Chapter 6

Sky-Farmers: Applications of Unmanned Aerial Vehicles (UAV) in Agriculture

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Additional information is available at the end of the chapter

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Abstract

Unmanned aerial vehicles (UAVs) are unpiloted flying robots. The term UAVs broadly encompasses drones, micro-, and nanoair/aerial vehicles. UAVs are largely made up of a main control unit, mounted with one or more fans or propulsion system to lift and push them through the air. Though initially developed and used by the military, UAVs are now used in surveillance, disaster management, firefighting, border-patrol, and courier services. In this chapter, applications of UAVs in agriculture are of particular interest with major focus on their uses in livestock and crop farming. This chapter discusses the different types of UAVs, their application in pest control, crop irrigation, health monitoring, animal mustering, geo-fencing, and other agriculture-related activities. Beyond applications, the advantages and potential benefits of UAVs in agriculture are also presented alongside discussions on business-related challenges and other open challenges that hinder the wide-spread adaptation of UAVs in agriculture.

Keywords: agriculture, crop production, farming, livestock, unmanned aerial vehicles

1. Introduction

An Unmanned Aerial Vehicle (UAV) is a type of aircraft that operates without a human pilot on-board. There are different types of UAVs employed for different purposes. Originally, the technology was employed by the military for anti-aircraft target practice, intelligence gathering and surveillance of some enemy territories. The technology has however grown beyond its initial purpose and in recent years has gained prominence in different spheres of human endeavor. Advancements in technology has allowed for the increased adaptation of unmanned aerial vehicles for various purposes. Without an on-board pilot, UAVs are controlled either remotely by a pilot at a ground station or autonomously, steered by a pre-programmed flight plan.

There is a huge potential for the application of UAVs in Agriculture. One such application is in accurate and evidence-based forecasting of farm produce using spatial data collected by the UAV. UAVs also allow farmers to observe their fields from the sky. This sky-view can reveal many issues on the farm, common among which is irrigation related problems, soil variations, fungal and pest infestations. Further information relating to water access, changing climate, wind, soil quality, the presence of weeds and insects, variable growing seasons, and more can all be monitored with UAVs. From a livestock perspective, UAVs are being used to perform head counts, monitoring animals and also studying eating habits and health related patterns. Utilizing the information gathered, farmers can provide fast and efficient solutions to detected problems and issues, make better management decisions, improve farm productivity, and ultimately generate higher profit. In this chapter, various applications of UAVs in Agriculture are discussed both in commercial livestock farming and crop farming. This chapter also presents some of the open challenges to the application of UAVs in Agriculture.

Immediately following this introduction is a discussion of the various types of UAVs which is done in Section 2. This is followed by the applications of UAVs in crop farming and in livestock in sections 3 and 4 respectively. Advantages of UAVs and corresponding challenges are discussed in Section 5, the chapter ends with the 6th and concluding section.

2. Types of UAVs

UAVs can be classified based on usage, with some being used for photography, aerial mapping, surveillance, cinematography etc. However, a better classification can be made based on their feature sets. Vroegindeweij, et al. in their paper [1], presented an overview of the different types of UAVs applied in Agriculture and categorized them into three main groups – fixed-wing, Vertical Take Off and Landing (VTOL) and bird/insect. The authors identified the VTOL with its agility, great maneuverability and hovering ability as best suited for Agricultural application. In [2], the authors however argued in favor of the fixed-wing UAVs, stating that their long flight time and speed makes them better suited in comparison to the VTOL, which have comparatively shorter flight time and slow speed. In other works, authors have argued in favor of unmanned helicopters such as the monocopter or single-rotor UAV [3, 4]. These types of UAVs have long flight time, can fly at different altitudes and have good hovering abilities. However, they are much more complex to fly. A comprehensive survey of various UAVs was also done in [5]. From these literatures, four major types of UAVs are identified, which are:

1. Multi-rotor UAVs
2. Fixed-wing UAVs
3. Single-rotor Helicopter
4. Fixed-wing-multi-rotor Hybrid UAVs

2.1. Multi-rotor UAVs

These are the most common type of UAV, evident by their wide popularity among professionals and hobbyists alike. They find applications in photography, aerial video surveillance, recreational sports and games etc. They are the easiest to manufacture and also the cheapest type of UAV. Multi-rotor UAVs are further classified based on the number of rotors on the platform. There are those with three rotors called tricopter, with four rotors called quadcopter, with six rotors called hexacopters and those with eight rotors called octocopter. Flying a multi-rotor UAV does not require exceptional skill unlike the other types of UAVs.

Multi-rotor UAVs though cheap and easy to manufacture have a few drawbacks which include: limited flying time, endurance and speed. They can only sustain an average flying time of between 20 and 30 minutes. This is because a large percentage of their energy is expended fighting gravity and wind to remain stable in the air. **Figure 1** shows an octocopter used for precision spraying of liquid pesticides and herbicides.

