Examples
Super heavy	>2000	Global Hawk, X-45, Darkstar, Predator B
Heavy	200 – 2000	A-160
Medium	50 – 200	Raven, Phoenix
Light	5 – 50	RPO Midget
Micro	<5	Dragon Eye, FPASS, Pointer, Silent Eyes

3.2. Classification by Strength and Range

Strength and range are frequently related criteria that allow the type of UAV necessary to be chosen based on the distance between the goal and the launch location. It also controls refueling time and influences how long it takes the drone to complete its mission and how long it takes to stop. According to their strength and range, UAVs are classified into three classes [16].

Type 1- The long-endurance UAVs; this type of UAV can fly for 24 hours or longer. This sort of UAV has a long range as well. Predator B and Global Hawk, for example, have ranges ranging from 1500 km to 22000 km.

Type 2- The medium-endurance UAVs: UAVs with a medium endurance can fly for 5 to 24 hours. The range of this type of UAV ranges from 100 to 400 km. This is the most popular form of UAV, such as the Silver Fox, Dark Star, Predator, and Shadow 600 [4].

Type 3- The low-endurance UAVs: This type of UAV has a flight time of less than 5 hours. This type of UAV has a range of less than 100 km. These are mostly employed for brief missions, such as Pointer [16].

3.3. Classification by Altitude

Another performance metric used to categorize UAVs is maximum flying height or altitude (Table 2) [16].

Table2: Classification of Unmanned Arial Vehicles (UAV) by Altitude [16].

Type	Altitude (m)	Examples
Low	<1000	Pointer, FPASS, Dragon eye
Medium	1000 – 10000	Finder
High	>10000	Dark star, X-45, Predator B, Global Hawk

3.4. Classification based on Wing Loading

Wing loading is another UAV performance metric that may be used to categorize UAVs (Table 3) [6].

Table 3: Classification of Unmanned Arial Vehicles (UAV) by Wing Loading [6].

Type	Wing Load (kg/m^2)	Examples
Low	<50	Seeker, Dragon Eye
Medium	50 – 100	X-45
High	>100	Global Hawk

3.5. Classification by Engine Type

UAVs are utilized for a wide range of purposes. These activities necessitate the use of several sorts of engines. Turbofans, two-stroke, piston, rotary, turboprop, push and pull, electric, and propeller engines may all be found in UAVs (Table 4) [16]. Among the several types of engines, electric and piston engines are the most commonly employed in UAVs. Electric motors are commonly used in lighter and smaller UAVs. However, piston engines are commonly used in large and battle-ready UAVs. The kind of engine has a direct impact on a UAV's endurance and range [16].

3.6. Classification by Ecological Benefits

Focusing on the ecological benefits, UAVs can be classified into 4 types according to their size and power [6].

Large: This type of UAV has a 500 km operational range and a high endurance of up to 48 hours. The operational flying ceiling ranges from 3 to 20 km. Furthermore, this type of UAV, such as NASA Ikhana, can carry an extra 200kg as internal payload. Large UAVs have a number of operating limitations. The cost of acquiring, producing, and deploying this sort of platform is high, and ground operations are complicated [17]. It also necessitates significant setup and operating expenditures, ground station assistance, complete aviation clearance, a lengthy runway for takeoff and landing, and other requirements [6].

Table 4: Classification of Unmanned Arial Vehicles (UAV) by Engine Type [6].

Type	Examples
UEL Rotary	Outrider, Shadow, Shadow 600, Cypher
Turbofan	Global Hawk, Dark star, Phoenix, X-45, X-50, Fire scout
Two-Stroke	Pioneer, RPO Midget
Piston	Predator, Neptune, Dragon Drone, Finder, A 160, GNAT, Crecerelle, Seeker, Brevel, snow Goose, Silver Fox, Heron
Turboprop	Predator B
Electric	Dragon Eye, FPASS, Dragon Warrior, Pointer, Raven, Luna, Javelin
Push and pull	Hunter
Prop	LEWK, Sperwer

Medium: This type of UAV has a range of 500 km and a medium endurance of up to 10 hours. The operational maximum flight ceiling is less than 4 km. It can also carry a payload of 50 kg, such as NASA SIERRA. As with any big UAVs, there are operational restrictions. However, the total cost is cheaper than that of big UAVs, there are fewer takeoff and landing requirements, and it is easier to handle than large UAVs [5].

