Review Article

Harvesting Efficiency: The Rise of Drone Technology in Modern Agriculture

Abstract

The abstract delves into the transformative impact of drone technology on modern agriculture, specifically focusing on its role in enhancing harvesting efficiency. Drones, equipped with advanced sensors and imaging capabilities, have revolutionized traditional farming practices by offering real-time data collection and analysis. This abstract explores how drones facilitate precision agriculture through the optimization of harvesting processes, including crop monitoring, yield estimation, and targeted harvesting. By leveraging drones, farmers can make informed decisions to improve productivity, minimize waste, and maximize yield. The abstract highlights the integration of drone technology into agricultural operations as a sustainable solution to meet the growing demand for food production while minimizing environmental impact. Moreover, it underscores the need for further research and development to fully harness the potential of drones in modern agriculture and address challenges such as regulatory hurdles and cost-effectiveness.

Keywords: drone, yield, maximize, productivity, research

Introduction

When compared to the agriculture sector, which contributes 18% to India's Gross Domestic Product, the service sector is the most important contributor to the country's GDP. Approximately 58% of the population, mostly those living in rural regions, regard this industry to be their principal means of subsistence[1]. As of the year 2019, the agriculture industry, in conjunction with the forestry and fisheries industries, contributes around Rs. 18.55 lakh crore, which is equivalent to approximately $265.51 billion in US dollars. On the other hand, the nation is confronted with a number of obstacles, including insufficient techniques for monitoring crops, water irrigation, the use of pesticides, and other essential agricultural tasks[2].

From the very beginning of its existence, technology has been exerting a favourable influence on the agricultural industry. The significance of food security, as well as the repercussions of environmental deterioration, pollution, and water shortages, has been acknowledged by both domestic and international governments and corporations. The effects of climate change and pollution on the environment are significant worldwide problems that have a significant influence on agricultural output. The conventional farming methods, in addition to other variables such as deforestation and the burning of fossil fuels, are contributing elements that contribute to the escalation of global warming and other associated difficulties. The practice of sustainable agriculture is one of the potential solutions to the problem of environmental degradation and the reduction of emissions of greenhouse gases, which would in turn mitigate the impact of climate change[3].

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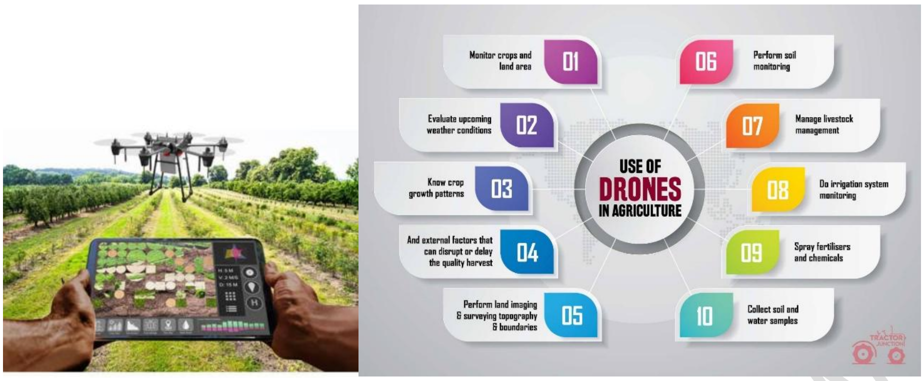

fig 1 :Use of drones in agriculture

Drones, also known as unmanned aerial vehicles (UAVs), may use either an autopilot or GPS coordinates to fly along a predetermined path, or they can be manually controlled by radio signals using a remote control or an app on a smartphone. Drones are able to detect objects that are beyond the visual range of human sight because of the availability of a large number of sensors. This allows them to provide information that is more accurate, reliable, and objective in real time[4]. Drones have a wide range of uses in a variety of industries, including but not limited to: military surveillance, cinematography, wedding films, monitoring of railway tracks, monitoring of animals, transportation of small goods, security objectives, law enforcement operations, search and rescue operations, and disaster management[5].

Currently, drones are becoming an integral part of precision agriculture and are making a contribution to the development of sustainable agriculture. There are many applications for them, including the counting of plants, the modelling of elevation, the visual inspection of agricultural fields, the management of water, the analysis of erosion, the counting of plants, the analysis of soil moisture, and the evaluation of crop health, the scheduling of irrigation, the study of plant physiology, and the forecasting of yield. The construction of unmanned aerial vehicles (UAVs) may be broken down into two categories: fixed-wing and multirotor. An aerial survey, the capture of high-resolution aerial images, mapping, and land surveying are all appropriate applications for fixed-wing unmanned aerial vehicles (UAVs). On the other hand, multirotor UAVs are the most effective for monitoring and the detection of agricultural pests, diseases, and weeds[6].