2.2. Fixed-wing UAVs

These types of UAVs have wings similar to normal aircrafts. Unlike the Multi-Rotor UAVs, they do not exert a lot of energy to stay afloat in the air, hence able to fly longer; having average flight times of over an hour. Longer flight time makes them most ideal for long distance operations. However, they cannot hover on a spot and are thus not suitable for aerial photography. Furthermore, they are more expensive and require exceptional flying skill to operate. **Figure 2** shows a sample fixed wing UAV used for capturing images across large acres of farmland.

2.3. Single-rotor UAVs

Single rotor UAVs are also called monocopters and look very much like helicopters in design and structure. Though they are called single rotor UAVs, they actually have two rotors - a large on top and a smaller one at the tail. The bigger rotor is for lift while the smaller is

Figure 1. Multi-rotor UAV [6].

Figure 2. A fixed-wing UAV [7].

used for control. They have significantly longer flying time than their multi-rotor counterpart, as they are often powered by gas engines. These UAVs are also highly maneuverable and much more efficient than the multi-rotor types. Similar to the multi-rotor, they are also able to hover, hence useful for aerial photography and precision spraying. Despite these beneficial attributes, they come with higher operational risks as the large sized rotor blades usually pose a risk which is mostly fatal in nature. Like the fixed wing UAVs, these also require special flying training. **Figure 3** shows a sample single-rotor UAV.

2.4. Fixed-wing-multi-rotor hybrid UAVs

These types of UAV combine features of the fixed-wing and the multi-rotor UAVs, with the hybridization gives these UAVs a best-of-both-worlds feature set. They are able to perform vertical take-off and land (VTOL) as well as hovering in place like the multi-rotor and single-rotor. Similar to the fixed-wing and single-rotor UAVs, these also benefits from long flight-time, but can stay in flight for much longer. **Figure 4** shows an image of one such UAV that is versatile enough to be used for image capturing, surveillance as well as precision spraying.

Figure 3. A single-rotor UAV [8].

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Though these are the four common types of UAVs, there is a unique type of UAV called the Flexible Membrane Wing (FMW) UAV [10]. The FMW has wings made from flexible membrane material, with the advantages of this being easy of storage (as the wings can simply be folded up) and better control and maneuverability in windy conditions (as the flexible wings dynamically adjust to cater for wind preventing "adaptive washout"). The FMW is a niche UAV, targeted flying in harsh and windy conditions. Flexible membrane also implies lighter weight and by extension the possibility of carrying larger payloads.

2.5. Comparison of various UAVs

Figure 5 shows a comparison of the four different types of UAVs based on their average weights, payload size and flight time; **Table 1** on the other hand summarizes their in-flight specifications. For each category, a model UAV was selected. The values shown were obtained from the respective manufacturer documentation and/or operator's manual of each product. On **Table 1**, the advantage of the hybridization can clearly be seen, as it resulted in

Figure 4. A hybrid fixed-wing-multi-rotor UAV [9].

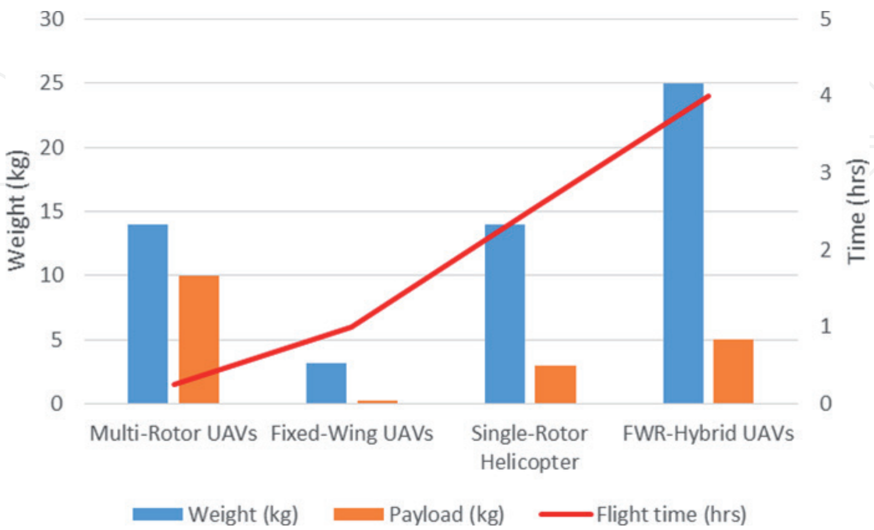

Figure 5. UAV weight and payload vs. flight time.

UAV type	Altitude (km)	Avg. control range (km)	Avg. airspeed (m/s)
Multi-rotor UAVs (DJI Agras MG-1P [6])	2	3–5	7
Fixed-wing UAVs (AgEagle RX60 [7])	0.125	2	18.8
Single-rotor (Alpha 800 [8])	3	30	15.2
Fixed-wing-multi-rotor hybrid UAVs (Jump 20 [9])	4	500–1000	30

Table 1. Feature-based comparison of UAVs.

higher flying altitude, wider control range, increased speed and longer flight time compared to the other UAV types.

