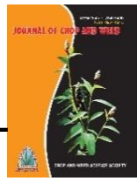
ISSN-O : 2349 9400; P : 0974 6315
Journal of Crop and Weed, 20(1):92-101 (2024)



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Mapping the future of farm management: A comprehensive analysis of application of drone technology in precision agriculture and livestock farming

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Received: 23.02.2024; Revised: 10.03.2024; Accepted: 15.03.2024

DOI: https://doi.org/10.22271/09746315.2024.v20.i1.1764

ABSTRACT

Traditional agricultural management practices are under increasing pressure to improve efficiency, sustainability, and precision. Drones have become transformative tools in agriculture, significantly improving various farming practices. These unmanned aerial vehicles (UAVs) collect real-time data, giving farmers exact information about plant conditions, soil health, water resources, and animal health. This information enables farmers to make informed decisions, optimize resource utilization, and implement targeted measures, resulting in higher yields, less waste, and better farm management. However, there are several challenges that must be addressed, including regulatory compliance, associated costs, efficient data management, adequate training, and public acceptance. Overcoming these challenges is essential for the widespread and successful adoption of drones in agriculture. By overcoming these challenges and continuing research, collaboration, and responsible use, drones can help to make agriculture more sustainable and efficient, with higher productivity and lower environmental impact.

Keywords**:** aerial sensing, crop management, disease detection, livestock management, rotary wing and UAV

Drone or unmanned aerial vehicle (UAV) or remotely piloted aircraft system (RPAS), is an aircraft without a pilot on board that operates either through remote control or autonomous flight based on pre-programmed plans or advanced automation system. Drones normally fly at lower heights to collect remotely sensed data. For agricultural purposes, the most common types of drones are small fixed-wing airplanes or rotary-wing helicopters that are inexpensive, slow, have limited altitude range, lightweight, and carry light payloads with short flight durations (Huang *et al.*, 2013). Furthermore, remote regulated balloons, kites, motorized parafoils, and gliders have been used for agricultural imaging (Pudelko *et al.*, 2012). A key feature of these drones is their inclusion of a low-cost imaging system, automated flight capabilities, and stabilization using inertial navigation sensors, such as the global positioning system (GPS), which enables geocoding of aerial photographs (Anand *et al.*, 2023). The desired image resolution for agricultural purposes is approximately 1–2 centimeters, which is generally superior to satellite-based images (Yusof *et al.*, 2006).

Traditionally, drones have been predominantly recognized for their role in defense operations, thanks to their customizable nature and remote capabilities.

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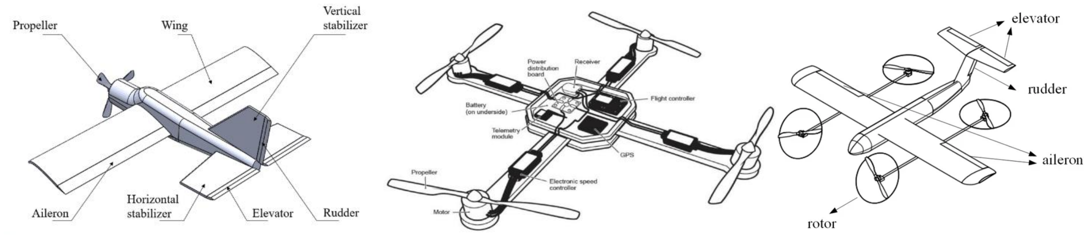
How to cite: Sahni, R.K., Sohail, M.M., Kumar, V., Qureshi, A.A., Dixit, P.S., Pawaiya, R.S. and Tanpure, K.B. 2024. Mapping the future of farm management: A comprehensive analysis of application of drone technology in precision agriculture and livestock farming. *J. Crop and Weed,* 20(1): 92-101.