Small/Mini: This type of UAV has a range of less than 10 km and a battery life of only 2 hours. The operating flying ceiling is less than 1 km. The carrying capacity of small UAVs is 30 kg and less than 5 kg for mini-UAVs, such as the Quest UAV [4].

Micro/Nano: A type of UAV having a range of less than 10km and a battery life of only one hour. The operating flight ceiling is less than 250m. AR-drone Parrot [18] has a carrying capacity of 5 kg. Due to the high operational expenses of medium and large UAV platforms, they are unsuitable for the majority of agricultural applications. As a result, the majority of UAV applications and research activities in agriculture are presently being conducted using small, mini, micro, and Nano UAVs. It can fly autonomously, allowing it to acquire photographs with high spatial resolution. It also offers a short turnaround time, a low operational cost, and is simple to activate.

4. Applications in Precision Agriculture

Over the last few years, numerous scientific studies have looked into the capabilities of UAVs to provide data on a variety of precision farming applications, including livestock and wildlife management, crop monitoring, chemical and fertilizer application, weed detection, field mapping, and soil condition assessment.

4.1. Livestock/wildlife management – monitor the locations, status, and movement of animals over time

Traditionally, in livestock management, the locations, status, and movements of animals were determined by examining by a person [19]. Furthermore, in industrialized countries, this is accomplished by photographing from a low-flying light aircraft, which comes at a high cost. As UAVs and image analysis are used to this work, the cost will be reduced in the near future [20]. Drones offer a practical option for viewing animals from above, counting their numbers, and monitoring their movement [21]. Due to the difficulty of the human eye to see in the dark, unmanned aerial vehicles (UAVs) are beneficial for monitoring farm animals at night [22]. Drones have also been used to conduct large-animal surveys on land [5]. The majority of the research was done in Indonesia, Malaysia, Nepal, the Netherlands, and Switzerland to identify a variety of wild species in environmental studies, such as orangutans, elephants, and rhinos, in order to provide information on animal density and mobility [23]. Table 5 shows the many applications of UAV technology for livestock and wildlife management.

Table 5: Applications of UAV in Livestock/ wildlife management

Application	Research description	Research highlights	References
Wildlife Researches Species Identification	For the inspection and supervision of livestock remotely, drones with high interpretation thermal cameras have been used.	*India has affiliated with Tata Consulting Service (TCS) to carry investigations, detect unauthorized establishments and to interfere poachers in Kaziranga National Park with 480 km^2 (e.g., Eudocimusalbus, Alligator Mississippiensis, Trichechusmanatus).*	[24][25]
	Visual observation and surveying of animals, habitat sensing, and automated telemetry tracking.	Birds, large mammalian terrestrial herbivores, and marine mammals are the most observed animals.	[26]
		Using IoT and UAVs movement and habitat of wild animals that cannot be easily reached, have been observed.	[27]
Cattle Herd Monitoring	Tracking the quantity and activities of animals.	This is mostly useful in monitoring at night-time. Because humans cannot see well in the dark.	[28]
Head counting	Headcounts of cows and calves are taken by drones.	Taking headcounts of animals' innumerous classes as they are surge around the savannas.	[29]
Heat detection/ Calving management	Thermal cameras fitted in drones have been used to recognize heat signs of vulnerable one-horned rhino even if they are hiding in dense vegetation	Drones are capable of monitoring calving pastures by applying fewer burdens to the livestock.	[30]
Disease Detection	UAV centered remote sensing systems and thermal imaging were used to detect injuries in fawns in the pasture lands.	Mortality injuries of roe deer fawns (*Capreolus capreolus*) were a major problem in Israel. Because of mowing machinery and to avoid these accidents by using UAV Octocopter Falcon-8 and remote sensing analysis based on thermal imaging was hosted.	[31]
Farm management	Generating high superiority and modernized maps of huge farms using Drones.	Expansion of infrastructure, crop rotation, and grazing can be done by using Aerial maps.3D information (sward height) which was taken from the UASs has been used for meadow biomass modeling.	[32]