3. UAVs in plant/crop farming

According to Massachusetts Institute of Technology (MIT), UAV technology will give the Agriculture industry a high-technology makeover, with planning and strategy based on real-time data gathering and processing. PwC put a $32.4 billion valuation on the UAV-powered Agriculture solutions market [11]. The application of UAV technology in Agriculture has become increasingly necessary with the increase in global population and the resultant pressure on agricultural consumption. The ever growing international population is not proportionately matched with crop growth; hence, there is a growing concern about food sustainability. In a bid to tackle this challenge, farmers around the globe have had to adapt modern and automated solutions in order to keep up with the agricultural needs of the world population that is in constant flux. UAVs are one such technology that could help improve crop yield. A number of UAV application areas are presented in the following subsections.

3.1. Soil and field analysis

The use of UAVs for soil information sourcing is helpful at the early start of a crop cycle. The data collected helps in early soil analysis, and is also useful in planning seed planting patterns. These data can also assists the farmer in making irrigation plans as well as determining the quantity of fertilizer needed on the soil or field after planting. Using a data-driven approach, the farmers can improve the overall yield quantity of agricultural produce, while significantly saving on fertilizers and pesticides. All these are made possible through the analysis of remote images captured with UAV. UAV imagery also has a huge potential in designing site-specific weed control treatments. With the high resolution images, farmers can quickly and precisely spot weeds almost immediately they spring up and apply minimal pesticide to contain them. The authors in [12] developed an Object-Based Image Analysis (OBIA) on a series of UAV images using six-band multi-spectral cameras on a maize field in Spain. While in [13] the technical specifications and configuration of a UAV which could be used to capture remote images for Early Season Site-Specific Weed Management (ESSWM) were given. The study also evaluated the image spatial and spectral properties necessary for weed seedling discrimination. They deployed an UAV equipped with multi spectral cameras and analyzed the technical specifications and configuration of the UAV to generate images at different attitudes; with the high spectral resolution required for the detection and location of weed seedlings in a sunflower field. The result of the study can be of help in the selection of an adequate sensor and configuration of the flight mission for ESSWM.

3.2. Planting

Planting crops is a costly and cumbersome endeavor that has traditionally requires a lot of manpower. UAVs have simplified crop planting for farmers, with their abilities to cover large acres of land within a short period with utmost precision and accuracy. Today's high-end UAV farming technology offers UAV-powered planting techniques that reduce planting costs by up to 85%. The reduction in planting costs is a result of the UAV's capability of performing multiple tasks at the same time.

UAVs have become increasingly popular in recent years in agricultural research applications. They have been found to have capabilities of acquiring images with high spatial and temporal resolutions in Agriculture. Reference [14] evaluated the performance of a UAV-based remote sensing system for quantification of crop growth parameters of six sorghum hybrids. Factors such as Leaf Area Index (LAI), fractional vegetation (fc) and yields were considered. The evaluation was carried out using a fixed-wing UAV, equipped with a multi spectral sensor to collect images during the 2016 growing season with flight missions carried out 50 days after planting. The flight missions provided data covering the different growth periods of the sorghum hybrids. The authors inferred that high resolution images acquired using UAV can be effectively utilized for in-season data collection from the field. The results obtained proved the relationship between Normalized Difference Vegetation Index (NDVI) and LAI, and between NDVI and fc. It was thus possible to determine/estimate LAI and fc from UAV derived NDVI values. It was shown also that imagery taken at flowing stage could be better indicator of yield, rather than NDVI obtained at earlier growth stage of sorghum crop. Furthermore, it was also established that early season NDVI measurement is useful index for estimating plant population density of sorghum.

The authors in [15] sought to develop a novel method to quantify the distance between maize plants at field scale using an UAV. The distance between roots and plants are essential in determining the final grain yield in row cops. An UAV-based image algorithm was developed to calculate maize plant distances. Knowledge of the exact number of plants per square meter is essential and helps to improve yields by deducing the fertilizer and pesticide application to match plant demand. Determining plant population is essential for several other processes such as soil-to-plant balance, nutrient recycling and resource use efficiency. The study demonstrated the possibility of quantifying the distance between maize plants and provided an innovative approach to quantify plant-to-plant variability and by extension crop yield estimates.