In many respects, the data obtained by drones is superior to the data collected by satellites. Drones are able to circumvent cloud obstructions, which allows them to avoid losing data during the monsoon season. In addition, drones may be operated at any time, but satellites can only travel over the sky at a certain time that has been predetermined. In order to improve the accuracy of the data collected by drones, it might be combined with data collected by satellites[7].

<u>Overview</u>

The Normalized Distinction Vegetation Index (NDVI) was used by Pedari and Cheporniuk (2015) in order to identify regions that lacked soil productivity in the context of agricultural spraying. Within the realm of intelligent agriculture, crop spraying has a significant place,

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Comment [114]: Same refence methods used and the use of land-based agricultural aircraft and sprayers that have been updated is continually growing. A total of forty percent of all grain fields in Japan are sprayed with the assistance of intelligent drones.

Using information from Landsat, Murugan et al. (2016) were able to distinguish between sparse and dense plant communities, and the impacts of their findings were shown with the use of drones. SAM, which stands for spectral perspective mapper, was categorized, and spectral signs were updated from hyper spectral and uneven signatures derived from time series multi-spectral up-to-date graphs for croptype class. The usage of drones has been foreseen by Floriano et al. (2017), and the use of drones may be good for decreasing the quantity of deadly little insects that are present within the crops. This possibility has been brought up by the researchers.

Two different methods were created by Porrino et al. (2018): the parasite moving algorithm and the allocated algorithm. A continuous memory was used by the drone, which maintained up-to-date facts about places that had been visited in the past. When the drone arrived, it immediately updated the data that had just been discovered. At the same time, the drone itself eliminated the records that were not productive, which allowed the intelligent drone to date pick the following step. The intelligent drone obtained data of the area that was surveyed, and then it chose the path that had not been investigated. The intelligent drone chose the region that was unmarked and close to the other drones in the proximity.

The approach of parasite transmission monitors the parasite regardless of the movements of the many animals and their environments. The view of the location's surroundings is restricted to a certain extent. When a crop is infected with a parasite, the parasite continues to reproduce until the plant dies. In the event that it is located in a field area that does not include a plant, its metrics will be changed in order to locate one.

fig 2 :parasite transmission monitoring

The Phantom 3 UAV, which was utilized by Quiroz et al. (2019), is equipped with a half-third digital camera that has a twelve-meter field of view lens, a ninety-four-by-twenty-millimeter field of view lens, and an RGB color area to capture updated seize area images of the field. These images have been used to carry out crop recognition using segmentation strategies and randomized Hough rework approaches. The YCrCbcolor area and the Gaussian Adaptive Segmentation (GAS) are the two primary phases that are involved in the process of tree sectioning. OpenCV is used for the purpose of recording updated photographs in the YCrCbcolor space, where the Y component maps the luma component of the image. It has been determined that the components of chromination differential have been modified to

reflect pink and blue, respectively, for the Cr and Cb indica categories.
During the GAS (Gaussian Adaptive Segmentation) stage, the GAT (Gaussian Adaptive Threshold) at the Cr portion is used to separate the wood that is included inside the picture from the rest of the images. A technique known as the randomized Hough rework method, which looks for forward strains during image updates, is used in order to fulfil the task of line identification. Eighty-six percent is the capability of this method.
The use of drones in intelligent agriculture may assist in the identification of regions that are deficient in soil production and can also lower the danger of illnesses and pests.

Various kinds of drones that are used in agricultural settings

Drones are used in agriculture in a variety of different ways, and there are various distinct kinds of drones. The skills and characteristics that are unique to each kind distinguish them from one another and make them appropriate for a variety of jobs. The following is a list of some of the most used kinds of drones in the agricultural sector:

(1) Drones with Fixed Wings

There is a kind of unmanned aerial vehicles (UAV) known as fixed-wing drones. These drones are somewhat similar to small airplanes. The fixed-wing architecture of these drones, in contrast to the multi-rotor design of multi-rotor drones, enables them to remain in the air for longer periods of time and cover more land. In most cases, they are launched manually and flown with the assistance of a remote control or a flight plan that has been pre-programmed[8]. In the agricultural industry, fixed-wing drones are often used for mapping fields, monitoring crops, and spotting possible difficulties such as pests or irrigation problems. Surveying, mapping, and aerial photography are some of the other use cases for these devices. Fixed-wing drones are a popular option for precision agricultural applications because of their capacity to cover bigger regions and their ability to fly for relatively lengthy periods of time. On the other hand, because to their increased complexity and the need of a bigger open area for take-off and landing, they may be more difficult to pilot than multi-rotor drones. Drones with fixed wings are often used in the agricultural sector for duties like as mapping, surveying, and crop monitoring[9]. A high-resolution aerial photograph of farmland is being collected for the purpose of conducting crop health assessments. Mapping fields in order to find changes in the health of the soil and the quantities of nutrients and Keeping track of the development and growth of our crops throughout time[10].
By carrying out topographic assessments of agricultural land in order to assist in the planning of irrigation, they Capable of covering enormous regions in a timely and effective manner they are able to fly for longer lengths of time thanks to the efficient design of their aircraft. Has the capability of being outfitted with high-resolution cameras and sensors for the purpose of collecting detailed data[11]. It is able to function even under hostile weather conditions
As a result of their more straightforward construction, they have a longer lifetime than multi-rotor drones. However, they need a big open space in order to take off and land. Because they are dependent on a runway, there is a possibility that they are more difficult to operate than multi-rotor drones. In contrast to multi-rotor drones, it is not possible to hover or make rapid alterations to the flight path. As a result of their more complicated design, multi-rotor drones could need more maintenance than single-rotor drones[12].

2. Drones with a Single Rotor

Unmanned aerial vehicles (UAVs) with a single rotor, commonly referred to as helicopter drones, are used in the agricultural sector for the purpose of capturing high-quality photographs and data for the purpose of crop mapping and analysis. Due to the fact that they have a single rotor blade and are able to take off and land in a vertical position, they are able to hover in place and fly with more precision than fixed-wing drones[13]. Compared to multi-rotor drones, single-rotor drones are often bigger and more costly. However, they have the potential to carry greater payloads and have longer flight periods, which makes them perfect for more sophisticated applications such as precision agriculture. In addition, they are outfitted with sophisticated sensors and cameras that are able to gather information on the state of the soil, the health of the crop, and other environmental elements[14]. It is generally agreed that single-rotor drones are a very useful tool for farmers and agricultural researchers who are aiming to increase crop yields and efficiency, as well as decrease expenses and the effect they have on the environment. Compared to fixed-wing drones, single-rotor drones are often used for activities that need a higher level of specificity and precision. Compared to fixed-wing drones, they are more maneuverable and nimble. It is more suitable for fields that are either tiny or unevenly shaped. Has the ability to remain stationary for long periods of time, which enables more accurate data collecting. Compared to drones with fixed wings, we have a shorter flying time. Greater difficulty in both operation and maintenance. The cost is higher than that of fixed-wing drones[15].

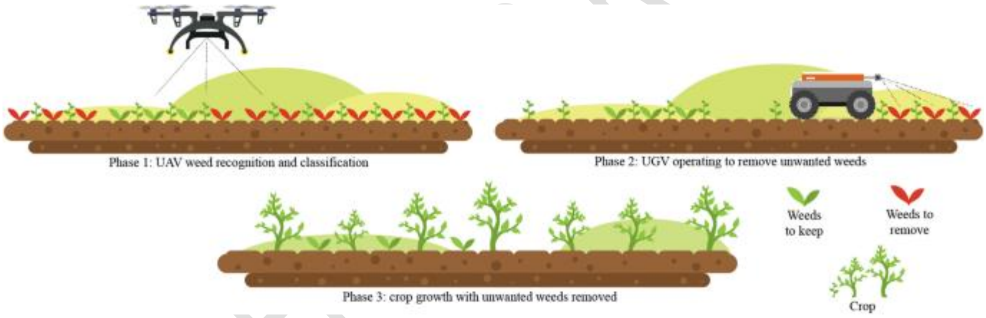


fig 3: Drones with a Single Rotor

3. Drones with Multiple Rotors

Some of the most common types of drones used in agriculture are multi-rotor drones, which are characterized by the presence of numerous rotors that are installed on the body of the drone. Because of their great degree of maneuverability and their ability to fly in any direction, these drones are well suited for close-range missions such as crop monitoring and monitoring of crops[16]. Multi-rotor drones are often used for the purpose of mapping and surveying huge agricultural regions. These drones provide high-resolution aerial photography that may be utilized for the purpose of determining the health of crops, identifying irrigation problems, and monitoring the spread of diseases and pests. Farmers are able to identify stress in plants and regulate irrigation and fertilizer appropriately when they are equipped with modern sensors such as thermal cameras, which can detect temperature differences in crops. These sensors may also be combined with other advanced sensors[17]. Drones with several rotors have the benefit of being able to hover in position, which enables them to gather and monitor data with greater precision. On the other hand, in comparison to fixed-wing drones, they have shorter flying periods and smaller ranges, which might restrict their usefulness in big agricultural operations. In the field of agriculture, hybrid drones combine the many benefits that are associated with both multirotor and fixed-wing drones[18]. These drones are equipped with the capabilities of vertical take-off and landing (VTOL), which are comparable to those of multirotor drones, as well as the expanded range and endurance afforded by fixed-wing drones. Because of their hybrid design, these drones are able to take off and land in a vertical orientation, which makes it simple for them to launch and land in restricted places or uneven terrain[19]. Additionally, they are able to fly horizontally for prolonged periods of time, which enables them to cover bigger amounts of farmland more efficiently. It is possible for hybrid drones to gather a broad variety of data on crops and fields since they are outfitted with a variety of sensors and cameras. Farmers are able to get significant insights on the health and condition of their crops as a result of their ability to collect high-resolution photographs and build precise maps of farms. They may also be used to monitor the levels of moisture in the soil, identify parts of the farm that may need more irrigation or fertilizer, and detect any signs of crop stress[20].