However, drone technology is rapidly advancing in marine and underwater environments. Automated underwater vehicles (AUVs) equipped with advanced technology are now capable of capturing images of the seabed, fish, and surrounding areas. These capabilities greatly assist researchers in fields like oceanography and habitat research. AUVs are also utilized in the oil and gas industry for inspection activities, as well as by defense organizations for search operations. In contrast, automated drone technology is still in its early stages in the field of agriculture. However, there are some automated drones being employed for data collection, automated seeding, and pollination, eliminating the need for human operators. Drone applications have also been explored for animal tracking and monitoring in farming, including tasks such as domestic livestock management, pasture utilization assessment, monitoring livestock behavior, and tracking grazing distribution. Drones can also aid in the detection of livestock theft or death. The application of drone technology in modern agriculture is gaining significance globally, including in India. Recent studies in India have focused on evaluating the potential of drones for precision agriculture applications. Successful drone studies have already been conducted, employing lightweight cameras (RGB, thermal and multispectral) to perform tasks such as spraying, sowing operations, surveying, and mapping. Therefore, this article aims to provide an overview of drone technology and its applications in agriculture, offering valuable insights for various stakeholders interested in adopting precision agriculture.

Drone types

There are three main categories that drones are typically classified into: fixed wing, rotary wing, and hybrid vertical take-off and landing (VTOL) drones. Fixed wing drones have the benefit of being capable of flying at high speeds for extended periods due to their simpler structure (Fig.1a; Cui *et al.,* 2020). However, these drones require a runway or launcher for takeoff and landing and are unable to hover. On the other hand, rotary wing drones can hover, take off, and land vertically, providing agile maneuvering capabilities. However, they have higher mechanical complexity, lower speed, and shorter flight range. As a result, they are well-suited for detailed inspections and surveying in hard-to-reach areas (Fig. 1b; Stewart *et. al.,* 2021). Drones with combined features of fixed wing type and rotary wing type are known as VTOL drones (Fig. 1c; Zhao *et al.,* 2023). VTOL drones are like multi-rotor systems in terms of takeoff efficiency. VTOL drone is used for surveying and mapping, agricultural monitoring, disaster management, traffic handling, wildlife and forest cover, and military uses.



(a) **(b)** **(c)**

Fig. 1: Drone types used in agricultural field, (a) fixed wing, (b) rotary wing, and (b) hybrid-vertical take-off and landing drone

Drone classification

According to the categorization presented in Table 1 by Anonymous (2021), drones can be grouped into five size classifications, namely nano, micro, small, medium, and large, based on their overall weight, including the payload. The directorate general of civil aviation (DGCA), GOI, has established guidelines stating that individuals operating drones weighing more than 250 g, excluding nano drones, are required to possess a remote pilot license.

Table 1: Classification of drone based on its all up weight (Anonymous, 2021)

Drone type	Weight	Remote Pilot license requirement
Nano	≤ 250 g	No
Micro	250 g to 2 kg	No-non-commercial use Yes-for commercial use
Small	2to 25 kg	Yes
Medium	25 to 150 kg	Yes
Large	> 150 kg	Yes

Basic components of a drone

Drones consist of various components that work together to enable their flight and functionality. Major components of a drone include frame, brush-less motors, propellers, electronic speed control (ESC) modules, rechargeable battery, flight control board, RF transmitter and receiver modules (Kumar *et al.*, 2023; Karar *et al.*, 2021). These components have been shown in Fig. 2 and discussed in following subsections:

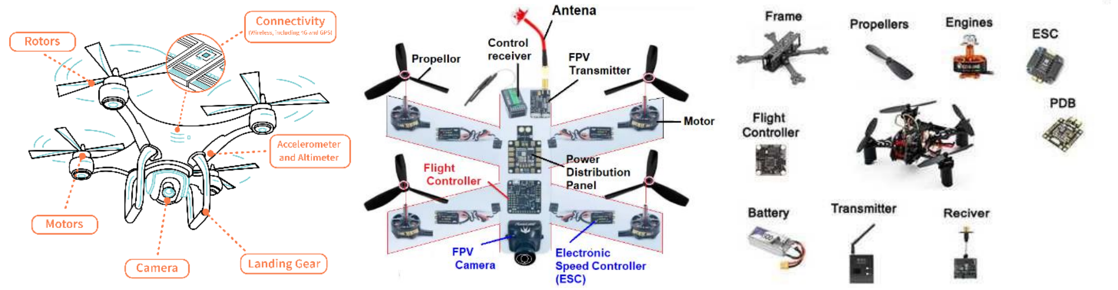


Fig. 2 : Major components of drone

Frame: The structure of a drone consists of a frame, to which components like motors and propellers are attached. Frames are available in different sizes and weight capacities, with the X-shaped frame being the most used design.