3.3. Crop and spot spraying

Crop spraying is usually a tough and onerous task for farmers and agricultural production companies. It involves covering extremely large expanses of land comprehensively to ensure proper growth of crops. Agricultural UAVs have simplified crop spraying for farmers; as they can cover large expanse of land within a very short time interval. Using sensors, UAVs can automatically adjust their height when spraying across uneven fields. This improves the spraying accuracy and conserves resources. The advantages of using UAVs for crop spraying include: time and cost savings for the farmer, efficient spraying as both the plants and the soil below can be reached, and protecting farmers from prolonged exposure to potentially harmful chemicals that are hitherto associated with manual spraying. Agricultural UAVs utilize state-of-the-art topographical scanning techniques to dispense the optimal amount of fluid required for proper crop growth. This ensures even coverage with limited wastage. Lv et al. [16] demonstrated the practicability of infrared thermal imaging in evaluating the droplet deposition in the field of aerial spraying. In the study, the effect of UAV flight speed on the spray droplets was investigated and the variable spray test was conducted by a UAV simulation platform, with airborne spray system under controllable environment. Several conclusions were drawn from the study among which were that deposition density decreases with the flight speed and droplet diameter (i.e. the distribution uniformity of particle size) decreases with an increased flight speed resulting in the worse uniformity of the sprayed droplets. The authors therefore provided a theoretical support for optimizing the spraying parameters of plant protection UAV, aimed at improving plant yield.

Spot spraying is similar to crop spraying but targets weeds. With the use of high resolution cameras, the UAV can identify weeds and precisely spray a jet of herbicide. Spot spraying can save up to 90% on chemical herbicides. Numerous research works [17–19] have been done in determining the efficacy of UAVs for spot spraying. Some factors considered were balancing UAV altitude and speed with spraying height and accuracy as well as droplet sizes, spray pressure and the possible effects of the UAVs' propeller(s) airflow direction.

3.4. Crop monitoring

A combination of large farm fields and low efficiency in crop monitoring system are some of the greatest farming challenges. The challenge of monitoring is further aggravated by unpredictable weather conditions, which drive up risk and field maintenance costs. An agricultural UAV helps the farmer overcome some of these challenges. UAVs with thermal imaging cameras enable the farmer to monitor his farm. The farmer can check the state of crops in the farm, as well as areas that need urgent attention. The result is improved yield and greater profit. [20] demonstrated the possibility of generating quantitative mapping products such as crop stress maps from UAV images and highlighted the value of UAV remote sensory when applied in precision Agriculture. The study applied a single-rotor UAV (monocopter), equipped with multiple spectral cameras, and then developed a framework to process the UAV images and generate mosaic images which can be aligned with maps for GIS integration at a later stage.

3.5. Irrigation

Agricultural UAVs fitted with thermal imaging cameras have the capability to providing tremendous insights into specific troubled areas in the farm. Using the thermal cameras, the farmers are able to determine areas with low soil moisture, pinpoint crops that are dehydrated, locate areas that are water-logged and in general have a sense of the overall health status of crops in the field. Such precise and specific monitoring were either not possible with traditional farming, inefficiently done or extremely expensive as experts have to be contracted to carry out the task and proffer adequate solutions. UAVs now give the farmers that ability to do these themselves. In [21], the authors carried out a study on vineyard water status variability by thermal and multispectral imagery using an UAV. Assessment of the water status variability of a commercial rain-fed Tempranillo vineyard was done, and concluded that an UAV can be used to assess vine water status, and to map within vineyard variability which could be useful for irrigation practices. The work done in [22] focused on the application of thermal remote sensory in precision Agriculture, and some of the concerns relating to its application. Gonzalez-Dugo et al. [23] further dealt with the assessment of heterogeneity in water status in a commercial orchard as a prerequisite for precision irrigation margent. High resolution airborne thermal imagery was employed. A UAV with thermal camera on board was flown three times during the day over a commercial orchard; and the indicators derived from the thermal imagery described the spatial variability in crop water status and thus allows the mapping of an orchard on a tree by tree basis. It therefore becomes a valuable tool for water management in precision Agriculture.

3.6. Health assessment

Farm health assessment is crucial for detecting fungal and bacterial diseases on the farm. By scanning a crop using both visible and near-infrared light, UAV-carried devices can detect temporal and spatial reflectance variations and associate it to the farms health for early interventions, which ultimately saves the entire farm. These two possibilities increase a plant's ability to overcome disease. And in the case of crop failure, the farmer will be able to document losses more efficiently for insurance claims. UAVs offer new and modern methods of accurately monitoring and assessing pest damage needs to be investigated. The authors in [24] explored the combination of UAVs, remote sensory and machine learning techniques as a promising technology to address the problem of agricultural pests in farmlands. UAV platform was deployed over a sorghum crop in South-East Queensland, Australia, to collect high resolution RGB images of certain areas which were severely damaged by white grub pest. An image processing pipeline was implemented prior to image analysis. The study demonstrates how UAV-based remote sensitivity and machine learning could be used to achieve biosecurity surveillance and pest management. The work presented in [25] also corroborated the use of UAV in crop health assessment, and outlined the benefits of deploying UAV remote sensing over the traditional methods. They developed a method that can quickly monitor crop pest, based on UAV remote sensing, which was deployed for inspection pests in Baiyangdian agricultural zone during the growth season. An improved SIFT Algorithm was adapted for image matching and mosaic with good result. The method adopted by [24] was used to check the status information of crop pest. Similarly, in the work done by Yinka-Banjo et al. [26], the authors proposed the use of UAVs for bird control in farmlands. Their solution combined the use of autonomous vehicles with bird scare tactics. The combination was reported to be more efficient than the traditional human-based manual approaches.