When it comes to large-scale agriculture operations, hybrid drones are perfect because of their enhanced range and durability. Within a single trip, they are able to cover bigger areas of farmland, which reduces the need for several flights and increases the efficiency of the operation. Furthermore, because of their prolonged flying length, they are able to stay in the air for longer periods of time, which makes it much simpler to monitor crops and identify any changes in their health[21].

Within the realm of agriculture, hybrid drones provide a number of benefits, one of which is their capacity to function in a larger variety of weather conditions. In contrast to fixed-wing drones, which must be launched from a runway or other designated location, hybrid drones are able to take off and land in a vertical position, which makes them less vulnerable to wind and rugged terrain[22].

Hybrid drones

Unmanned aerial vehicles known as hybrid drones combine the characteristics of fixed-wing and multi-rotor drones into a single kind of aircraft. As a helicopter, they are able to take off and land, and as an aircraft, they are able to fly. The employment of electric motors and gasoline engines in tandem allows hybrid drones to attain better flying periods and range than their conventional counterparts[23].

There are several applications for hybrid drones in the agricultural industry, including crop mapping, crop scouting, and pesticide spraying, to name a few. The capability of hybrid drones to take off and land vertically, in conjunction with the range and speed of fixed-wing drones, makes them an excellent choice for large-scale agricultural operations.

Compared to fixed-wing or multi-rotor drones, hybrid drones have a larger flying duration and range than their counterparts[24].

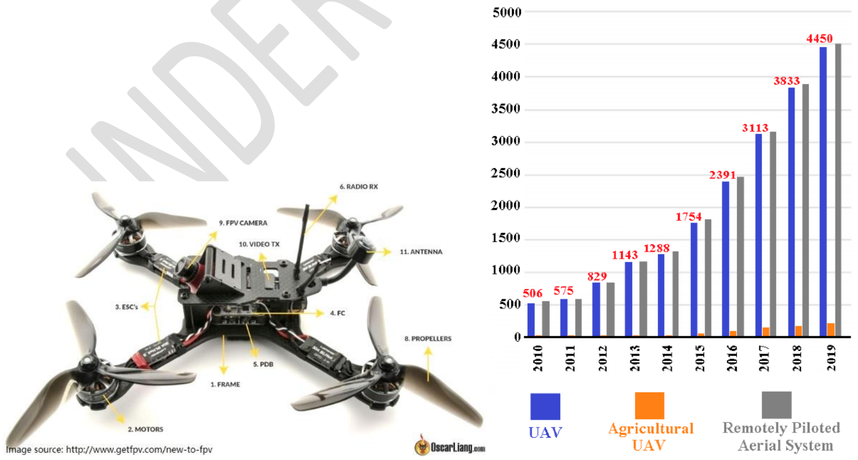
Because they are able to take off and land in a vertical position, there is no need for a runway. The ability of hybrid drones to carry greater payloads makes them an excellent choice for applications involving agricultural spraying.

Imagery with a high resolution may be obtained with hybrid drones, which allows for precise mapping and crop analysis. In comparison to other kinds of drones, they are more

complicated and need more frequent maintenance[25].
To fly hybrid drones in a manner that is both safe and successful, specialist training is required. It is possible for hybrid drones to contribute to both noise pollution and air pollution if they are powered by gasoline engines. To summarize, hybrid drones are the most cutting-edge sort of drone that is used in contemporary agricultural practices[26]. They are superior to other kinds of drones in terms of versatility, range, and flying length, which makes them an excellent choice for large-scale agricultural operations. The advantages that they provide make them a reasonable investment for many farmers and agricultural enterprises, despite the fact that they are more costly and sophisticated than other kinds of drones with the same capabilities[27].