4.2. Crop scouting and crop health monitoring

Crop scouting is an integrated pest management (IPM) method for measuring pest pressure, generally from insects, and crop growth performance. This aids in calculating the economic risk posed by insect infestations and diseases [19]. The majority of agricultural pests (fall armyworm) are more common in tropical and subtropical climates. Following infestations, fall armyworms consume mainly the juicy portions of the leaves, particularly the main midribs [8]. Because of this tendency, the leaf area of such fields decreases considerably in a shorter period of time (Figure 3). This type of destruction may be evaluated using remotely sensed high-resolution images. Infected regions should show a reduction in NIR band reflectance. In addition, the red band's reflectance should be increased due to the loss of flag leaves, exposure of the soil surface, and shadows [8].

The most common use of drones in agriculture is to inspect ongoing crops with NDVI or NIR sensors [33]. The NDVI index has been used to assess the health of green vegetation. The post-processed high-definition images enable the exposure of a larger surface area in a field in a shorter period of time, as well as the collection of data that cannot be seen by the human eye [22]. Drones capture high-resolution images of crops, and the reflected intensities of near-infrared (NIR) and visible light are compared [33]. After examining the imagery, NDVI or NIR images may be required to extract human mistakes that may exist in traditional works [2].

A Research was conducted at Virginia Tech University to detect airborne diseases using UAVs [34]. Drones gather spore samples while flying in the lower atmosphere, and the samples are examined in a laboratory. Researchers determine where the spores are moving by analyzing data and observing weather trends [34]. Table 6 indicates that different UAV applications for crop monitoring and health assessment.

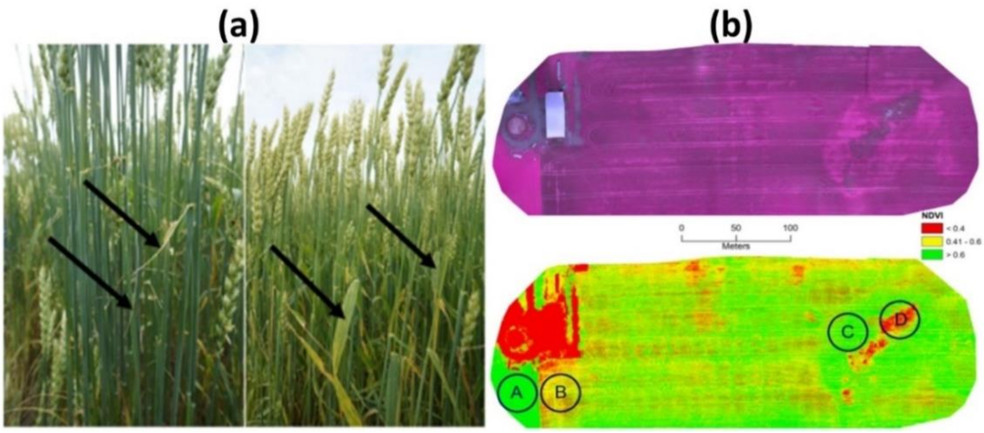

Figure 3: (a) The difference between flag leaf of the infested (left) and healthy (right) wheat plants; and (b) Mosaicked infrared color composite map and NDVI derived map of a wheat field located in Verner on Canada

