AUTONOMOUS AERIAL SPRAY SYSTEM FOR SUSTAINABLE AGRICULTURE: ENVIRONMENTAL IMPACT

ABSTRACT:

Drones are now a days emerging as a component of precision agriculture along with contributing to sustainable agriculture. The use of advanced technologies such as drone in agriculture offer potential for facing several major or minor challenges. The major applications of drone in agriculture are spraying, irrigation, crop monitoring, soil and field analysis and bird control. In this review analysis, considered the latest trends and applications of leading technologies related to agricultural UAVs equipment, and sensors development. And also, the use of UAVs in real agricultural environments. Furthermore, the future development of agricultural UAVs and their challenges are considered. There is a problem with workflow for the use of UAVs in such applications, as it is a relatively new area. In this paper, we review the available agricultural drones and most recent applications of UAVs for Precision Agriculture used sensors on it for agriculture data and current trends and future challenges are suggested.

Keywords: Agricultural applications, Components, Sensors, Smart Agriculture, Unmanned Aerial Vehicles UAVs)

1. INTRODUCTION:

The adoption of modern technologies in agriculture, such as the use of Unmanned Aerial Vehicles (UAVs) or drones (Dynamic Remotely Operated Navigation Equipment), can significantly enhance risk and damage assessments (Boursianis *et. al.*, 2020). UAVs are one type of aircraft that can fly autonomously in the air without the involvement of a pilot on board, and the aircraft's motion is controlled remotely by an operator. An operator controls the UAV's movement from a distance. UAVs have been widely employed in agriculture due to the quick development of smart agricultural technology, assisting farmers with tasks like crop monitoring, crop spraying, weed and disease diagnosis, etc. UAVs are now a better choice for farmers in the agricultural industry thanks to some of the sophisticated characteristics, including cheap maintenance costs, quick setup, low acquisition costs, and live data collecting (Xia *et. al.* 2020).

The potential of drones to become an element of the green technologies in the near future with vast utility in attaining sustainable agriculture cannot be undermined. Presently, farmers are facing many problems like unavailability or high cost of labours, health problems by coming in contact with chemicals (fertilizers, pesticides, etc.) while applying them in the field, bite by insects or animals, etc. Manufacturers and researchers are designing new formulations of pesticides to meet the global demand. Ideally, the applied pesticides should only be toxic to the target organisms, should be biodegradable and eco-friendly to some extent. The repeated use of persistent and non-biodegradable pesticides has polluted various components of water, air and soil ecosystem. Pesticides have also entered into the food chain and have bioaccumulated in the higher tropic level [39]. Drones are nowadays emerging as a component of precision agriculture along with contributing to sustainable agriculture.

The market for agricultural UAVs is growing rapidly (Brief, *2011*), and several venture companies have emerged. According to market research by Price-Waterhouse-Coopers, the market size of agricultural UAVs is forecasted to grow to about $32.4 billion by 2050, accounting for about 25% of the global UAV market (Mazur *et. al., 2016*). Major UAV companies include DJI, Parrot, Precisionhawk, AGEagle, and Trimble Navigation. Although various UAVs have been developed and commercialized, some challenges remain to be addressed for advanced agricultural solutions. Leading technologies include precision positioning, navigation, controls, imaging, communications, sensors, materials, batteries, circuits, and motors. Depending on the use of the UAV and the characteristics of the farming sector various technologies (e.g., equipment development, nozzle controls, and big data) are required. It is challenging to provide information about all UAV technologies. Therefore, in this paper, we focus on the components of drone systems, sensors, and platform types, which are mainly examined in terms of research and development.

2. DRONE COMPONENTS:

Complete drone system is combination of different components as shown is fig. 1.

Frame: - It is important to take the weight of the frame in consideration because if weight is high then there can be difficulties in the lifting of the drone. The design of frame is a trade-off between strength and additional weight, which will require longer propellers and stronger motors.

