The Unmanned Aerial Vehicles in Agriculture (UAVs)

Chapter 4: Unmanned Aerial Vehicles (UAVs) in Agriculture

Introduction

The civilization of humanity is associated with agriculture. The journey started with the domestication of animals and plants in ancient ages, developing hand tools and animal propelled tools in about ten centuries BC. The mechanized era started with the invention of steam farm machinery in the 19th century and the internal combustion engines tractors in the first third of the 20th century. The development continued till we reached the era of using unmanned aerial vehicles (UAVs) in agriculture.

Because the UAV has a buzzing sound while flying, it is commonly known as a Drone, which is the name of the male honeybee. Another reason for naming the UAVs as drones is that the male honeybees usually have a single mission to fertilize the queen. The is always a no-return mission as the drones died during or after it. The first military use of the UAVs in the 1990s, they used it to perform suicide missions to destroy some of the enemies' properties without the ability to restore them. So, they call it a drone (204).

Types of agricultural drones

Drones have many forms and shapes; each design has its features and functions. Generally, we can categorize drones into three main groups based on the takeoff, landing, and operation paths. The three categories are the vertical, the horizontal, and the hybrid paths. Some drone designs that are currently in the market are listed in (205,206). The vertical takeoff and landing (VTOL) type is the most common type of drone due to its ease of operation, low price, and wide range of applications. The VTOL type includes single-rotor drones and multi-rotor drones.

The multi-rotor drones

The multi-rotor drones, Figure 1, are further classified into tri-copters, quadcopters, hexacopters, and octacopters for drones with 3, 4, 6, and 8 rotors respectively. More types are included depending on the number of motors. The main advantage of the VTOL type is that it does not require a runway for takeoff and landing, like the regular helicopter, which is more suitable for farms. Another significant advantage is the stability to take high-quality photos or apply a precise application of herbicides or fertilizers. The main drawback is the short flight times, which becomes shorter with the increment of the number of rotors (if the power is the same). There is a trade-off between the number of rotors and the payload capacity; as the number of rotors increases, the ability to lift more loads increases, but the power consumption increases too, hence the flight times decrease. So, to extend the flight time, we must decrease the payload. i.e., we must reach an acceptable balance between the drone design and the required functions. The VTOL drones have excellent maneuverability capabilities, and they can hover over a specific spot to apply chemicals or take high-quality pictures. This type of drone, especially the quadcopter, requires limited training to fly them, unlike the fixed-wing drones that require expert training and a special certificate in many countries.

Figure 25 Multi-rotor drones in agriculture

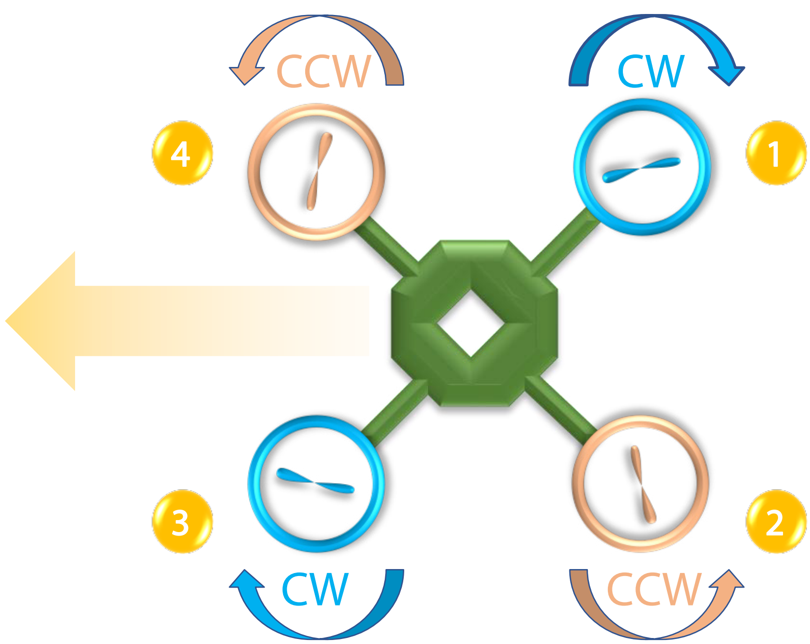

Figure 26 Motion model of quadcopter drones.