Table 6: Applications of UAV in crop monitoring and health assessment

Application	Research description	Research highlights	References
Unsupervised detection of crops	A study conducted on the assessment of crop characteristics of a vineyard (row height, width, spacing, and percentage of missing) by using UAV imagery analysis.	The accurate revealing of vineyards from 3D point-cloud maps, created from UAV multispectral imagery, will act a vital role, e.g., both for accomplish upgraded remotely sensed data and to handle path and process of unmanned UAV. The good accuracy obtained in ground data and UAV imagery data.	[35]
To take field measurements	A study investigated to estimate crop height, crop cover and vegetation of eight different tomato varieties in the growing season by collecting RGB and multi-spectral UAV images.	Results highlighted that height could be highly accurate and crop cover was highly correlated with field-based data. Therefore, UAV is useful for the measurements of traits such as crop height, canopy cover and NDVI throughout the growing season of a particular crop.	[36]
For vegetation analysis	VTOL quadcopter UAV is used for the applications which required a closed examination of crops such as analysis of leaf area and leaf pests. Also, fixed-wing UAVs are used for the applications which required coverage of large areas such as discrimination of crop types and counting of trees.	Spectral-spatial classification methods can be used for the mapping of crop region and tree crown with the use of images acquired by UAV.	[37]
Crop mapping	The skip maps of sugarcane fields can be created by using images taken from UAV.	The application of UAV technology has optimized the surveying of skips in fields. The object-based image analysis (OBIA) method solves complications associated with UAV images through the creation of process trees. It allows a high level of automation and adaptability.	[38]
	An automatic identification method was applied for tobacco fields with the use of UAV images. For the purpose, it was combined with supervised classifications methods with image morphological operations. The study was conducted in Yunnan, China. A method based on the digital mosaics based on UAV images which produced a map of gaps in a pilot study in Nicaragua.	The overall accuracy of the proposed method was 95.93%. Calculated values of real field data and derived map data for plant gaps and crop planting quality was highly correlated.	[39,40]
Crop Health Monitoring	Images acquired from Unmanned Aerial Systems were used to generate Multispectral Imaging and Elevation Mapping. Those are valuable data sources for Precision Agricultural applications.	Monitoring of crop health in mid-season. It was used NDVI maps to inspect and assess immature crops.	[30]
Estimate crop emergence	RGB images were acquired through UAVs to develop a system to estimate crop emergence of potato with the from the image analysis	This method is an efficient way to estimate crop emergence due to the results indicated higher accuracy (r^2 =0.96) with the comparison to manual assessment.	[41]

Table 7: Applications of UAV in chemical and fertilizer applications

Application	Research description	Research highlights	References
Variable-Rate Fertility	Fertilizer requirement could be determined by developing variable-rate application (VRA) maps from drones.	VRA maps used to determine the struggling areas which required the application of more fertilizer and healthy areas which required the application of less fertilizer. Finally, this allows decreasing the cost of fertilizer and boosting the yield.	[30,45]
Crop spraying	A research study conducted to develop a methodology to spray agrochemicals onto rice fields.	Effective Spray application pattern gives the manipulation of the flying path and swath width. UAVs could be used for successful crop spraying conditions.	[46]
Crop sprayer development	A drone-mounted sprayer developed to evaluate the field routine of groundnut and paddy crops.	This method would be useful to chemical spray for crop field areas which are not possible to spray with human interventions.	[2]

4.3. Applying chemicals and fertilizer

Drones have the ability to spray insecticides, weedicides, and fertilizer to agricultural areas [42]. Spraying agrochemicals on crop fields, for example, is now done using small planes piloted by humans or by hand walking through the fields [43]. In the future, drones may be employed to spray fields [7]. Furthermore, most farmers are frequently lacking in data to determine the number of agrochemicals truly required for a crop or whether spraying is absolutely necessary [44]. Drones will not eliminate the need for chemicals, but they may reduce the quantity of chemicals used since drones can inspect crops and identify the real demand for chemicals. This might reduce production costs [23] (Table 7),

4.4. Weed detection

Weed maps may now be created utilizing images captured by NDVI compatible sensors and image pre-processing [19]. Farmers may readily differentiate high-intensity weed proliferation areas from healthy crop areas in agricultural fields using the data [22]. Many research studies have been conducted on the use of UAVs for agricultural monitoring in various countries across the world. Table 8 summarizes various research studies on the use of unmanned aerial vehicles (UAVs) in weed management.