Propeller: - It is made up of carbon fiber which possesses high strength. Longer propellers can achieve greater lift at a lower rpm but take longer to speed up/slow down. Shorter propellers can change speed quicker and thus are more maneuverable; however, they require a higher rotational speed to achieve the same power as longer blades. This causes excess motor strain and thus reduces motor life span (Ahirwar *et. al., 2019*).

Electronic speed controller (ESC): - It is used to vary the Revolution Per Minute (RPM) of the motor.

Flight controller: -Maneuvering operations and also it provides Auto level function. The accelerometer and gyroscope sensors in the Flight controller process the signals from the receiver and gives the output to the ESC to control UAV.

Power distribution board: -A board which allows transferring the power from the battery to ESCs / Motors and generate power supply for the flight controller and other peripherals with different voltage levels.

Brushless direct motor: - 1 per propeller, its movements can be controlled via an electronic controller and speed feedback mechanism. These motors are energy saving as compared to the brushed dc motors.

Radio transmitter and receiver: - Firstly, the transmitter should be calibrated with the flight controller using the receiver. After the calibration the transmitter is linked with the drone, as per command of the transmitter the drone will work (Desale *et. al.*, 2019).

Battery: -Generally, the battery used is a Li-Po battery due to high power density and ability [Pham *et. al.* , 2020].

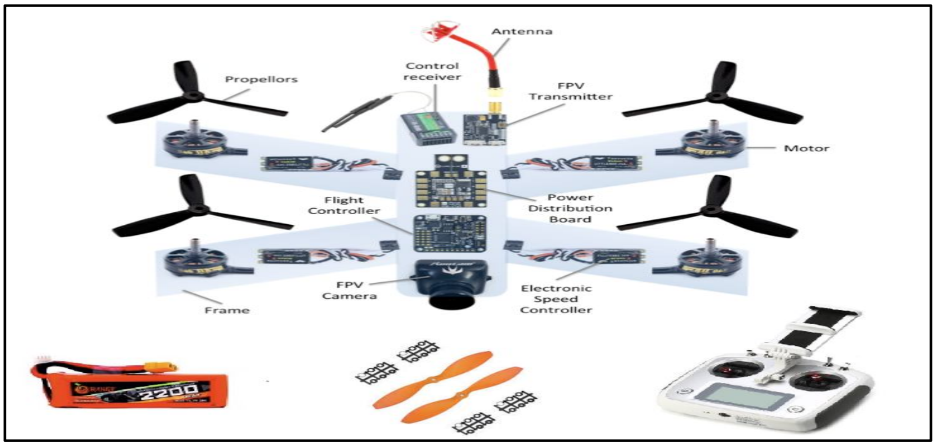


Fig. 1 Components of UAV

3. TYPES OF UNMANNED AERIAL VEHICLES BASED ON WINGS AND ROTOR:

The number of rotors corresponds to differences of payload and UAV size as shown in fig. 2. Octocopters, helicopter types, and fixed-wing types have the largest payload capacities (9.5 kg) and are mainly used for spraying (Dai *et. al.*, 2017). Quadcopters and hexacopter are relatively small and carry a smaller payload (1.25–2.6 kg). They are used for reconnaissance and mapping (Sánchez *et. al., 2013*), (Özaslan *et. al.*, 2016). Fixed and rotary-wing UAVs have the largest payload (23 kg), followed by the helicopter-type (22 kg). Currently, fixed- and rotary-wing UAVs are increasingly being used for precision agriculture. Multi-rotor UAVs are used for extremely precise tasks.