Anatomy of multi-rotor drones

The main component of the drones is the controller, which operates the rotors and the sensors. Each drone contains basic aviation sensors like the accelerometer, the gyroscope, and the magnetometer. The accelerometer measures the linear movement along each axis of the three dimensions. The gyroscope measures the tilt degree, the angular velocity, and the rotation rate. The magnetometer is used as a compass to determine and correct the aviation direction. The sensor readings are all sent to the controller that combines and analyzes them to determine the correct speed of each rotor to match the desired motion.

To understand how the multi-rotor drone moves, let us take the quadcopter as an example, Figure 2. The quadcopter consists of four rotors; if all rotors rotate in the same direction, the drone will spin in the opposite direction around its center (following the first law of motion). To avoid the unneeded spin, two of the rotors rotates in the opposite direction of the others, Figure 2; thus, each couple vanishes the effect of the others, so the drone flies steadily. To move the drone forward, in the arrow of the direction shown in the figure, the controller increases the speed of rotors 1 and 2 while decreases the speed of rotors 3 and 4 (retaining the same revolving direction). To move in another direction, the controller does the same but for other rotors. To rotate the drone clockwise, the controller increases the speed of rotors 1 and 3 and decreases the rotation speed of 2 and 4. Similar patterns apply to hexacopters and

The single-rotor drones

The single-rotor drone, Figure 3, is like a regular helicopter. Despite its name, it has two rotors; the main rotor which spins horizontally, and the small tail's rotor to control side movement. This type of drone can carry heavy loads while having the ability to hover and move forward at a fast speed. Some single-rotor drones operate in a gasoline engine, which is easier and cheaper than electric motors. The main drawbacks of this type are that they produce more vibration than others, are not easy to operate, and the most crucial downside, they are dangerous due to their large uncovered blades, so they must be used with extra caution (207).

Figure 27 Single rotor drones in agriculture

The fixed-wing drones

The fixed-wing drones, Figure 4**Error! Reference source not found.**, or the horizontal takeoff drones have faster forward speed than the VTOL drones. However, they require a runway or a launcher to takeoff and a large flat area for landing; otherwise, a parachute should be attached to the drone for a gentle landing. Unlike the VTOL drones, fixed-wing drones can not hover in the air, and their maneuverability is limited. The main advantage of this type is that it depends on its wings to gain lift and stability, unlike the VTOL drones that depend on their continuous moving blades to produce lift. That is why the fixed-wing type consumes less power and hence fly for longer distances than the VTOL drones. One of the essential considerations for the fixed-wing drones is their price, as they are generally expensive to buy and require certified or special-trained personnel to operate (208,209)

The hybrid drones

The hybrid drones are fixed-wing drones with attached rotors to enable vertical takeoff and landing, **Error! Reference source not found.** They combine the VTOL from the multi-rotor drones and the stability and long trip times from the fixed-wing drones. They are under continuous development, and we expect they will be the future of drones especially for agricultural applications. More information about hybrid drones' types and models is in Zhou et al (206).

Figure 28 Fixed-wing dronesin agriculture

Figure 29 Hybrid type drones in agriculture

Types of sensors in agricultural drones

In addition to the aviation sensors described in section 0, there are several types of sensors in drones. The sensors are categorized into imagery sensors and weather sensors.

Imagery sensors

The imagery sensors have two types, depth sensors and spectral sensors. Depth can be measured using time of flight technology (ToF) that uses sound or light waves to measure the time of the reflection of such waves to determine the distance between the objects and the drone. One of the most accurate sensors for depth determination is the light detection and ranging sensor (LiDAR) which is used for 3D mapping and to determine the height of crops (210).

Spectral sensors include red-green-blue (RGB) sensors, multispectral sensors, and hyperspectral sensors. To understand the difference between the three types of sensors, we can look at Figure 6 that shows the visible and invisible spectrum of light. The wavelength of the visible spectrum ranges from 400 nm to 700 nm. The human eye cannot see any wavelength above or beyond this range. However, plants and other living creatures emit light above this wavelength that shows signals about their health, especially at the near-infrared (NIR), the shortwave infrared (SWIR), and the thermal infrared (TIR) ranges. The TIR can be further divided into mid-wave infrared (3000-5000 nm, MIR) and longwave infrared (5000-14000 nm, LWIR). Knowing the values of these spectrum ranges helps to determine several growth properties of the plants.