Motor: The motors are responsible for rotating the propellers. The speed at which the motor can spin is determined by its kV rating. It's important to note that a higher kV rating results in a faster motor spin. However, it's not always advantageous to have a faster spin. A fast motor spin consumes more power from the battery, leading to shorter flight times. Additionally, a higher RPM can reduce the motor's lifespan in the long term.

Propeller: A quadcopter (four-motor drone) consists of four propellers, with two located at the front that rotate counterclockwise and two at the back that rotate clockwise. The front propellers function like a tractor, pulling the quadcopter through the air. As a result, they are referred to as "tractor" propellers. On the other hand, the propellers at the back push the UAV forward, earning them the name "pusher" propellers. Most drone propellers are constructed from materials such as plastic or carbon fiber.

Electronic speed control (ESC): Each of the quadcopter's four motors is equipped with an ESC. The ESC is responsible for adjusting the speed and direction of the electric motor. It converts the power from the DC battery into 3-phase AC to drive the brushless motors. The ESC ensures that the motors receive the appropriate modulated current, enabling them to spin at the desired rates for lift and maneuvering purposes.

Flight controller: The flight controller serves as the central processing unit of the drone, responsible for receiving and interpreting signals from various components such as the receiver, GPS module, battery monitor, inertial measurement unit (IMU), and other sensors on board. It manages the motor speeds through ESCs to control steering and can activate cameras or other attached equipment. Additionally, the flight controller governs autopilot features, waypoints, failsafe mechanisms, and a range of other autonomous functions.

Radio transmitter and receiver: The operator uses a ground control station (GCS) with a radio transmitter and receiver to control the drone. The flight controller's receiver receives signals from the transmitter. At least four channels are needed to operate the different functions of the drone. These four channels correspond to specific controls on the GCS: channel 1 for controlling the drone's vertical movement (up/down), channel 2 for turning left or right, channel 3 for moving forward or backward, and channel 4 for tilting the drone left or right (ailerons). Additional channels can be available on the GCS depending on its purpose or requirements.

Battery and charger: Lithium ion/Lithium polymer (LiPo) batteries are mainly used to supply power to the UAV. It has high energy density, power density and lifetime. For getting the longer duration operation, a high capacity (in terms of mAh and C rating) battery is required, but it causes the increase of load in quadcopter due to its weight. Hence, optimum selection of battery capacity is very important.

Gimbal: In order to stabilize and point cameras or other sensors, it is rotated within the drone along the x, y, and z axes. A brushless DC motor gives drive to the Gimbal. Rotation of Gimbal is controlled by Gimbal control unit.

Camera: For recording video and taking hyperspectral and multispectral images, a good quality camera is provided. The latest drones are all in one, which come with an integrated gimbal and camera. These cameras and lens are specifically designed for aerial filming and photography.

Sensors: Different types of sensors like thermal sensor, collision avoidance sensors, terrain following sensor obstacle detection sensor and many other types of sensors being mounted onto drones and being used in a wide variety of sectors according to specific application.

GPS module: Waypoint navigation and numerous other autonomous flight modes such as return to home (RTH), GPS coordinates for spraying particular area, measuring /surveying of area etc. depend heavily on GPS.