4. UAVs in livestock farming

Livestock farming is the act of rearing animals for food and/or other uses such as medicine, leather, fur and fertilizer. The authors in [27, 28] showed that traditionally Livestock Production Systems (LPS) were grouped into three major classes, namely: livestock production integrated with crop, land based and agro-ecological. They further sub-divided LPS into 11 groups – solely livestock production, temperate and tropical highlands grassland-based, arid and subtropics grassland, humid and subtropical mixed-farming based, temperate and tropical highlands rain-fed mixed farming, humid and subtropics rain-fed mixed, temperate and highlands irrigated mixed farming, humid and subtropics irrigated mixed farming, arid and subtropics irrigated mixed farming, landless monogastrics and landless ruminant farming. Similarly, in [29], the authors reviewed five (5) types of livestock production systems in tropical areas based on factors such as agro-ecological zones, animal type, function and management. The identified classes were Pastoral Range, Crop-livestock (low and highlands), Ranching and landless.

With respect to livestock, sheep and goats are the most farmed animals, followed by cattle. **Table 2** shows a numerical distribution of global livestock produce adapted from [30].

Livestock farming as with other aspects of Agriculture can be monotonous and laborious. Humans are however not well suited to such task over a prolonged period of time. Machines therefore can find practically applications in this arm of Agriculture, as they are designed to perform repeatable tasks, faster and possibly more efficiently (over a long period of time) than humans can. UAVs are therefore no exceptions and have found practical applications in livestock farming. Applications of UAVs in livestock farming are discussed as follows:

Animal type and/or produce	Number/quantity (10^6)
Animal	
Sheep and goats	1777
Cattle and buffaloes	1526
Animal produce	
Milk	594.4
Pork	95.2
Poultry meat	73.7
Beef	60.7
Eggs	58.9
Mutton	11.9

Table 2. Global livestock produce.

4.1. Livestock censors

To further put **Table 2** in perspective, according to the National Development Agency of South Africa, there were over 13 million units of cattle, 30 million sheep and 6.6 million goats and 1.6 million pigs bred in each province annually between up on to 2003. The figures are even significantly higher in European countries according to Eurostat. These are staggering numbers, hence monitoring and daily head counts of these large number of animals can be challenging. UAVs can thus find application here and be used to perform headcounts of livestock across these large grazing areas [31–33]. Animal counting can be done either by using image recognition [31] or using heat detecting infra-red cameras [34]. For image processing, Convolutional Neural Network (CNN) has emerged in recent times as the most widely used [35]. In large grazing areas, the UAVs can also be used to detect and count the number of animals present. In most of these works, the UAVs fly across the field, and counting the number of animals present. In the work done by [33] however, the authors proposed an approach, wherein the number of goats are counted and tracked using fewer numbers of pictures, sometimes only one. The authors reported 73% count accuracy and 78% tracking accuracy.

In contrast, in their book [34], the authors reviewed numerous methods of performing thermal imaging for monitoring animals in the wild. Among many other factors, the authors argued that thermal imagining is not dependent on time of the day unlike image processing. This therefore provides a unique opportunity to observe animals in their natural habitats without causing disturbances – which can lead to dispersion and possibly double or inaccurate counts.

4.2. Animal health

Beyond counting, research work is underway at the Texas A&M University, to investigate the use of infra-red cameras mounted on UAVs to monitor the health of animals. The research is based on the premise that, animals with fever tend to have heightened temperature. This can easily be detected by the UAV and appropriate medication can be administered [36]. Similar research targeted at monitoring health has also been carried out in [37]. **Figure 6** shows a sample heat map of a herd of cattle captured by a UAV.

4.3. Monitoring and identification

On an individual levels, animals can be tagged with RFIDs or similar sensors and can then be monitored using UAVs. With this, farmers can effectively monitor the movements and feeding behavior of a specific animal [38]. This has also been extensively used in monitoring endangered animals, raised in captivity and released into the wild. Similar to the two application areas discussed above, the identification can be carried out using UAVs fitted with normal cameras or IR cameras (which detect heat emissions from the animal) or RFID readers.

A major challenge to the application of RFID is that passive RFID tags have very short range, hence might be difficult to use. Potential solutions might include:

1. Painting QR codes on cattle, which the cameras fitted on the drone, can simply scan in order to identify the animal.
2. The use of a relay drone, such as the RFly being researched at MIT [39]. The RFly acts as a relay between the RFID tags and the reader. Using RFly, the authors recorded up to 50 meter range extension for passive RFID tags.

These technologies can be borrowed and used for animal identification and monitoring in Agriculture.

Figure 7 shows a potential use case of UAVs and RFID tags in animal identification.