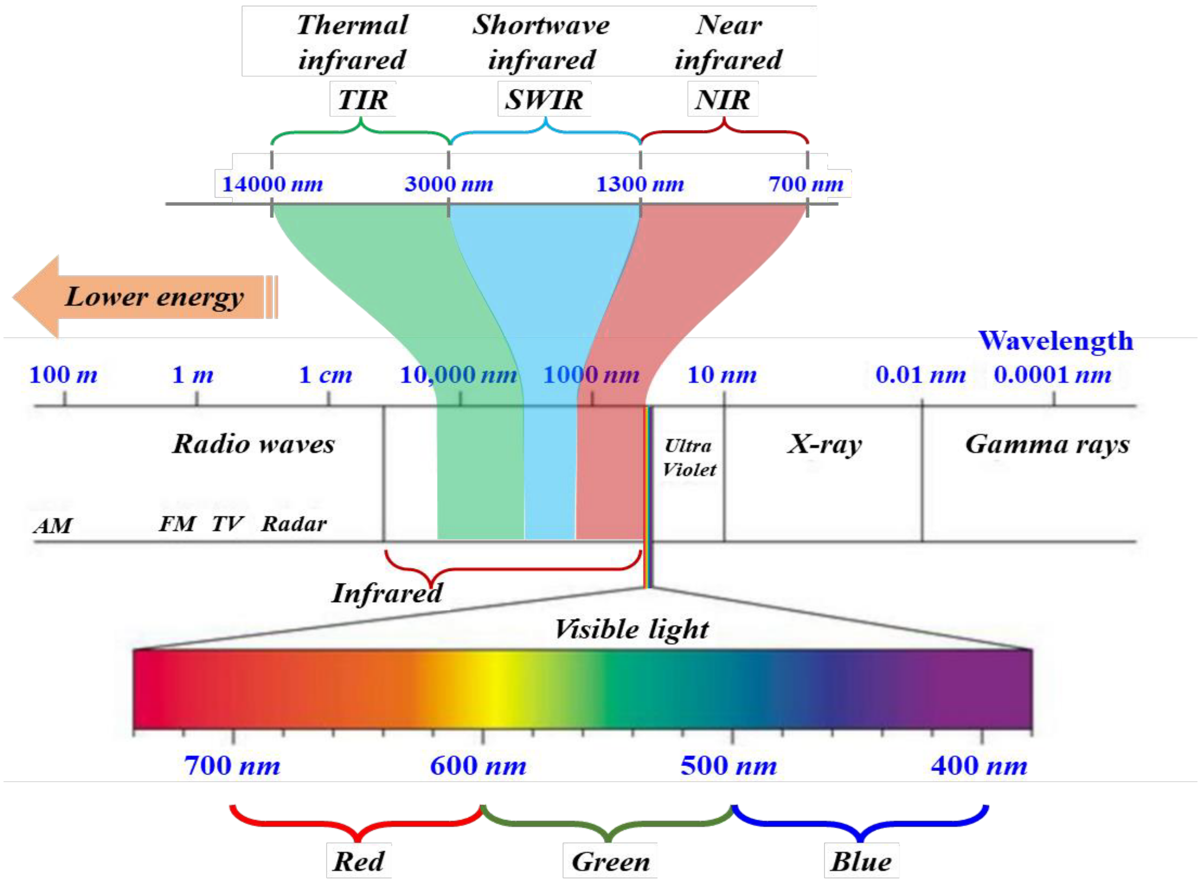

Figure 30 Visible and invisible wavelengths used in agricultural imagery (src: by the author)

For example, the NIR value combined with RGB values are used to determine the health of the plants, Figure 7. As the healthy plants tend to emit more NIR and green waves, as shown in the figure. Knowing the values of NIR and the red band reflectance (R), we can calculate the normalized difference vegetation index (NDVI). The NDVI is calculated as follows

$$NDVI = \frac{NIR - R}{NIR + R}$$

The value of the NDVI ranges from -1 to +1. The vegetation coverage has values of 0.1 and above. The higher the vegetation coverage, the higher the NDVI value. Similarly, the green normalized difference vegetation index (GNDVI) is calculated using similar formula replacing the G (green) band with the R band. The GNDVI is used to estimate the chlorophyll in leaves. Other indices are found in the literature, where many of them are collected in (210).