Application of drone technology in agriculture

Aerial sensing in agricultural field

Drones equipped with appropriate sensors for remote sensing of plant responses to both abiotic and biotic stress, as well as performance in field conditions provides several advantages. The integrated system offers (i) enhanced field accessibility, (ii) high-resolution data with precision ranging from 1 to 2 cm (iii) timely data collection, even in cloudy conditions, (iv) rapid evaluations of field growth conditions, (v) simultaneous image acquisition, (vi) self-automated flights to monitor plots regularly throughout a growing season, and (vii) low operational costs. Various optical sensors, such as thermal, multispectral, hyperspectral cameras, and Light Detection and Ranging (LIDAR) systems, can be used to measure crop growth and development (Tiwari *et al.*, 2019). These sensors rely on the interaction between objects and the electromagnetic spectrum to gather information. This interaction can involve the reflection or emission of light in visible and infrared regions, as well as the measurement of time-of-flight (TOF) of sound or light signals. TOF sensors are commonly employed to assess physical and morphological characteristics of plants, including growth, height, and canopy volume/vigor. Spectroscopic and imaging techniques allow for the evaluation of various plant phenotypes, such as susceptibility to diseases and drought stress, chlorophyll content, nutrient concentrations, growth rates, and potential yield (Zhang and Kovacs, 2012). The specific traits of plants can be correlated with the wavelength of spectral radiation and the amount of light energy detected by the sensors. Different types of sensors used on drones are depicted in Fig. 3. In precision agriculture, small UAVs are utilized for various remote sensing applications (Sahni *et al.*, 2018). These applications encompass weed detection, aerobiological sampling, estimation of leaf area index, characterization of soil, assessment of water status, identification of diseases, pest management, and estimation of yield. Table 2 shows the different sensors and its characteristics which can be mounted on UAV and data can be collected.

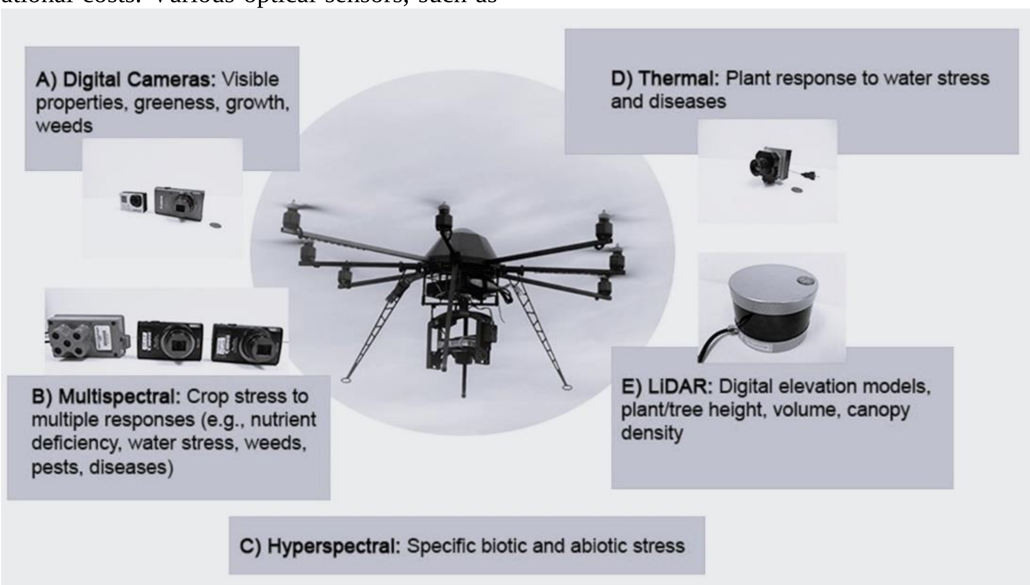


Fig. 3 : Optical Sensors integrated with drone and their application in agriculture (Khot, 2017).