Table 8: Applications of UAV in weed detection and control

Application	Research description	Research highlights	References
Invasive Species Identification	Generate a weed map to identify invasive species (weed infestation) by using UAV image processing and NDVI sensor data.	Developed weed map that enabled farmers to separate areas with weed infestation and adjoining areas with healthy crop growth. Subsequently, it is possible for farmers to selectively spray pesticides only on areas having problems, which minimized environmental damages and cut down of costs.	[30]
Crop–weed discrimination	A model developed to detect weed in crop fields through the drone images.	The developed model has the ability to assess crop-weed discrimination in crop fields.	[47]
Weed mapping	UAV images collected to develop a weed cover map through the ortho-mosaic images over a rice field.	The proposed Fully Convolutional Network (FCN) method has high effectiveness and accuracy. Therefore, it would be used for weed mapping.	[48]
	A study to test the capability of UAV imagery to measure weed densities by mapping a grass weed, *Alopecurus myosuroides*, in wheat crops	Field reference and image processed weed densities were highly correlated	[49]

4.5. Assessment of soil conditions

Soil maps created using high-resolution sensors may be used to detect soil types, organic matter levels, and soil moisture levels in an agricultural area [50],[7]. If this could be done with typical soil samples, a significant number of samples would be necessary to achieve the same resolution across the area. It is also time-consuming and expensive [18]. Soil conditions are extremely important for adjusting irrigation and fertilization of field conditions that rely on weather and wet areas [35]. Many research investigations indicated that UAVs would be employed for a variety of soil evaluation applications (Table 9).

Table 9: Applications of UAVs for soil assessments

Research Application	Research Description	Research Highlights	References
Soil mapping	A novel methodology develops to determine soil sample locations by using created soil maps based on an acquisition of drone images in southern Finland.	Color maps of soil could be created for bare field plots by using UAV based imaging technology. In this study, a topsoil map was created for the objective of management of fields from ploughing to soil sample analysis.	[51]
Classification of soil characteristics for ploughing	A novel approach developed to identify different soil characteristics with different ploughing techniques by using an RGB-D sensor.	Research results revealed that the developed approach could be used to classify different ploughing depths of the fields.	[33]
Volumetric assessments of soil erosion	Research conducted to develop a methodology for volumetric asses-sments of soil erosion in rill by using UAV based images in the Central Bohemian Region. Arc GIS software was used to develop volumetric assessments of soil erosion.	A Digital Surface Model (DSM) was developed by using UAV photogrammetry for the calculations of volumetric assessment in larger areas such as; agricultural fields, catchments, or extensive gullies.	[52]
Monitoring Soil Erosion	A study conducted to develop a classification of soil eroded gullies on a large area in South Morocco by using UAV based systems.	Digital Terrain Models (DTMs) and ortho-image mosaics were created by using UAV based image processing and created models were used to monitor and quantify the gully and soil eroded lands in a large extent of fields.	[53]
Determination of Soil moisture content	A methodology developed to identify soil moisture content of topsoil by using UAV hyperspectral images in arid regions of Xinjiang, China.	High accuracy UAV images were used to develop spectral indices and prediction models. Results exhibited that pre-processed spectral indices and machine learning algorithms permit estimation of SMC precisely on the regional scale.	[54]

5. Limitations

Although there is a growing interest in employing UAVs in precision agriculture, there are significant restrictions [55]. The period of data gathering in UAVs is long, and it is necessary to choose the time of day and frequency to suit. They are technically flexible, but their higher initial cost is a practical constraint for small-scale farmers [56]. Sometimes satellite data often miss important time-windows [57]. Drones used in agriculture (Nano, Mini, and Micro) cannot be used to deliver large quantities and they would carry only small amounts [43]. The main limitations of agricultural drones are their high cost, payload, and reliability for practical agricultural usage [21]. Small UAV technical restrictions include engine power limits, limited flight time, trouble maintaining flying altitude, aircraft stability, and mobility due to winds and turbulence [58].

Although the plane and the camera are inexpensive, the costs of assembly and integration of the plane are significantly higher because it necessitates the hiring of highly trained technicians and engineers. The sensor payload is limited if they employ low-cost UAVs. Furthermore, they are not as stable as high-end sensors. Because low-cost UAVs are often built with lightweight engines, their maximum flying height is limited [59]. Furthermore, it will diminish image quality, and the most significant constraint in agricultural applications is the lightweight drone payload. A UAV's payload weight restriction is typically 20–30% of the overall weight of the UAV. Payload design, as well as electrical and mechanical drone accommodation, is key elements for successful agricultural applications. Drone mishaps and component failures are driving up the price of agricultural drones and limiting their availability [21]. In addition, a drone cannot be used to collect photographs in inclement weather such as rain or strong winds. Drones can potentially be damaged by external factors like bird strikes and other unmanned aerial vehicles (UAVs) [60].