Correspondingly the SWIR and MIR are useful in detecting moisture content in soil and plants, smoke, and minerals. The SWIR can help distinguish between white bulks in the pictures whether they are snow, ice, water clouds or ice clouds. It can also help to detect fires and burned lands and mapping different rock types (211). The TIR can gauge the temperatures of land and water bodies. It is also used o monitor crop evapotranspiration.

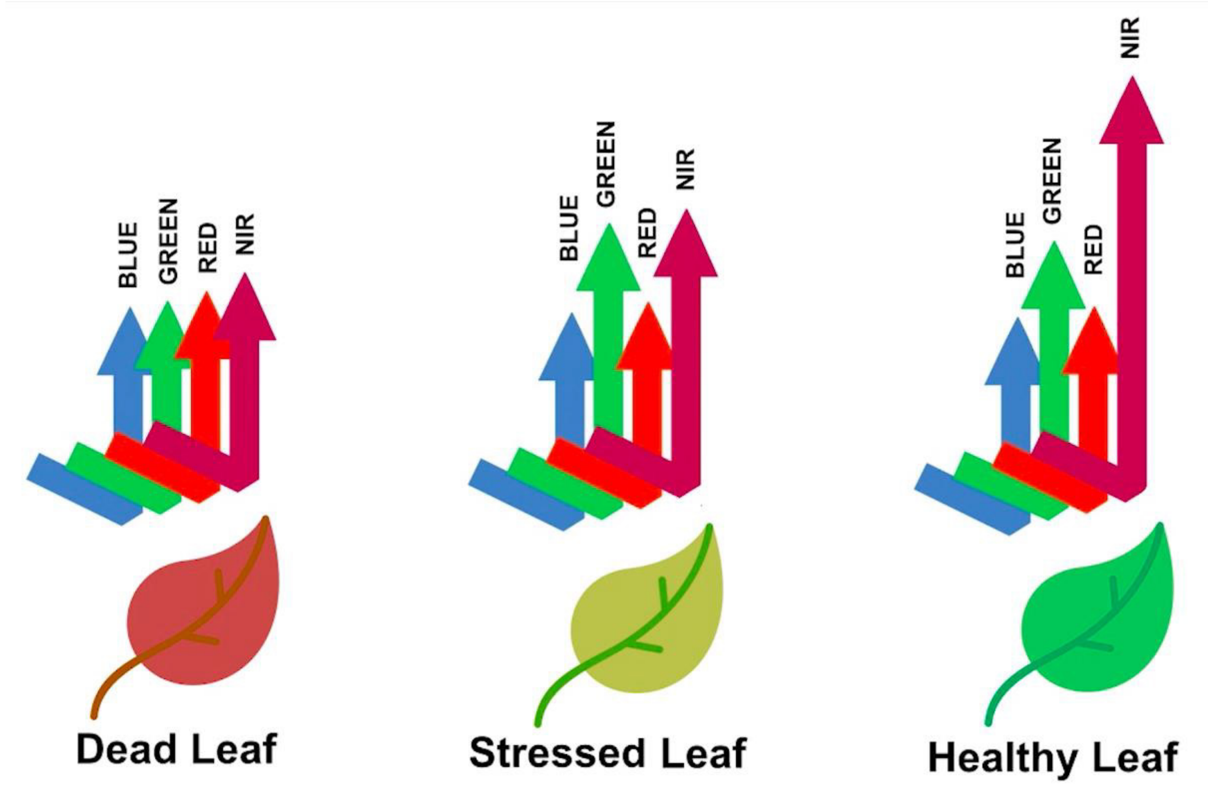

Figure 31 Using the NIR and RGB values to determine plant health (src: https://youtu.be/1kcUNdyIeaM?t=32)

Back to the types of spectral sensors, the RGB sensors capture only the three visible bands; the multispectral sensors capture 3 to 10 bands, where each band has a meaningful title, like the bands shown in Figure 6, Red, Green, Blue, NIR, SWIR, MIR, and TIR. The hyperspectral sensors divide the light spectrum into hundreds or thousands of narrower bands with a bandwidth of 10-20 nm. Hence, the red spectrum which spans from 600 to 700 nm (100 nm range) is divided into 5 to 10 bands, with no descriptive meaning to each band. Hyperspectral sensors can precisely identify the color of plants so that they can differentiate between different plant types. Thus they can detect unwanted plants like weeds in the field (13).