Mapping of crop health using drone surveillance

To aid growers in assessing the condition of their crops, drones equipped with advanced cameras capable of capturing high-resolution multi-spectral, hyper-spectral, and thermal images are being utilized (Kumar *et al.*, 2018). One aspect of this monitoring system focuses on mapping and monitoring the health of horticultural crops, specifically addressing water stress in fruit trees and grape vines. When trees and vines experience water stress, they conserve water by ceasing their transpiration systems, which are responsible for cooling. Consequently, the temperature within the plant canopy rises, and this change can be detected by thermal cameras mounted on drones flying above the crops. By analyzing the thermal data, a water stress map of the crop can be generated within just one hour, with a pixel resolution of 10 cm. This is a significant improvement compared to the traditional method of measuring water stress tree-by-tree, which takes approximately 30 minutes per tree. As drone and sensor technology becomes more affordable and software is developed to automate the collection and analysis of thermal data, this system holds great potential for broad application in the field of horticulture. For orchardists and vineyard owners, maintaining a slight level of water stress can enhance the sweetness and value of their fruit.

Table 2: Sensor used on drone for plant properties characterization (Sankaran *et al*., 2015)

Sensor type	Details	Applications	Limitations
Digital camera (RGB)	Colour or grayscale images (texture analysis)	Visible characteristics, outer defects, greenness, growth	• Only red, green and blue bands and properties
Multispectral camera	5-10 spectral bands for each pixel in image	Multiple plant responses to nutrient deficiency, water stress, diseases etc.	• Only 5-10 spectral bands
Hyperspectral camera	Continuous or discrete (10-200) spectra for each pixel in image	Plant stress, quality, and safety control	• Expensive sensors • Challenging and complex image processing
Fluorescence sensor	Passive sensing in visible and NIR regions	Photosynthesis, water stress, chlorophyll, spraying	• Affected by background noise • Not suitable for UAV based research
Spectrometer	Visible-NIR spectra averaged over a given region of interest	Stresses, disease detection	• Background i.e., soil may affect the data quality • spectral mixing may be possible • Mostly used for ground-based systems
Thermal camera	Temperature of each pixel	Plant responses to water stress and diseases, stomatal conductance,	• Can not detect very small temperature differences • Performance affected by environmental conditions • Havier high resolution cameras
3D camera	IR laser detection utilizing time-of-flight data	Plant height, canopy characteristics	• Limited field applications • Accuracy is lower
LIDAR sensor	Physical characteristics measurement	Accurately estimates plant height, area, and volume	• Receptive to minute changes
SONAR sensor	Sound wave propagation for object detection	Quantification of canopy volumes, used in sprayers or fertilizer application research	• Sensitivity limited by acoustic absorption etc. • Lower sampling rate

Disease identification of agricultural crops

Drones have been employed in agriculture with the aid of image processing technologies for evaluating plant characteristics and detecting vitality issues. One challenge faced in using UAVs for agricultural purposes is the limited duration of flight. To capture a large number of plants within the available time, it is necessary to fly at higher altitudes, but this diminishes the resolution of the captured images. It is of utmost importance to evaluate the condition of crops and detect bacterial or fungal diseases in trees and plants. Drones equipped with sensors play an important role in this process. These devices use visible and near-infrared light to examine crops and analyze how different plants reflect green and NIR light (Chowdhury *et al.*, 2024). This information is then utilized to generate multispectral images that track plant changes and provide an indication of their overall health. A swift response can help save an entire orchard, and prompt detection of diseases allows farmers to apply precise remedies and monitor their effectiveness. These possibilities enhance a plant's ability to overcome diseases. Furthermore, in the event of crop failure, farmers can document losses more effectively for insurance claims.

Judicious and precise application of agrochemicals

According to researchers, the use of drones for aerial spraying is significantly faster compared to traditional machinery, estimating up to five times the speed. Drones offer several advantages over manned crop dusters, including easier deployment, reduced pesticide exposure for operators, and the potential to decrease spray drift (Kumar *et al.*, 2024). For specific crops like groundnut and paddy, drones are capable of spraying approximately 1.15 and 1.08 hectares per hour, respectively. When spraying pesticides from a height of 3.5 meters, drones provide better coverage and uniformity on wheat canopies compared to ground spraying. Adopting drone technology for pesticide spraying can result in considerable savings, such as an estimated 80% reduction in operating time, 90% less water consumption, and a 50% decrease in pesticide usage (Verma *et al.*, 2022). This technology also contributes to efficient water usage by employing ultra-low volume (ULV) spraying techniques. Furthermore, drones enable precise application of nutrients, pesticides, herbicides, and liquid fertilizers to taller trees such as mango, litchi, guava, sapota and various vegetable crops. With the use of drones, over and under use of agrochemicals can be checked and target application of these can be ensured (Sahni *et al.*, 2024).