Furthermore, there are several recognized problems with utilizing cameras in drones with zoom lenses, such as limitations in optical quality, completely automated focus operations, and, most significantly, a lack of a near-infrared (NIR) band for vegetation surveys. There are small UASs with multi-spectral cameras that include the NIR band, although they are currently rather costly [61].

Because of the low flight altitudes of UAVs, significant geometric distortions can develop.

Furthermore, low flight altitudes produce a huge quantity of UAV images for a particular field. Furthermore, as a technical issue with recorded images, the forward-image motion of the UAV camera may result in blur. Oversampling is often used to compensate for the issue. However, it causes an increase in data volume [62].

UAV-based applications confront the same difficulties as those based on traditional aerial and satellite imaging. Equipment calibration, atmospheric error correction, line-shift correction, and band-to-band registration are only a few of the significant problems [24]. Despite the fact that precision agriculture is becoming increasingly widely used throughout the world, remote sensing applications in agriculture are still underutilized.

The regulations governing the use of UAVs are currently lacking. Flying of UAVs is also prohibited in some areas owing to security concerns. As a result, the frequency of flying UAVs must be carefully planned. The most significant barrier to the deployment of UAVs in environmental and agricultural applications is the aviation sector's regulations. These rules are relatively lax in certain nations. In Germany, for example, no authorization is necessary to operate a UAV weighing less than 5 kg, and the field must be 1.5 kilometers away from residential areas and airfields [19]. In the United States, however, each UAV flight requires a Certificate of Authorization (COA) and a substantial ground crew during the operation. In Canada, an annual Special Flight Operations Certificate (SFOC) is necessary, and some training in UAV management is strongly recommended [63]. Insurance is necessary in the case of a UAV platform failure, in addition to the certificate, because such failures may cause injury to persons, livestock, or property. Failures can occur when a UAV loses control due to a system fault or signal loss [64].

6. Future perspectives

Agriculture UAV applications are still in their early phases. There is much space for advancement in both UAV technology and the much potential of UAV uses in precision agriculture [64]. The enhanced mapping between UAV images and ground data, as well as the flexibility of data gathering and the relatively low cost, are the major elements that motivate others to consider UAV as a significant instrument in future precision agriculture attempts [24].

This will strengthen the integration of UAV in PA applications and consequently accelerate the evolution of technology development. The motivations for future UAV applications largely depend on the further improvements of UAV design, comparatively lower system prices, methods and procedures on enhanced image acquisition and processing, flexible regulations on agriculture and environmental applications, and availability of practical information dissemination system for farmers [66].

Furthermore, drones may be utilized to swiftly transport harvested goods from the fields to the warehouse for packing and delivery, using less fuel and people. Drones can also be utilized to transport things to the market and lower product pricing [43]. In the next years, more durable and powerful UAV platforms with advanced camera technologies such as NIR and automated geo-referencing techniques are likely to strike the market [67, 68].

Currently, many research groups and companies are working together on exploring the improvements of image pre-processing and processing which is a mandatory requirement for other applications. Most time-consuming steps are ortho-rectification and mosaicking, and new approaches that require little or no ground control are needed [69]. There are designs and development of a seeders system that is coupled with UAVs that is the spatial positioning and propulsion system. This seeder system will deposit seeds with accurate distances pre-established between plants [70,71,72]. UAVs have the potential to be a valuable tool for evaluating and monitoring rangelands and other natural resources [51]. As technology progresses and smaller and lighter multispectral and hyperspectral sensors become accessible, UAVs will become more common in natural resource applications [73].

7. Conclusions

UAV classification, models of agricultural UAVs, and control systems were addressed. Subsequently, agricultural UAV applications such as mapping, spraying, planting, and monitoring were reviewed and identified comprehensively. We also discussed over the constraints (such as battery life, the number of UAVs, and user interface), potential applications (such as harvesting, AI-based precise mapping, and developing countries), challenges and technological advancements in depth. Further, this research offers a glimpse at UAVs, which have a wide range of potential applications. As a result, future agricultural UAV research, markets, and applications will benefit from this study.

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