Weather sensors

In addition to the imagery sensors that can estimate temperature, drones can precisely measure some weather properties using attached sensors. The weather sensors include a digital temperature thermometer, humidity indicator, barometer (to measure atmospheric pressure), solar sensor, anemometer (measuring wind speed and direction). These sensors are combined with the GPS and altimeter (measuring altitude) to record the 3D location of the measured point in the air. It is worth mentioning that sensors tend to be smaller and more precise; the sensors technology has developed so that some compact instruments can measure all of the weather properties at once. These instruments are developed mainly for drones (212,213).

UAVs agricultural applications

Basics or aerial imagery

Drones are used in agriculture for several functions. The functions are categorized into imagery functions, sensors functions, and applicators or robotic functions.

Imagery-based applications

The main advantage of the drones is that they can monitor agricultural fields from the sky at low to medium altitudes (unlike the satellite imagery), so we can get high-definition images of the fields. Drones can monitor the health of the plants to determine thirsty levels, as shown in section 0 which can be used to determine transpiration rate and sunlight absorption rates as well (205). These images are currently used to estimate crops' evapotranspiration, thus, to compute the precise irrigation amount that saves water and increases the yield.

Drones can take high-quality images of vast areas in a short time; thus, this is used for powerful mapping applications. Using drones, we can make a 2D or 3D map of the field including layers of soil, vegetation, weeds, field boundaries and obstructions, grazing zones, and other layers. The maps can then be used for precision agriculture applications such as determining the regions that require specific care like fertilization, pest control, or even water for irrigating specific thirst spots. The images can also determine the plants that are ready to harvest either for farm crops or orchards.

Unlike the tedious operation of soil sampling, drones can scan soils to determine the moisture level even in the presence of plants. They can also map other soil properties like nitrogen, phosphorus, potassium, pH, and other properties about the content of metals like iron calcium, magnesium, potassium, and the cation exchange capacity (CEC) (214–218).

Additional image based applications of drones are to count whole plants in the field or only the fruits in a tree or a row of plants before harvest, especially for research purposes The images can also detect the density of row crops like wheat and maize, from which we can estimate the growth state and predict the field yield.

Drones can also be used for livestock monitoring, like supervising the grazing area to ensure the herd is inside the desired region. The operation also includes monitoring the state of motion of each individual cow, whether it is standing, sleeping, or walking, from which we can identify the animal's health in the meantime and predict possible health problems. Thermal cameras can measure the body temperature of the animals, which gives an essential sign of their health and heat stress. This remote measurement has benefits over the manual measurement of temperature because it is faster and eliminates the contact between staff and the animals which might cause infections to spread (204,219).

Sensors-based applications

As we mentioned, the drones can be equipped with meteorological sensors where several applications benefit from using this data. For example, calculating the evapotranspiration based on weather information or knowing the health of the plant by comparing the temperature next to the plants to its value at higher altitudes (healthy plants usually lower the temperature and increases the relative humidity around them). Knowing the weather conditions is also vital for livestock.

Robotic applications (actuation drones)

One of the advantages of drones is that they can see what the farmer cannot see easily, and they can reach places that the standard farm machinery cannot reach. Large drones can carry fluids' tanks and equip with sprinklers to apply precise amounts to any part of the field. This fluid could be water, fertilizers, or pesticides (Figure 8Figure 10). The main benefit of drone application is that it is more precise, faster, and cheaper. Before drones, if we noticed an infection on a field, we would spray the whole field, but with drones, we can only spray the infected region and a little surrounding around it. This application reduces the amount of applied pesticides and herbicides and eliminates their expenses and hazards as well.

Figure 32 Spraying drones preparation and operation.

Drones can help in the planting process; they can shoot seeds to plant plots with missing plantations or plant the whole field using a drone-based planting system which helps to reduce the planting costs and duration dramatically. This system shoots pods that include the seeds surrounded by a small amount of soil and fertilizers for the plant's initial growth. Figure 9 shows two types of drone seeders, bullet type (a) shoots a biodegradable bullet (b) contains the seed surrounded by soil, nutrients, and a biodegradable container. The bullet is typically dropped vertically to the ground. The second type is a capsule/pod type, where the seeds, soil, and nutrients are compacted together in a spherical or cylindrical shape (Figure 9 d), which is easier to be shot from the drone (13,220,221).