4.4. Aerial mustering

Mustering is the process of using aircraft to locate and gather animals across a large span of land. Dogs (sheep dogs) and human on horses (cow boys) or motorcycles have traditionally been used to direct livestock along specific paths. For larger expanse of land, small sized helicopters are used. These helicopters are often piloted by one person and have highly

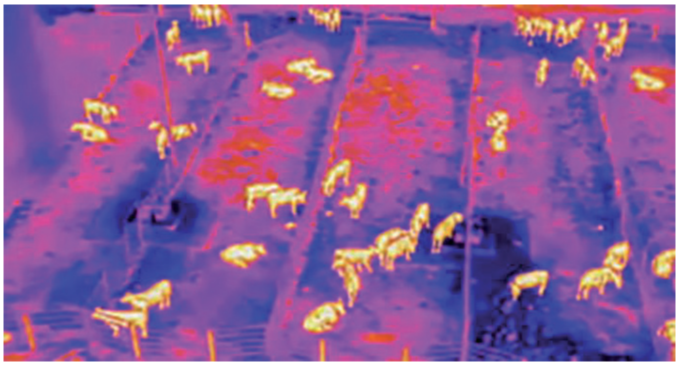

Figure 6. Heat map of herd of cattle [36].

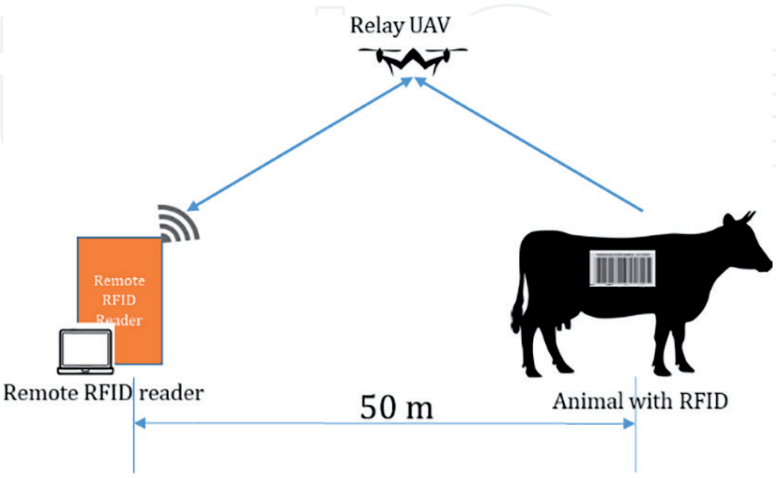

Figure 7. Animal identification using relay UAVs.

maneuverable and agile. The challenges with the use of helicopters are the need for extensive training, the cost of licenses and certifications, the cost of fuel and most especially the high level of risk exposure and casualties associated with it.

UAVs provide a unique opportunity for aerial mustering as they are comparatively risk free, cheaper to fly and require shorter training period, yet able to achieve similar results. UAVs have successfully been used in Australia and New Zealand to muster sheep and cattle [40]. According to [41], aerial mustering UAVs are fitted with sirens to herd sheep, deer and cattle. The UAVs can also be used to guide the animals to feeding, drinking and milking areas. Numerous case studies of the application of the DJI Phantom in Agriculture are given in [41]. **Figure 8** shows a use case of UAVs for sheep mustering.

4.5. Geo-fencing and virtual perimeter

Geo-fencing, virtual perimeter or geo-zoning simply means creating a virtual barrier or perimeter around a geographical area of interest [42, 43]. It has also been defined as an enclosure, or a boundary without the use of physical barriers. It can be accomplished by using a combination of RFID, LoRaWAN and GPS based location sensors for instance. Sensors obtain the location of the subject of interest relative to a map. Geo-fencing has been used in numerous fields such as fleet management and logistics – to monitor movement of vehicles, proximity marketing – which prompt users of products when they are close enough, asset management – which send alerts when an asset is moved without authorization, people monitoring – such as in monitoring movement of children and employees and in law enforcement – to restrict and/or monitor persons of interest.

Figure 8. Aerial mustering using a UAV.

Figure 9. A virtual fence around a grazing area.

Geo-fencing has also seen immense application in Agriculture, more specifically in free-range livestock farming. Sensors are placed on collars of cattle, goats etc. and these send location data to the farmer. There are two major forms of application of geo-fencing in agriculture: in the first, the sensors simply notify the farm owner when animals have grazed outside a pre-defined perimeter [44]. In this system, the farmer has to actively go muster the animals back into the perimeter. In the second approach, the animals are given subtle stimulations when they wonder outside set perimeter. Such simulations might include high frequency sounds or low voltage jolts – this approach depends on associative learning [45]. An illustration of a geo (virtual)-fence is shown in **Figure 9**, with the red boundary showing the grazing area and the blue circle showing an animal grazing outside the boundary.