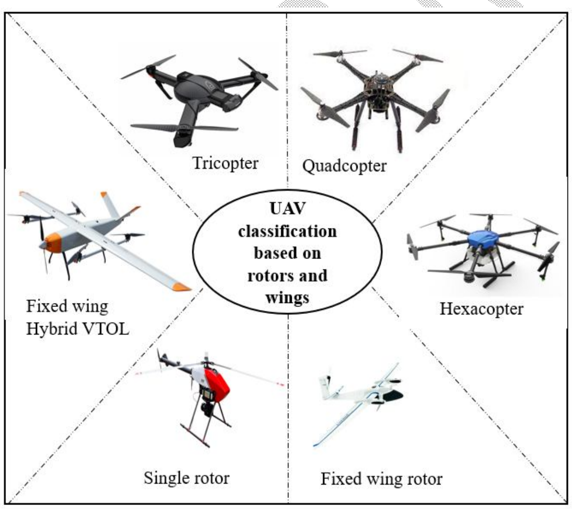


Fig. 2 UAV based on wings and

1] **Multi Rotor UAVs**: These UAVs are mostly used for applications like aerial surveillance, photography etc. These are easy to manufacture and are the cheapest of all kinds of UAVs. Different categories of Multi Rotor UAVs are Tricopters which have 3 rotors, Quadcopter which have 4 rotors, hexacopter which have 6 copters and octocopter with 8 rotors (Shaw and Vimalkumar, 2020). Some of the limitations are limited flying time of 30 minutes, limited speed, so they are not suitable for projects such as long-distance surveillance and aerial mapping.

2] Fixed wing UAVs: These UAVs are controlled autonomously without a human pilot on-board. They have average flying time of 2 hours and some of the recent Fixed Wing UAVs can fly upto 16 hours. They are ideal for long distance operations. Some of the limitations are high costs and highly skilled training to operate. They need runway for launching (Panagiotou and Yakinthos, 2020).

3] Single Rotor UAVs: These categories of UAVs look very similar to the helicopters. These UAVs have only one huge rotor and a smaller one near the tail of the UAV. They can fly for higher number of times compared to multi-rotor UAVs. Some of the limitations are more complex and prone to operational risks, higher costs.

4] Hybrid Vertical Take-off and Landing (VTOL): These UAVs are a hybrid of fixed wing UAVs and rotor-based models. These UAVs are equipped with sensors and can be controlled remotely (Ryi and Choi, *2020*).

Some sensors are mounted on drone for mapping, surveying, detection of crop related to diseases for easy identification, different types of agricultural sensors are available described as below:

4. Types of Agricultural Sensors

1) Location-based Sensors: Location sensors are used for locating different areas and spots in the agriculture fields (Lee and Mase, 2002, Bayrakdar ,2020). The farmers utilize various locations sensors that help them during the different stages of the life cycle of crops. Normally, GPS receivers are used for finding the longitude and latitude of a particular point on the earth's surface with the help of a GPS satellite network. These smart location sensors play an important role in precision agriculture by pointing out the location in fields of monitoring growing crops for watering, fertilization, and treatment of weeds.

2) Electrochemical Sensors: These sensors are used to extract a composition from a particular biological sample such as plants, soil etc. (Salam, 2020). In smart agriculture, these sensors are generally used to detect pH levels and soil nutrient levels where sensor electrodes detect specific ions within a soil.

3) Temperature and Humidity Sensors: Temperature and humidity are among the most important weather factors which directly affect the health and growth of all types of crops. Correct measurement of these environmental factors is helping the farmer adjust the quantity of fertilizer and water (Singh *et. al.*, 2020). Various types of temperature, humidity sensors are available which helps the farmers to measure and monitor the levels of humidity and temperatures of their fields and greenhouses. These sensors are wireless-enabled and battery operated.

4) Optical Sensors: These sensors work on the principle of converting light rays into an electrical signal (Beltran *et. al.*, 2020). There are several optical sensors (such as RGB camera, converted near infrared camera, six-band multispectral camera, high spectral resolution spectrometer etc.) that have been used in UAVs for precision agriculture related applications (Bueren *et. al.,* 2015). A brief description of few sensors working on this principle are as described as the following.

(a) Visible Light Sensors (RGB): Visible Light Sensors (RGB) are most popularly used by UAVs in precision agriculture and related smart agro applications. It is a recognized fact that human eye is sensitive to red, green and blue bands of light. The RGB sensor in UAV camera captures the image such that they reproduce the same effect as seen with a human eye. Also, the costs of the RGB sensor-based cameras are relatively affordable, light weight and extremely good at creating orthomosaic maps that captures images and aerial videos of the entire field at a single instance as shown in fig. 3. This enables to take quicker observations and after entering the geographical data into the GPS, one can immediately get into the root of the problem without affecting the entire field (Singh and Singh, 2020). The RGB cameras thus help in detailed inspection of agricultural assets efficiently and effectively in varying weather conditions. The associated challenges of this sensor include its inadequacy to analyze large number of agro parameters requiring spectral information existing in non-visible spectrum.