Assessment of temporal land use

The global land use and land cover are undergoing significant transformations, and this is particularly evident in the eastern plateau and hill regions of India. The utilization of remote sensing technology on drones will be helpful in evaluating the alterations in land use and land cover over a period.

Mapping of weed and crop species

Using drones outfitted with sophisticated sensors and cameras capable of identifying particular crops and weeds can enhance the precision of weed management strategies. This, in turn, can increase the efficiency of mechanical approaches while minimizing the need for herbicide usage.

Horticulture and plantation crop management

Horticulture and the management of plantation crops involve performing tasks such as applying fertilizer to crops at the right moment, insect, and pest detection, as well as weather-related monitoring. Drones with RGB, multispectral, hyperspectral, and thermal cameras can be used to determine the extent of various horticultural crop in the area. These technologies can also be used to assess the expansion of water bodies and the area occupied by water-dependent crops like makhana and singhara, aiding in effective planning and management. Additionally, they facilitate the mapping of water resources on a village or watershed level.

Insurance inspection

The drone possesses traits such as quick and agile maneuvering, capturing high-quality images with great precision for positioning data acquisition. It also can accommodate different task devices for expanded applications and offers convenient system maintenance. These features enable it to effectively carry out tasks related to disaster response. By conducting aerial surveys and analyzing aerial photographs in combination with on-site measurements, insurance companies can obtain more precise information about the actual extent of a disaster. Drones provide insurance companies with a reliable means of assessing damage after a hailstorm, enabling them to easily differentiate between fields with 70% loss and those with 90% loss.

Seed sowing

A drone-based mechanism has been employed for dispersing seeds. The seeds are released once the drone reaches specific locations. These agricultural drones can quickly cover large areas while accurately and precisely distributing seeds at the ideal spacing. In order to ensure consistent coverage and reduce human effort, the drones are programmed to fly over the countryside along predetermined routes. This technology not only makes planting quicker but also enables targeted seeding, which maximizes resource use and supports sustainable agriculture. Drones' capacity to reach difficult-to-reach or uneven terrain amplifies their contribution to raising agricultural yield. The system can drop up to 60 seeds per minute and can disperse a total of 28,800 seed balls within an 8-hour period (Ghazali *et al.*, 2022). Drone seeding and planting systems have been successfully created by startup firms, achieving 75% seed germination rate and 85% reduction in sowing expenses.

Soil mapping and analysis

Drone mapping is more cost-effective than traditional terrestrial mapping, significantly faster (around 68 times), and needs fewer personnel (Ghazali *et al.*, 2022). Additionally, it offers valuable insights into various soil parameters, including pH level, soil type, and chemical composition. The integration of ortho photos, multispectral images, and digital surface model data in drone mapping results in highly accurate classification, with an accuracy rate approaching 90%.

Livestock management

Drones can be utilized in precision livestock farming (PLF) to monitor individual animals in real-time and gather data regarding their health, well-being, productivity, and environmental impact. This application of drones' aids in collecting information through livestock tracking, resulting in improved sustainability of agricultural systems. By identifying pasture areas susceptible to environmental degradation, drones contribute to the efficient and accurate management of agro-ecosystems. Additionally, the implementation of drones with high-resolution infrared cameras enables the monitoring and management of livestock by detecting sick animals and initiating suitable measures for their recovery (Li and Xing, 2019; Alanezi *et al.,* 2022; Li *et al.,* 2022). Common lands are source of food, fodder, firewood and livelihoods to rural communities (Chandra *et al*., 2022).