Recent research work has focused on improving the efficiency of geo-fencing technologies. Low cost GPS being the most commonly used geo-fencing sensors have an error range of between 5 and 10 m and sometimes take long to locate and lock on to the required number of satellites. In a bid to improve on them, Assisted-GPS and WiFi have been used to respectively improve accuracies and reduce the time-to-first-fix [43]. LoRaWAN has recently been introduced as an alternative protocol for accurate location of animals [44, 46].

Though some arguments have been raised with respect to the effectiveness of geo-fencing, such as in the work of [47], rather than purely depending on stimuli, UAVs can be used to steer the animals back into range when they roam out of grazing perimeters. UAVs can therefore provide a cheap and effective way of getting animals back "inline" and are particularly useful when a number of animals stray outside different ends of the perimeter.

5. Advantages and challenges of UAVs

5.1. Advantages

1. Limited Constraints: Being air borne they are not hindered by physical constraints such as road/soil terrain, uneven paths and obstacles. They can simply fly over them all.

2. Shorter travel path: It is well known that the shortest distance between two points is a straight path. UAVs are best suited for this, as they can fly directly in straight paths. This is not always the case with land based vehicles.

3. Flying dark: In the case of autonomous UAVs, the UAVs can be programmed to fly in pitch darkness or at times with near zero visibility when it would be difficult for humans to manually control them.

4. Time and labor savings: Activities such as head count, monitoring and mustering often require the employment of more hands to help out. These can be both labor intensive and time consuming. With the use of UAVs, the number of extra laborers required is significantly cut down, while simultaneously saving time. Similarly in crop farming, UAVs can spray crops about 40–60 times faster than human laborers can.

5. Cost: Beyond savings in time, cutting down on laborers directly translates to cost savings. Though, capable UAVs are not cheap and there is also the added cost incurred in form of electricity to recharge the batteries; the cost savings and advantages of UAVs still significantly outweighs the manual and labor intensive processes of traditional/crude agriculture.

6. Aerial photography and imaging: With the use of UAVs, farmers can quickly obtain aerial images of their entire farm or select areas of interest. This can be useful in determining when fruits start to sprout or when pests and weeds are choking out crops.

5.2. Hindrances and challenges

UAVs have seen a wide range of applications in a smart city, all of which contributes greatly to the development of any smart city. In [48] the authors pointed out some of the challenges associated with the use of UAVs. Though these works focused on smart city applications, a number of these challenges are also applicable to the Agricultural space. The challenges were broadly classified into business and technical, and include:

1. Cost: The technology is perceived as expensive as a result of the technical nature of UAVs. Deployment, integration and training can be very expensive [48]. Similarly, in [49], the authors took a project management perspective to deployment of UAV related projects and highlighted cost as a key element that needs to be considered. It was also noted that proper estimations need to be using various technique prior to undertaking any such project.

2. Licensing and regulation issues: This is still a gray area with respect to UAVs. Regulations are either none-existent or a loose adaptation of aviation laws, which do not perfectly fit in with UAVs. There is therefore the need to draw up legislation to regulate the new possibilities and application areas of UAVs. Countries such as the USA, the UK, Germany and Spain [31] are leading the way in this direction by drafting guidelines for the use of UAVs and areas over which they can be flown. Other countries of the world are however still some way behind.

3. Business Adoption: From a business perspective, it might not be out rightly easy to justify the adaptation of UAVs into Agriculture. Though one might argue that there might be cost savings in the long run, counter arguments can be put forward regarding the actual acquisition cost of the UAVs, insurance / replacement of crashed UAVs, purchase of high resolution cameras for imagery as well as the accompanying software solutions and other running costs. When all these are added, it makes it a hard case to sell to farmers and Agriculture business owners.

4. Technical Challenges: These come in the form of system integration - integration of the middleware services with the UAV, high performance systems for data analytics, Net-centric infrastructure which enable any member of a team to control the UAV and retrieve imagery and sensor information in real time and application of machine learning / computation intelligence to identify and retrieve useful insights from the large pool of data.

5. Ethics and privacy: Some feel that the use of UAVs for monitoring and surveillance would lead to the invasion of their privacy. A lack of standard operational and technological procedures needed for safe performance of the UAVs is a great challenge. There could be GPS-jamming and hacking because of the vulnerabilities in the command and control of UAV operations.

5.3. Other open challenges

1. Limited flight time: UAV flight time is largely dependent on battery capacity. In most UAVs, particularly the multi-rotor, batteries can often times only sustain a flight time of between 10 and 30 minutes, and can be less when flown during high wind speeds. For activities such as crop spraying UAVs are only effective on hills, small areas, and in areas where other equipment cannot easily reach, for longer distance/range they are less efficient and even more costly than larger ground-based crop spraying equipment. The same challenge can be seen in the area of NDVI imaging, where farmers obtain NDVI images to assess the plant health. Alternative solutions are airplanes and satellites. While UAVs are the most cost-effective for small areas, they are currently not competitive against planes and satellites for larger areas.