<u>Sensor Technologies in Drones Used for Agriculture</u>

Agricultural drones are outfitted with a wide variety of sensors that are able to gather information on crops, soil, and other elements that have an effect on farming. The use of these sensors enables farmers to evaluate the data and make choices based on that analysis in order to maximize their harvests[28]. There are several kinds of sensors that are used in agricultural drones, and each of these sensors has a distinct function.
The following are some of the sensors that are used in agricultural drones the most frequently:-
<u>RGB Cameras</u> = These sensors are capable of capturing high-resolution pictures of crops, which in turn provides farmers with comprehensive information on the health of their crops, growth rates, and possible problems such as insect infestations[29].
Farmers are able to monitor plant health, detect nutritional deficits, and spot early symptoms of illness with the use of multispectral cameras, which are sensors that gather data in many wavelengths[30].
<u>Thermal cameras</u> = the thermal cameras are sensors that analyze heat signatures and provide farmers with crucial information about plant stress, watering requirements, and even insect infestations[31].



<u>Fig 4 :Sensor Technologies in Drones Used for Agriculture</u>

LiDAR = The LiDAR sensors are able to generate three-dimensional maps of the landscape by using lasers. This provides farmers with the ability to examine topographical data, recognize crop trends, and plan for more effective planting[32].
GPS = The Global Positioning System (GPS) is a sensor that gives drones the ability to fly independently and correctly map fields, monitor crop development, and assess possible problems[33].
Through the use of these many sensors, agricultural drones have the potential to assist farmers in making more informed choices, which ultimately results in farming techniques that are more productive and efficient. As an example, multispectral cameras have the capability to identify signs of agricultural stress before they are apparent to the naked eye[34]. This enables farmers to take preventative measures before the crop is harmed. The use of thermal cameras enables farmers to detect regions of low or high plant stress, which in turn allows them to modify the amount of irrigation or fertilizer they apply. In general, sensor technologies that are integrated with agricultural drones have changed current farming operations, making it possible to produce crops in a manner that is both more sustainable and more efficient[35].

The Equipment Used in Precision Agriculture

The practice of precision farming is characterized by an approach to farming that is very scientific.
The health of a crop is determined by a number of factors. Beginning with the seedling stage and continuing through the harvesting phase, there are a multitude of aspects that need to be taken into consideration. The information that has to be gathered includes things like the composition of the soil, the existence of weeds and pests, and irrigation systems. On top of that, this is just the beginning. Each of the following pieces of equipment and pieces of technology would be necessary in order to have a completely effective precision agriculture setup:

- The use of auto-guidance equipment allows for the successful application of systems such as insecticides and irrigation over extensive areas of land[36].
- The variable rate technology allows for the modification and modulation of the rate at which chemicals and water are dispensed in accordance with the requirements.
- Drones or satellite photos are examples of remote sensors that may be used to gather photographs of farms[37].
- The Geographic Information System (GIS) software is a strong piece of software that can analyse geographical data and provide valuable insights for intelligent decision making.

Importance of drones in agriculture

Over the last several years, the use of drones, which are often referred to as unmanned aerial vehicles (UAVs), has been more widespread in the agricultural sector. These aerial vehicles provide a broad variety of advantages, such as enhanced crop monitoring, accurate mapping, and the capacity to administer fertilizers and pesticides with a precision that is unmatched by any other method. Within the scope of this blog article, we will investigate the many ways in which drones are bringing about a transformation in contemporary agriculture[38].
1. Monitoring of the Crops

In the context of contemporary agriculture, the capability of drones to successfully monitor crops is among the most important advantages they provide. These drones, which are fitted with cameras and sensors that have a high resolution, have the capability of providing farmers with real-time information on the health and condition of their crops[39]. Farmers are able to immediately detect any issues, such as nutritional deficits, insect infestations, or illnesses, and take fast remedial activities as a result of this. Farmers may also use drones to monitor the growth and development of their plants, which provides them with crucial data that can be used to maximize agricultural production[40].

2. Cartography

The use of drones also allows for the creation of precise maps of agricultural fields, which may assist farmers in determining which portions of their farms need further care. Using the Global Positioning System (GPS) and other modern sensors, drones are able to generate three-dimensional maps that are very precise[41]. These maps may display the topography, soil composition, and other important aspects of the farm. The use of these maps may assist farmers in making educated judgments on the agricultural kinds that are most suitable for planting, optimizing irrigation systems, and improving crop management in general[42].