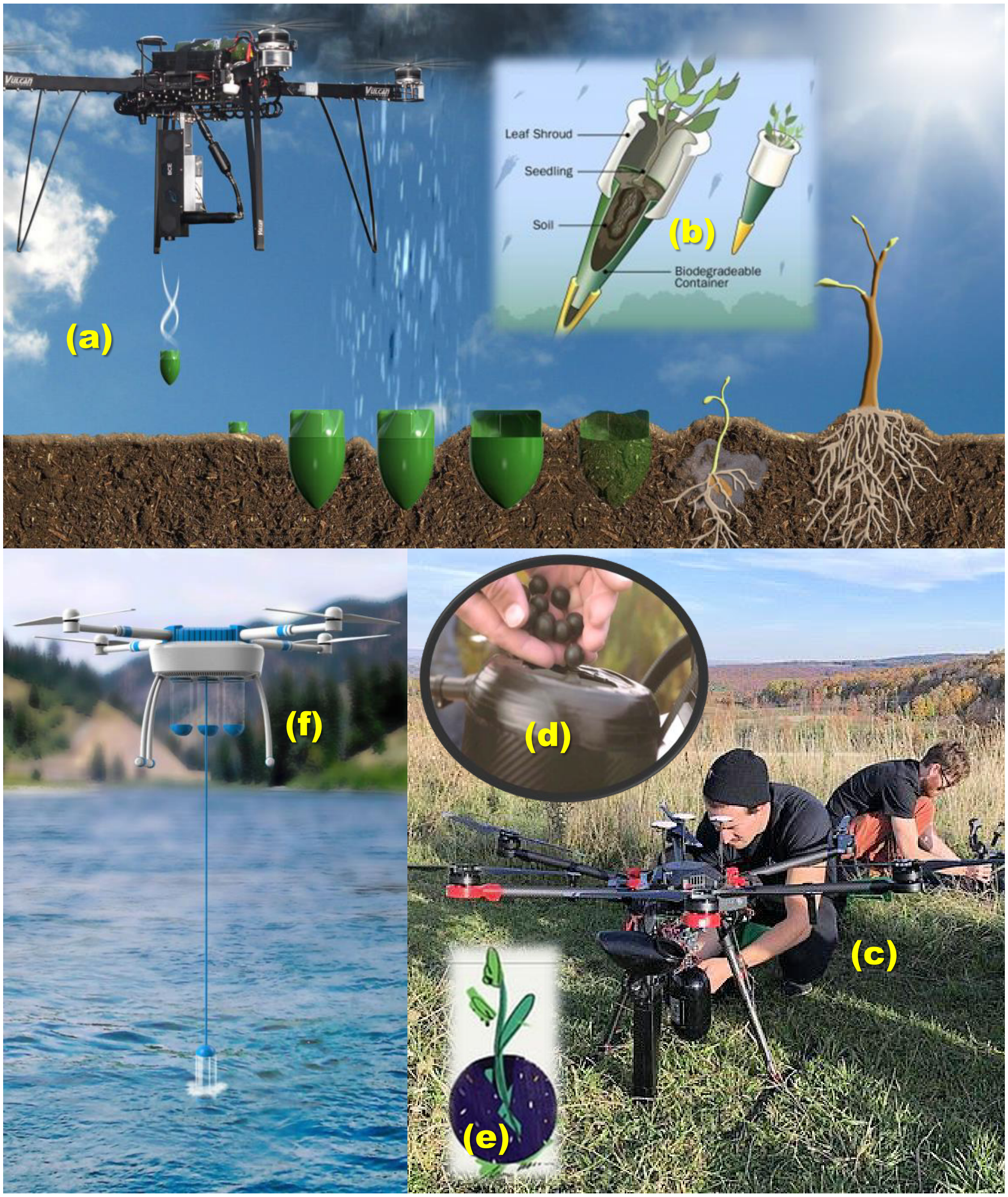

Figure 33 Actuation dronesin action. (a, b) Planting trees using biodegradable bullets. (c, d, e) Planting trees using soil capsules, c: preparing the drone, d:loading the soil-seeds capsules, e: illustration of growth (f) Water sampling using drones.