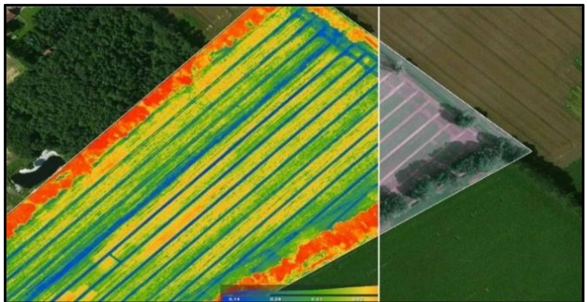


Fig. 3 Image by Visible Light Sensor

Table 1: Review of used smart agriculture UAVs with applications

Sr. No.	Agriculture UAVs	UAV Type	Potential Application	UAV image
1	eBee SQ	Fixed wing	RGB imagery, spanning vast areas of every flight, Soil Temperature	
2	Sentera PHX	Fixed wing	Weed management, pest management, crop health monitoring	
3	Lancaster 5	Fixed wing	Plants counting and number, assessing plant quality, creating prescription maps	
4	Honeycomb	Fixed wing	Navigating, surveillance, Soil H20 levels, air pressure	
5	AgEagle RX-60	Fixed wing	Aerial Imaging, crop health monitoring, maps prescription	
6	Dji matrice 600 Pro	Multi rotor	Plants counting, Navigating, aerial photography	
7	Dji matrice 210	Multi rotor	Fire-fighting, pipeline inspection	
8	AgBot	Multi rotor	Plant height, assessing plant quality	

[Maddikunta *et. al.*]

(b) Multi-spectral Sensors: Multi-spectral sensors are extremely appropriate for UAV based agricultural analytics. These sensors capture images with exceptional spatial resolution and also possess the capability to determine reflectance in near infrared (Nhamo *et. al.,* 2022) as shown in fig. 4. Thus, these sensors are very effective and essential for farmers, researchers and agronomists. The collection of multi-spectral data is an absolute necessity for performing analysis of crop health. The multiple bands of light enable researchers to conduct precision analytic and produce insights on plant vigor, canopy cover, leaf and various other parts of the plants. The absence of such multi-spectral data would make early detection of plant diseases, weeds, pests and calculation of vegetative biomass almost impossible.

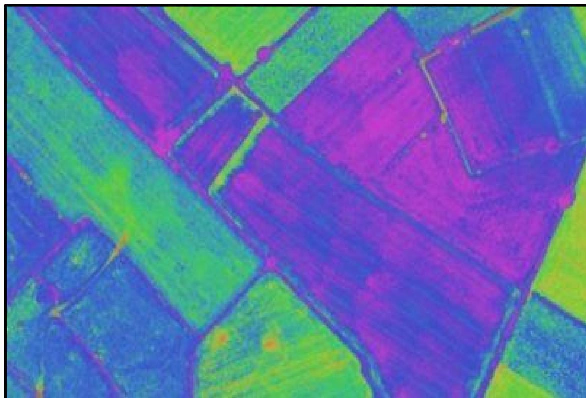


Fig. 4 Image by Multi-spectral Sensor

(c) Hyper-spectral Sensors: Hyper-spectral sensors are extremely capable of capturing detailed images in the spectral and spatial range. These sensors are equipped with area detectors that quantify the captured light resulting from the conversion of incident photons into electrons as shown in fig. 5. The successful use of hyper-spectral sensors in UAV is possible through the availability of pre-built systems constituting of the sensor manufacturer, the UAV manufacturer and the party responsible for system integration at the pre and post flight level (Weiss *et. al.,* 2020). The combinations of all these three aspects ensures commercial success of the hyper-spectral sensors in measuring hundred bands, performing data processing and achieve decision making in agriculture and forestry.