3. Dusting of the Crops

The use of aircraft or helicopters for crop dusting was a traditional method historically. On the other hand, drones are now being used to administer pesticides, herbicides, and fertilizers with an exceptionally high degree of precision. As a result of drones' ability to spray crops with more precision, the quantity of chemicals that are required is reduced, and the effect on the environment is minimized[43]. In addition, drones have the capability to visit regions that are difficult or even impossible to access using conventional techniques, such as regions with rugged terrain or steep slopes inside the area[44].

4. The Observation of Livestock

Drones may also be used for the purpose of properly monitoring livestock. In addition to lowering the amount of physical work that is required, they are able to offer farmers with real-time information on the health and location of their animals, so enhancing the overall wellbeing of animals. It is also possible for drones that are fitted with thermal sensors to detect changes in body temperature, which allows them to identify animals that may be wounded or ill[45].

5. Irrigation Management

It is also possible for drones that are fitted with sophisticated sensors to assist farmers in optimizing their irrigation systems, which would result in less water being wasted and increased agricultural yields. Farmers are able to irrigate their crops with more precision and efficiency when they use drones since they can offer data on the levels of soil moisture[46].

6. Planting

There is also the possibility of using drones to plant crops, which would provide farmers with a technique of planting that is both more efficient and less expensive. When compared to more conventional techniques, drones are able to plant seeds at a quicker pace, allowing them to cover a bigger area in a shorter period of time. This may be particularly helpful for agricultural activities that are carried out on a broad scale[47].

7. Estimation of the Yield

It is also possible for drones that are fitted with sophisticated sensors to assist farmers in properly estimating agricultural yields. Drones have the ability to offer farmers with data on the productivity of their crops by monitoring the height and density of the crops[48].

Fig 5 :Importance of drones in agriculture

Drones designed for use in agriculture are having a huge influence on modern farming operations. These drones are giving farmers with useful technologies that can be used to improve their agricultural processes[49]. The use of these remotely piloted aerial devices is bringing about a modernization in the way that farmers manage their fields and plants, which ultimately leads to increased production and environmental responsibility[50].

<u>An Overview of Crop Health from a Bird's-Eye Perspective</u>: Assessing Field Performance In order to obtain information on their crops from above, farmers now have access to a high-tech method. Drones that are outfitted with advanced software are used to remotely fly over fields in order to gather important data on the plant life below[51]. They do more than just monitor the crop in a passive manner; they assess the crop's health, measure the growth trends, and provide essential information. Drones, which are able to fly at a constant height, are able to carefully inspect whole fields, identifying issues such as poor drainage or problematic soil quality. Farmers then utilize this knowledge as a guide, concentrating their efforts on specific areas that need attention. This, in turn, leads to decisions that are better informed and have a greater effect[52].

<u>Targeting Crop Threats with Accuracy through Precision Pest Control</u>: In the cautious application of pesticides, drones have the potential to play an important role. It is possible for a crop spraying drone to identify specific areas that need treatment by scrutinizing information on the health of the crop[53]. By making the most of what is available, this targeted strategy reduces the amount of chemicals that are needed, which in turn benefits both the environment and the financial situation of farmers. The outcome is a method of pest control that is less harmful to the environment and more cost-effective, allowing farmers to address problems in a manner that is both accurate and efficient[54].

<u>Targeted Nutrient Delivery</u>: Agriculture spraying drones, which make use of modern data processing, make it possible to precisely distribute fertilisers in the areas of crops that need them the most. This concentrated approach to the provision of nutrients helps to avoid excess and ensures that plants are in the best possible health[55]. Farmers are able to reduce their expenditures without compromising the quality of their output, so striking a balance between financial viability and environmental responsibility. It illustrates a creative method of

applying fertilizer, which achieves the most possible results while having the least possible negative influence on the environment[56].

Surveillance from Above: Effectiveness in the Field and the Monitoring of Livestock: When fitted with standard cameras, drones offer farmers a time-saving and effective method of surveying big regions in a short amount of time[57]. Whether it's checking on animals or inspecting fields after a storm, drones provide a time-saving alternative to the more conventional methods of inspection, which include walking along or driving a vehicle. The use of this airborne surveillance technology not only improves crop management but also shows to be advantageous in terms of properly monitoring and controlling animals. Having the capacity to immediately evaluate and react to circumstances is essential to ensuring the health and safety of both crops and animals, which in turn contributes to the total production of the farm[58].

Fig 6 :Overview of the report analysis

Factors affecting cost of drones in agriculture

In India, the cost of agricultural drones is influenced by a number of components.

The use of agricultural drones has grown more common among farmers in India as a means of enhancing farming techniques and making harvests more substantial. On the other hand, the expense of owning and operating drones might be a significant burden for farmers who are considering making an investment in this technology. It is possible for the price of agricultural drones in India to fluctuate greatly based on a number of different variables. In the next blog article, we will investigate the primary elements that have a role in determining the price of agricultural drones in India.