2. There is the need to improve battery technology and find a way of using batteries with bigger capacity yet small footprint in UAVs. The use of solar photo-voltaic cells to power UAVs, such as [50] or the hybrid fixed-wing might be promising direction to be explored.

3. Limited payload size: Due to the small size of most UAVs, they are unable to carry a lot at once. This therefore limits their applications to basic aerial photography and observation. Though there are large-size UAVs such as [51], these are still limited in terms of flight time which is even further shortened when they are fully loaded. This limitation is prominent in application of UAVs in crop dusting (spraying pest/weed controlling chemicals or fertilizer on crops). Large gas powered monocopters might be a potential solution to this challenge.

4. Autonomy of UAVs: The possibilities of UAVs in Agriculture are numerous. However, most are currently being manually operated by humans. This limits their applications to certain times of the day when there is clear visibility. Advancements in computational intelligence specifically in areas of navigation, obstacle avoidance automatic sensing and actuation (performing pre-programmed tasks) can further accelerate the acceptance and usage of UAVs in livestock Agriculture.

5. Data Processing: Recent research works have shown the importance of data and information in almost all areas of human endeavor. Agriculture is certainly no exception. The use of UAVs as data gathering tools is still very much in its infancy. There is the need to develop effective techniques for data acquisition, data muling and most importantly converting these data to useful information. For instance, by observing the movement and body temperature of cows, farmers might be able to detect possible health related issues early on before they become fatal.

6. Empowering Farmers: In an article titled "on Drone technology as a tool for improving agricultural productivity", in [2] the authors identified empowering farmers as a vital process in improving agriculture. They concluded that it's one thing to have the technology and have the ability to gather billions of data for analysis, however all these are of no use, if they cannot be properly integrated and applied into agricultural business processes; where it can bring the much needed improvement. This can only be done by empowering the farmers themselves – either through formal class room education or informal practical demonstrations.

7. Cost: The ideal UAV for agriculture applications is one that has a good balance of durability, long flight time, stability and optional ability to fly autonomously. Such a device would cost much more than an average farmer might be able to afford. Most especially for farmers in developing countries. For those in much developed countries, there might also be the challenge of justifying how the purchase of such expensive devices can directly translate to measureable profit. To this end Farmers are still largely depend on manual ways of carrying out their farm operations.

8. Safety: There are also safety concerns with the use of UAV in Agriculture. One such is the UAVs' inability to recognize and avoid other airborne aircrafts and objects within the same airspace. This could result in collisions. Though obstacle avoidance is not too far-fetched, incorporating such features into basic UAVs would further drive up the already expensive cost of the UAVs.

9. Availability: There is also the problem of manufacturing, and meeting up with the demands for UAVs by farmers. This is largely expected since the industry is still exploring and testing Agricultural use cases. Manufacturing is being done on a small scale and the fixed costs remain high. In [22], it was pointed out that despite the numerous potential advantages of thermal remote sensing has over the optical RS in crop and soil monitory, there are a number of practical difficulties in its use. These include but not limited to atmospheric attenuation and absorption, calibration, climate conditions, crop growth stages as well as complex soil and plant interaction that have thus far limited its use in the agricultural sector.

6. Conclusion

Unmanned Aerial Vehicles or UAVs are essentially flying robots. Though initially designed for military use, they have are now widely used in various areas, from recreational sports, fire-fighting, flight simulations / trainings to toys for children. In this chapter we presented an application of UAVs to commercial Agriculture. We presented four major types of UAVs, and though the multi-rotor UAV with its ability to hover on spot and take-off and landing vertical may seem well suited for agriculture, its limited flight time is a major limitation. The hybrid-fixed-wing-motor-rotor might be a better fit. A detailed insight into the applications of UAVs in crop production and livestock farming was also presented. A prominent requirement for most UAV application in Agriculture is an integrated camera, as it allows images to be taken. Images are used in weed identification and control, soil analysis, animal monitoring, animal head counts, geo-fencing, mustering among others. Like most machines, UAVs have the advantage of doing repetitive and monotonous works better and more efficiently when compared to humans. Some advantages of applying UAVs in Agriculture were presented, some of which include limited path constraints, time saving and reduction in manual labor. However, there are a number of challenges limiting UAVs, most prominent among which is cost. UAVs that are well suited for Agriculture use are expensive. Operation and maintenance also come at a cost. It is therefore often difficult to convince farmers and Agriculture related stakeholders to integrate UAVs into their business. Beyond cost, battery limitations, safety and legal related issues are still major hurdles that need to be scaled before UAVs can find a strong foothold in agriculture.

Acronyms

CNN	convolutional neural network
ESSW	Mearly season site-specific weed management
GIS	geographic information system
GPS	global positioning system
LAI	leaf area index
LoRaWAN	long range wide area network
LPS	livestock production systems
NDVI	normalized difference vegetation index
OBIA	object-based image analysis
QR	codequick response code
RFID	radio frequency identification

SIFT	scale-invariant feature transformation
UAV	unmanned aerial vehicle
VTOL	vertical take off and landing

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