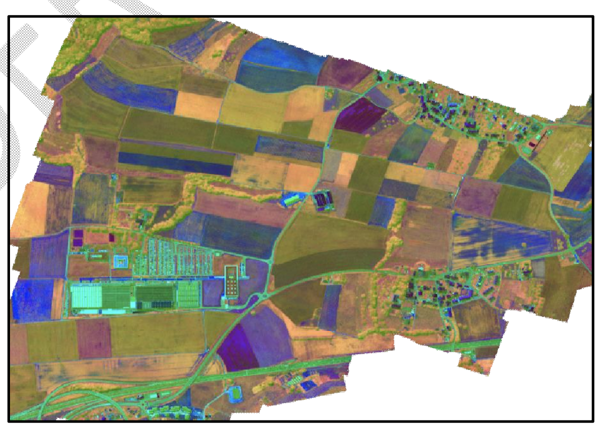


Fig. 5 Image by Hyper-spectral Sensor

4) Thermal infrared sensors: Thermal sensors are widely used for many agricultural related applications such as monitoring of various conditions of crops and soil. The thermal cameras detect the radiations relevant to their wavelengths and converts it to grayscale image generating heat in this process as shown in fig. 6, (Allred *et. al.*, 2020). The applications of these thermal sensors mounted on UAVs are irrigation management/scheduling by calculating the soil and crop water stress, detection/prediction of various crops disease (Gadekallu *et. al*, 2020, Reddy *et. al.*, 2020) (e.g., pathogen), mapping soil texture, crops maturity monitoring as shown in table 2.

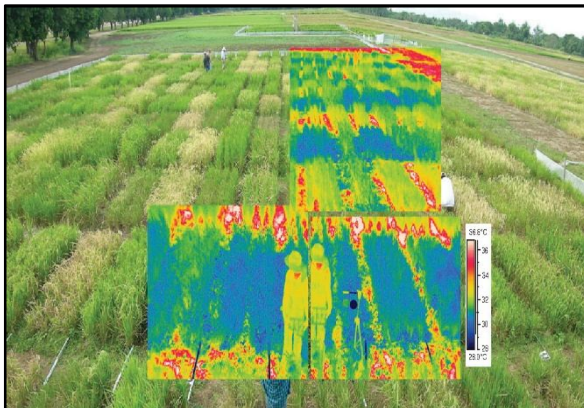
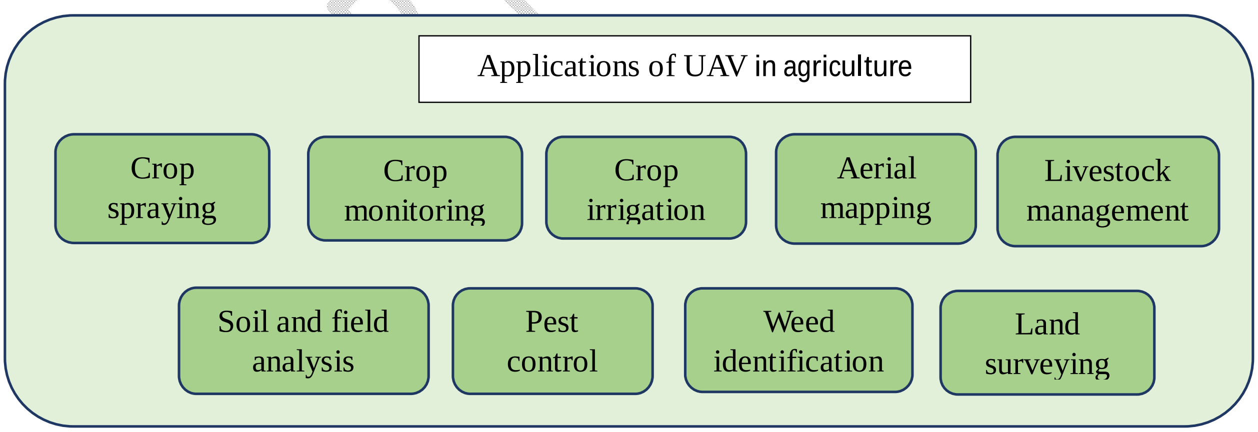