(1) The Kind of Drone

There is a key aspect that may have an effect on the pricing of agricultural drones in India, and that component is the kind of drone. There are many different kinds of drones that are now available on the market. These drones range from smaller, more basic versions to bigger, more complex models that are geared for usage in commercial settings. The price range for entry-level drones that are intended for amateurs and small-scale farmers is normally between Rs. 50,000 and Rs. 1,50,000. On the other hand, the price of more sophisticated models that are intended for commercial usage may range anywhere from Rs. 500,000 to Rs. 500,000 or even more.

2. Feature and Capabilities of the Device

There are a number of important factors that influence the price of agricultural drones in India, one of which is the capabilities and characteristics of the respective drone. There are drones that are fitted with modern imaging technology that may give farmers with extensive information on the health and condition of their crops. On the other hand, there are drones that may be more basic and provide limited functionality. It is possible for simple types of drones to be more costly than more sophisticated models that include superior imaging technology, extended flight times, obstacle avoidance sensors, and GPS capabilities.

3. The Manufacturer and the Brand

There is also the possibility that the cost of agricultural drones in India is influenced by the brand and manufacturer of the drone. Brands that have been around for a long time, like as DJI, Parrot, and Yuneec, are well-known for manufacturing drones that are of superior quality and come equipped with features that are considered to be cutting-edge. On the other hand, India is home to a number of local and less well-known manufacturers that provide drones that are available at more inexpensive prices.

4. The costs of general upkeep and repairs

The initial investment required to acquire an agricultural drone is only one component of the total cost of ownership for this kind of operation. While purchasing an agricultural drone, it is important to take into consideration the costs associated with its maintenance and repairs. It is essential to do routine maintenance on the drone in order to improve its performance and ensure its life. In the process of estimating the total cost of ownership, farmers should take into account the expenses associated with maintenance, batteries, and replacement components.

5. Costs Related to Training and Support

When contemplating an investment in agricultural drones, it is important to take into account the fees associated with receiving training and assistance in order to efficiently operate the drone. In order for farmers to be able to make choices based on accurate information, they need to be taught on how to operate the drone, take pictures, and evaluate data. In addition to the drones themselves, several manufacturers also provide training and support services, which may incur extra fees [80].

Benefits of drones technology

New technologies are being introduced by inventors, and their commercial applications are growing on a daily basis. The government has been reducing the limits placed on the use of drones and is providing assistance to new businesses in order to encourage them to develop innovative concepts[59]. Drone surveys are becoming more widespread, which means that they are also becoming more cost-effective. They have a multitude of benefits to provide in the agricultural sector. Among them are the following:

Enhanced Production - The farmer has the ability to enhance their production capacity by engaging in thorough irrigation planning, sufficient monitoring of crop health, better understanding of soil health, and responsiveness to changes in the environment[60].

Practices that are both effective and adaptable - The use of drones provides farmers with accurate and timely information on their crops and contributes to the development of more robust agricultural practices. They have the ability to adjust to the weather conditions and distribute resources without wasting any of them[61].

Increased safety for farmers - The use of drones to spray pesticides in terrains that are difficult to access, diseased regions, higher crops, and power lines is not only safer but also more convenient for farmers. Farmers are also able to avoid spraying their crops, which results in a reduction in the amount of pollutants and chemicals that are present in the soil[62].

Quicker data for rapid decision-making — Drone surveys provide farmers with precise data processing that allows them to make quick and conscious judgments without second-guessing themselves. This enables farmers to save the time that they would have spent on crop scouting. The drone is equipped with a number of sensors that provide it the ability to collect and analyse data from the whole area[63]. The data may concentrate on problematic regions such as diseased crops or crops that are unhealthy, various coloured crops, moistness levels, and other similar topics. It is possible to equip the drone with many sensors for a variety of crops, which will result in a crop management system that is both more accurate and more versatile[64].

The use of agri-drones allows for the most efficient use of all resources, including fertilizer, water, seeds, and pesticides, resulting in minimized resource waste. With a 99% accuracy rate, the drone survey provides farmers with the ability to accurately assess the size of their property, divide their crops into several categories, and engage in soil mapping[65].

Beneficial for Insurance Claims: Farmers may utilize the information that is gathered by drones to file a claim for crop insurance in the event that certain losses occur. At the same time as they are insured, they even analyse the risks and losses linked with the land[66].

Proof for the sake of insurance companies – Agri-drones are used by the agricultural insurance industry to collect data that is both reliable and efficient. They are able to accurately estimate the amount of money that should be paid back to the farmers by capturing the damages that have been incurred[67].