A. *Monitoring and tracking the animals*

Detecting and pinpointing livestock in agricultural farms may be classified as object detection, which involves identifying and quantifying livestock in images or videos. When tracking livestock in videos or sequential frames, an extra temporal aspect is introduced into the detection process. To track goats, for example, various shape characteristics of the detected contour, including equivalent diameter, roundness, perimeter, aspect ratio, area, contour moment, eccentricity, convexity, form factor among others, can be employed. These features can be utilized to monitor the movement of livestock across frames. Subsequently, these features can be input into different machine learning classifiers to identify specific behaviors or actions (Herlin *et al.,* 2021).

B. *Search of grazing lands including allocation and redistribution*

Understanding the spatial and temporal distribution of livestock is essential for effectively managing grassland ecosystems. To achieve this, the grazing area can be divided into grids, and the number of livestock in each grid can be counted using images from drones. To gather scattered livestock together, multiple drones can be employed for a coordinated goat roundup. Satellite images of the pasture can provide GPS coordinates of the animals, which can be further enhanced by attaching GPS modules to the goats. Drones determine the best flight path to guide the animals to the desired location, taking into account the shape of the region and the target position. Continuous tracking of the distance between the animals and the drones allows for optimization of the drones' trajectory.

C. Livestock health monitoring and optimal distribution in the grazing land

Using the photographs and videos taken by drones, an intelligent surveillance system can monitor health and behavior-related issues. Drones can be useful in monitoring livestock health, which includes checking their blood pressure, temperature, and other parameters. The temperature information emitted from the Radio Frequency Identification (RFID) tags fastened to a goat or sheep's ear can be recorded using drones equipped with an RFID repeater. Furthermore, taking clear pictures with the linked drone camera can make it easier to visually evaluate the area and find any additional issues. Moreover, recent software is also capable of analyzing videos in order to monitor respiration rate and heat stress. By recording an animal's feeding behavior and quantifying the number of times and amount of food consumed, feeding behavior monitoring can assist in the detection of sick cattle (Alanezi *et al.,* 2022).

D. *Autonomous livestock health monitoring system*

The progress in sensor and connectivity technologies, including the imminent arrival of 5G in India, will enable the integration of drones and Internet of Things (IoT) systems. This integration can be utilized for tasks such as collecting data, analyzing it, and making real-time decisions in livestock health and production management. Moreover, this application can benefit from additional tools like artificial intelligence, machine learning, and deep learning techniques (Alanezi *et al.,* 2022).

E. *Water and asset management*

Drones possess the ability to swiftly and effectively survey and manage assets, resources, and land, whether they are large or small in size, due to their safe and relatively fast flying capabilities. In modern times, farms are utilizing drones to monitor and control water levels in dams and other hard-to-reach resources, which eradicates potential risks for operators and the surrounding environment.

F. *Animal stock management*

With the expansion of herd sizes and farms, effectively managing and keeping track of stock counts and numbers becomes challenging. However, one potential solution to address this issue is the utilization of drones, which can accurately count and identify areas of concern from a distance. By employing drone cameras, stock movements can be monitored and recorded for further analysis. Several advantages come with this strategy, such as lower costs, increased output, and better operational efficiency (Alanezi *et al.,* 2022).

G. *Fodder and other crops yield*

To ensure optimal care for fodder crops and fields, it is crucial to assess the crops regularly in order to make informed decisions regarding their management. Drones can play a valuable role in expediting this process and identifying specific areas that require special attention. Equipped with advanced sensors that offer precision and accuracy, drones can effectively detect indicators such as water stress, nutrient deficiencies, and soil degradation. By incorporating drone technology into farming practices, the cultivation of fodder and other crops can be made more economically and environmentally efficient by prioritizing care for the areas that need it the most.