Fig. 6 Image by Thermal infrared sensor

5. Applications of drones in agriculture

There are various applications of drones in agriculture: -

The main advantages of using UAVs for smart agricultural applications as shown in fig. 3 include mobility of UAVs in variable weather conditions, ability to capture high-resolution pictures from different ranges (average range 50 to 100 meters). It is also, possible to use UAVs for determining and monitoring the quality of crops, monitoring attacks attempted by pests/weeds/animals. The farmers and other stakeholders can access the data gathered through UAVs from cloud-based platforms remotely through apps from their smart devices which can help in predicting the yield of the crop, requirements like pesticides, fertilizers, seed sowing, etc.



(Alka rani *et. al., 2019*)

Fig. 7 Applications of UAV in agriculture

Table 2: Smart agriculture UAV'S with specifications

Operation	UAV type	Indices	Sensors		References
			Type	**Model**	
Irrigation	Fixed-wing UAV	Crop water stress index, transformed Chlorophyll absorption in reflectance	Multispectral camera	Canon IXUS 125 HS	Baluja *et. al.*, 2012
		Near Infrared domain (NIR), NDVI	Digital camera	Tetracam MCA-6	Romero *et. al.*, 2017
	Quadcopter	Difference Vegetation Index (DVI), NDVI	Multispectral camera	Parrot SEQUOIA	Romero *et. al.*, 2018
Crop monitoring	Octocopter	NDVI, soil adjustment vegetation index	RGB sensor	Panasonic Lumix GX1	Bendig *et. al.*, 2015
	Quadcopter	Green-red ratio index, visible-band difference vegetation index	Digital camera	Sony ILCE-6000	Du and Noguchi *et. al.*, 2017
Spraying	Helicopter	Route precision	Image transmitter	-	Giles and Billing *et. al.*, 2015
	Quadcopter	Droplet coverage rate, density, droplet size	Digital plant canopy imager	Camas CI-110	Pan *et. al.*, 2016
		Observed deposition rate, field work rate	Multi-spectral camera, Hyper-spectral camera, Near-infrared	-	Meivel *et. al.*, 2016

1) Crop spraying: - Drones can be used to spray chemicals like fertilizers, pesticides, etc. as shown in fig. 8 based on the spatial variability of the crops and field. The amount of chemicals to be sprayed can be adjusted depending upon the crop conditions, or the degree of severity of the insect-pest attack. In this way, drones pave the pathway to precision agriculture.

Fig. 8 Crop spraying

2) Crop monitoring: - Drones can be used for monitoring the conditions of crops throughout the crop season as shown in fig. 9 so that the need-based and timely action can be taken. The quick and appropriate action can prevent yield loss. This technology will eliminate the need to visually inspecting the crops by the farmers.

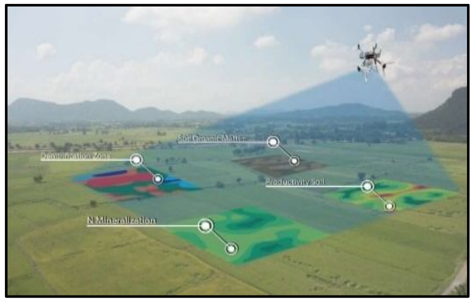


Fig. 9 Crop monitoring

3) Crop irrigation: - Drones loaded with thermal, multispectral or hyper-spectral sensors can identify the parts of the field with moisture deficits using multispectral indices. This helps in planning timely irrigation to the identified areas with precision as shown in fig. 10.

Fig. 10 Crop irrigation

4) Aerial mapping: - By using different kinds of sensors pertaining to visible, NIR and thermal infrared rays, different multispectral indices can be computed based on the reflection pattern at different wavelengths image of aerial mapping is as shown in fig. 11. These indices can be used to assess the conditions of crops like water stress, insect-pest attack, diseases, etc. The sensors present over the drones can see the incidence of diseases or deficiency even before the appearance of visible symptoms. Thus, they serve as a tool for early detection of the diseases. In this way, drones can be used for early warning system so that timely action can be taken by applying the remedial measures based on the degree of the stress.