Physical soil and water sampling can be performed by drones as well. Drones can be equipped with particular soil sampling arms and tools (or tubes pumps for water sampling Figure 9 f) so that they can be programmed to take the sample from certain locations at a specific depth (218,222).

Fruit-picking by drones is one of the latest technologies that took place using free or tied drones. Free drones are the regular drones that can fly freely, while tied drones are special drones that are connected to a docking station via wires, Figure 10, so that they can take power and exchange data with the docking station that is attached to the fruit collection bins (93,223,224).

Figure 34 Fruit picking by tied (up) and free (Middle) drones. Bottom images show the spraying drones

As we talked about livestock monitoring, there is a step further the drones can do, which is cattle herding. The drone cameras, combined with artificial intelligence and cloud computing, can provide real-time herding of the cattle. The operation begins by choosing the pasture borders, then specifying the destination gate The drone will fly to the area, tracking the animals one by one, forcing them to go to the destination by hovering around them. In some cases, a piece of cloth or leather is hanged to the drone to increase the drone footprint. Figure 11 shows the application interface, the detection of animals using AI, and the herding of camels (225,226).

Figure 35 Livestock herding by drones and AI. Specify the borders of the field and the gate through a mobile application, then the drone will herd the cattle anusing targetted filgths and a hanging closth (shown inellipses).

Source of images: (225)

Challenges and Obstacles

Despite their significant advantages that can change the agriculture and livestock industry, drones have some problems that slowdown their spread. The challenges are technical, operational, and legal.

Technical challenges

Limited endurance (battery)

Most of the drones are battery-operated, while a gasoline motor operates few. Both batteries and fuel tanks have a considerable weight that competes with the desired load of the drone, like sensors and containers. The limitation of power is the most significant challenge, especially with larger areas and the increasing number of sensors. The fixed wings drones are better than the multi-rotor drones in this regard. They have fewer rotors and have a better aerodynamic system for flying depending on wings than the continuous rotating blades. The advances in sensors technologies made them lighter and more compact to be held easily in drones.

Limited payload

As we discussed in the previous point, there is a tradeoff between battery and payload. So, to have heavier payloads, the drone will have less flight time and vice versa. Even the lightweight sensors are still unaffordable for most farmers, especially in developing countries.

Limited resolution

Like the lightweight sensors' price, the high-resolution image sensors are expensive; thus, most clients use low spectral resolution sensors. For advanced agricultural applications like weed identification and disease detection, it is required to use hyperspectral sensors which is expensive to most users. We hope that the development of sensor technologies will reduce their prices and make high-resolution sensors accessible to everyone.

Weather sensitivity

As drones fly in the air, they are vulnerable to weather conditions. The biggest enemy of drones is wind. Strong winds can bring the drone down, sometimes in a hard-to-reach place. However, modern drones have advanced control microchip that is programmed to face strong winds. Other weather conditions like fog and rain may affect the quality of the drone images, so we must select the time of flight that is free of such conditions. The cloud cover's blockage problem is one of the well-known issues for satellite imagery; however, drones fly below the clouds; thus, they are free of this issue.

Data transmission

Drones have plenty of sensors that record data. This data must be analyzed to get the proper interpretation of it and to have a data-driven decision. Depending on the operation model, some drones record data, and then after landing, the data is being transferred to the analysis computers via cables, flash drives, or wirelessly. On the other hand, some advanced drones processes data in real-time (especially the actuation drones). These drones can process the data internally or transfer the data wirelessly to cloud servers that can make complex AI predictions and send the decision back to the drone to act accordingly. As the sensors become more advanced, the amount of data increases, and reliable transmission methods are needed either for real-time analysis or post-analysis.

Ownership and operational challenges

High cost for precise drones

Recreation drones' prices vary from $200 to $2000, while the prices of the agricultural drones range from $1,500 to more than $25,000 for multi-rotor drones (Prices of 2021), while fixed-wing drones' prices exceed $50,000. These prices are still very high for most farmers, especially for the developing countries' farmers. Additionally, the prices of the additional sensors, equipment, and software are all considerable. The good news is that the costs are on the way to decrease with the development and popularity of technologies. The costs problem can be eliminated by establishing a governmental model to purchase advanced drones and then renting them at subsidized rates to farmers.