Laws related to use of drones in India

The drone regulation in India, known as the drone rules-2021, was officially announced on August 25, 2021. (Anonymous, 2021). These rules apply to all registered drones being operated in India, as well as to individuals who operate, own, lease, transfer, or maintain a UAV in the country. When flying a drone of over 250 grams, operators must adhere to the regulations: Every drone needs to be registered on the DGCA, GoI's digital sky platform and have a unique identification number (UIN). Before every flight, operators need to consult the airspace map on the digital sky platform of DGCA. Drones are not permitted to fly in the red and yellow zones indicated on the dynamic airspace map without prior permission, while no permission is required for flying in the green zone. Drones shouldn't be flown over big crowds or densely populated places. Drone flights should only take place during daylight hours and under favorable weather conditions. It is highly forbidden to fly drones in critical places, such as military or government buildings, and drones, including camera drones, are prohibited in restricted areas. Operators must be at least 18 years old, have good visibility certified by a doctor's fitness certificate, and have completed a training course. Every drone must have a license plate with the operator's name and contact details on it. Drones should only be operated within a visual line of sight, and flying more than one UAV simultaneously is not permitted. Any drone larger than a nano drone needs to be insured against liability by a third party. Any accidents must be reported to the DGCA's digital sky platform by owners or remote pilots within 48 hours.

Restrictions of using drones in agriculture

When it comes to practical applications, drones face several limitations. These limitations encompass various aspects such as standards, payload, operation, cost and reliability. There is currently no established protocol that governs the technical and economic aspects of any specific project. While it is possible to minimize the costs of the drone itself and its camera, the assembly process still demand substantial time and labor, even for skilled engineers and technicians. This can potentially increase the overall cost. The limited carrying capacity of lightweight drone payloads poses a significant constraint in agricultural applications. It is vitally important that UAV system designers and users carefully choose the best payload that fits the mission requirements. (Torun, 2000). The design of the payload, along with the mechanical and electrical accommodations for drones, are crucial considerations for successful agricultural applications. Drone can be flown either in an automated or manual manner. For practical use in agriculture, the ability to perform GPS-based autonomous flights is highly desirable. However, crashes and component failures contribute to increased costs and hinder the availability of drones for agricultural operations. Researchers believe that the pursuit of low-cost requirements is leading designers to compromise on safety measures, and there is a need for enhanced safety and reliability to establish trust in UAVs for performing tasks (Bhamidipati and Neogi, 2007).

CONCLUSION

Low altitude aerial images obtained through drones have become one of the most widely used methods for determining the characteristics of plants and soil. Drones offer real-time and high-quality aerial imagery for weed and disease detection, soil property determination, identification of vegetation variations, and the creation of precise elevation models. By utilizing drones, farmers can acquire comprehensive knowledge about their fields, which in turn aids in increasing food production while minimizing chemical usage. Furthermore, drone spraying technology has been becoming popular among farmers and has significant potential and may involve electrostatic nozzles, adjustable spray nozzles for controlling droplet size and flow, ultra-low-volume liquid, nano biological agents, and chemical adjuvants. Drones have the potential to change conventional farming processes and introduce smart farming practices, if they are widely adopted in the agricultural sector. Drone technology has applications in agriculture that go beyond increasing crop yield; it also protects farmers. While these technologies have had limited application in the Indian context according to reports and documents, their usage is likely to increase in the near future for various applications. These applications include plant health monitoring, disease and pest control, efficient water management, characterization of water body, soil health monitoring, livestock monitoring, planting, and other multiple uses from farms to households. The advantages of drone technology are numerous, including significant input savings such as operating time, pesticide use, fertilizer costs, water consumption, and planting expenses. Both central and state governments in India are actively promoting this advanced technology through various policies and schemes in collaboration with agricultural institutions and industries. With appropriate research-based modifications and applications, drone technologies can significantly contribute to the economic management of livestock health and production, as well as cost reduction in pasture and crop field operations.

ACKNOWLEDGEMENTS

Authors would like to thank the PBC's AERO HUB's instructors, especially Mr. Ganesh Arvind, Mr. Pranav B Chitte, Ms. Anjali Chitte and other staff for training and teaching us (batch number-25, group- A) the know-how of flying drones.

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