Fig. 11 Aerial mapping

5) Livestock management: - Drones can be used to manage the large herd of livestock as shown in fig 12. The sensors having high-resolution infrared cameras present over drone can detect the diseased animal swiftly by their heat signatures. The detected diseased animal can then be separated from their fellow animals, and the early treatment can be provided. So, the drone could be used for precision dairy farming (Alka rani *et. al.*, *2019*).

Fig. 12 Livestock management

6) Soil and field analysis: - Drones can be used to mount sensors which are able to analyze as shown in fig. 13 the soil conditions, terrain conditions, moisture content, nutrients content and fertility levels of the soil which can be further used for planning the pattern of sowing of different crops, irrigation scheduling as well as for managing fertilizers application considering spatial variability of the crop growth and field conditions (Alka rani *et. al.*, *2019*).

Fig. 13 Soil and field analysis

7) Pest control: -Apart from soil conditions, drones can also detect and inform farmers about field areas inflicted by weeds, disease and insect pests.

8) Weed identification: - Drones can be used to identify the weeds present in the field. These weeds could be timely rooted out from the field so that they do not compete for resources with the main crop as shown in fig. 14, (Pan *et. al.*, 2016).

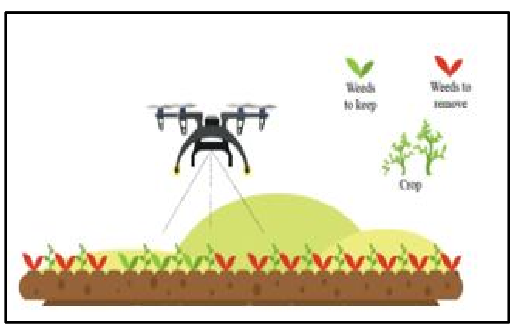


Fig. 14 Weed identification

9) Land surveying: -It is nearly impossible to estimate the overall state of crops in large fields. Drones based agriculture mapping can help farmers remain area-wise updated on the plants status and point out which field areas require attention as shown on fig. 15.

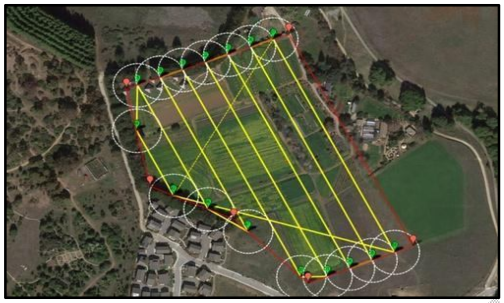


Fig. 15 Land surveying

6. Current trends and future challenges: -

Currently, simultaneous localization and mapping (SLAM) technology, which leverages autonomous driving, is being used with UAVs. SLAM technology maps in real time using a camera and/or LiDAR. It recognizes its own position and identifies obstacles, autonomously traveling or performing tasks. The technology does not require the use of existing controllers, and it is efficient and practical, because it works autonomously. With these developments, we arrive closer to smart agricultural capability (Sofonia *et. al.*, 2019, Nex *et. al.*, 2020). Practical limitations, such as the short flight time, are also expected to be solved by the advancements in technology. These improvements will ensure that farmers can reap more from the use of UAVs for remote sensing in Precision Agriculture (Tsouros *et. al.*).

7. Conclusion: -

This paper gives a systematic and comprehensive overview of the latest development in UAV and sensors. It is apparent that the agriculture industry is undergoing an important turning point during the last few years. The traditional practices in agriculture are transforming into a new "intelligent" perspective in the process of cultivation. Agricultural UAVs show unlimited potential in agriculture. We review the platforms, control, applications of agricultural UAVs, and different sensors that have been developed or understudy. Besides, various limitations, available applications, and the latest trends of agricultural UAVs are introduced to describe the direction of future research. This review paper is regarded as eye-opener for Industry and Agriculture for development and integration of more drones for making Agriculture tasks better and in turn yielding best crop quality in near future.

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