Problems that arise while attempting to use drone technology in the agricultural sector

The use of drones by farmers has a number of opportunities for improvement; however, there are also a few obstacles that may prevent farmers from fully embracing this technology. Here are some of the most significant difficulties:

Concerns about the loss of jobs: Many farmers are afraid that the implementation of drone technology will result in the loss of jobs. This is because there will be a reduction in the number of humans required to undertake manual labour on the farm[68].

A lack of knowledge and training: It is possible that farmers do not possess the knowledge or training necessary to operate drones in an efficient manner. Since of this, it may be challenging for individuals to accept this technology since they may not have full faith in their capacity to understand and use it. There is a possibility that many farmers do not have the financial resources necessary to engage in this technology due to the fact that drones may be rather pricey[69].

Obstacles posed by regulations: There is a possibility that there will be regulatory obstacles in the way of the use of drones in agricultural settings, which may make it challenging for farmers to embrace this technology[70].

The use of drone technology in India's rural agricultural sector is still in its infancy and is still in the early phases of acceptance. Concerns have been raised over the loss of jobs, as well as a lack of expertise and training, despite the fact that there is interest in this technology. On the other hand, there are now initiatives under way to overcome these difficulties and to actively promote the use of drone technology[71]. The Digital India campaign is one of the most important efforts, and its primary objective is to increase the availability of digital infrastructure and connection in rural regions. This effort places an emphasis on education and training, which may be of assistance in addressing the knowledge and training gap that exists among farmers[72].

Fig 7 :use drone technology in the agricultural sector

Future scope of drones in agriculture

The future scope of drones in agriculture is brimming with potential, poised to revolutionize farming practices across the globe. As technology continues to advance, drones will play an increasingly integral role in various aspects of agricultural operations:

1. Precision Agriculture: Drones equipped with high-resolution cameras, multispectral sensors, and other advanced imaging technologies will enable farmers to monitor crop health, identify pest infestations, and assess soil conditions with unprecedented precision. This data-driven approach allows for targeted interventions, such as precise pesticide application and optimized irrigation, leading to improved yields and resource efficiency [73].

2. Crop Monitoring and Management: Drones can autonomously survey vast agricultural landscapes, providing real-time data on crop growth, canopy coverage, and yield estimates. This information allows farmers to make data-driven decisions, adjust cultivation practices, and mitigate risks such as disease outbreaks or adverse weather conditions [74].

3. Crop Spraying and Fertilization: Drone-mounted spraying systems offer a more efficient and environmentally friendly alternative to traditional tractor-based methods. By precisely

targeting areas in need of treatment and minimizing chemical runoff, drones reduce pesticide and fertilizer usage while maximizing effectiveness, thus promoting sustainable agriculture practices [75].
4. Mapping and Field Analysis: Drones equipped with LiDAR (Light Detection and Ranging) technology can generate highly accurate 3D maps of agricultural landscapes, enabling detailed terrain analysis, slope mapping, and drainage planning. This data facilitates optimal field design, precision planting, and land management strategies tailored to local environmental conditions [76].
5. Livestock Management: Drones equipped with thermal imaging cameras can aid in livestock management by monitoring animal health, tracking herd movements, and identifying anomalies such as predator intrusion or fence breaches. This proactive approach enhances animal welfare, minimizes losses, and improves overall farm efficiency [77].
6. Infrastructure Inspection: Drones offer a cost-effective means of inspecting agricultural infrastructure such as fences, irrigation systems, and crop storage facilities. By conducting routine aerial inspections, farmers can identify maintenance needs promptly, prevent costly downtime, and ensure the smooth operation of essential facilities [78].
7. Data Analytics and Integration: The integration of drones with advanced analytics platforms and farm management software enables farmers to derive actionable insights from aerial data. By harnessing the power of artificial intelligence and machine learning algorithms, farmers can optimize production workflows, forecast yields, and implement personalized agronomic strategies tailored to specific field conditions [79].

Conclusion

In conclusion, the adoption of drone technology in modern agriculture heralds a new era of efficiency, precision, and sustainability in harvesting practices. Drones equipped with advanced sensors and imaging capabilities enable farmers to monitor crops with unprecedented detail, identify areas of concern, and optimize harvesting schedules with pinpoint accuracy. By streamlining operations and reducing manual labour, drones not only increase productivity but also minimize environmental impact and resource usage. As the technology continues to evolve and become more accessible, its potential to revolutionize agriculture on a global scale is undeniable, promising a future where feeding the world's growing population is not just a challenge, but a sustainable reality.

Comment [115]: Add some refences in conclusion
Add here discussion with references

References

Comment [116]: References add according to journal format.
Author did not use journal format

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