Training and certification requirement

Most agricultural drones require specially trained personnel. The drone operator must have agricultural knowledge besides aviation knowledge. In some countries, a special certificate is required from each commercial operator of the drone including agricultural purposes. The operation of multirotor drones is easier than fixed-wing and hybrid drones. Thus, it is recommended for operators to start training g on a small multirotor drone, then practicing with bigger ones. After mastering operating multirotor drones, the operator can start practicing the operation of fixed-wing models.

Maintenance and Repair proficiency

Depending on the type of the drone motor, we need specially trained professionals for maintaining mechanical and electronic problems, as well as debugging and fixing software problems. In many models, there are no serviceable parts, only replacement of parts is allowed; in that case, we must have a supply of replaceable parts to ensure continuous operation of the drone.

Legal challenges

As we said, the drones can fly anywhere so that they can reach hard-to-reach places. It can also see and record what no one else can see. This benefit can be an advantage in the farms and fields, but it will be a significant disadvantage near private and sensitive areas. For that reason, many countries banned the use of drones, while others allow drones under strict conditions. For example, the United States Federal Aviation Administration (FAA) distinguishes between recreational and commercial purposes of drones operation. Recreational or hobbyist use requires passing an online course before operating any type of drone, while it requires registering any drone that is heavier than 0.5 pounds (~225g) with the FAA. Commercial operations of drones, including agricultural purposes, require special certification from the FAA. All drones should not fly above 400ft (122 m) and should be 5 miles (~ 8 km) away from airports. The payload at flight is restricted to 25 kg, while more loads are allowed with special permission. They also have some regulations banning flights over or near some sensitive areas, and the ban is also at specific times like a presidential visit to the location. Other countries have different regulations; some are easier than the US model, like Japan, while others are stricter than the USA like Germany (227). Unfortunately, most Arab middle eastern countries ban drones, except six countries that have legalized drones with solid regulations. The six countries are UAE, Saudi Arabia, Jordan, Bahrain, Kuwait, and Oman. Five countries banned drones with few exceptions after a complex licensing process; they are Egypt, Qatar, Morocco, Syria, and Tunisia. In three countries that seem ambiguous in their position on drones, no explicit laws prohibit or allow them. These are Algeria, Lebanon, and Palestine. While the rest of the Arab countries strictly banned any kind of drones with no exemptions. Detailed legal status in the Arab countries is listed in Table 3 (228,229).

Table 3. Drones legal status in the Arab countries

Country	Drones responsibility organization	Allowed	Exceptions?	Regulations	Max Height	Max Diameter	Commercial allowed	Classes (kg, c: commercial classes)	Distance from airports (km)	Licence required	Notes
Algeria	DACM	!	!				✗				
Bahrain	CAA	✓		▮	122	500	✓	<5, <25, >25	9.26	✓	Cameras are not permitted
Comoros	ANACM	✗	!				✗				
Djibouti	ACAM	✗	!				✗				
Egypt	ECAA	✗	✓	▮	122	250	✗		9.00		
Iraq	ICAA	✗	✗				✗				
Jordan	CARC	✓		▮	121	500	!	<25	9.10	✓	
Kuwait	DGCA	✓		▮	50, 100, 120, 150	50, 120, 250	✓	<0.3, <5, <25, <150, <150c, >150c	9.10	✓	Cameras require explicit permit, All classes require licencing except the lightest class, flight path must be specified
Lebanon	DGCA	!	!				✗				
Libya	LCAA	✗	✗				✗				
Mauritania	ANAC	✗	!				✗				
Morocco	DCA	✗	✓				✗				
Oman	PACA	✓		▮	122	30	✓	<.25, <2, <25, ,<25c, <150c, >150c	9.10	✓	Only commercial and heavy classes require licencing
Palestine	PCAA	!	!	▮	50	500	✓		2.00	✓	Flight path must be specified
Qatar	QCAA	✗	✓	▮	122	250	✓		9.10		Flight path must be specified
Saudi Arabia	GACA	✓		▮	150	600	✓	<25, >25	8.00	✓	
Somalia	SCAA	✗	!				✗				
Sudan	SCAA	✗	!				✗				
Syria	SCAA	✗	✓				✗				
Tunisia	DCA	✗	✓				✗				
UAE	GCAA	✓		▮	122	####	✓	<5, <25, >25	5.00	✓	Camera are not permitted in some zones
Yemen	CAA	✗	!				✗				