International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

AI-Driven Drone Technology for Precision Farm Monitoring and Pest Management

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ABSTARCT

The world receives more than 200 thousand people in a day and it is expected that the total world population will reach 9.6 billion by the year 2050. This will result in extra food demand, which can only be met from enhanced crop yield. Therefore, modernization of the agricultural sector becomes the need of the hour. There are many constraints that are responsible for the low production of crops, which can be overcome by using drone technology in the agriculture sector. This paper presents an analysis of drone technologies and their modifications with time in the agriculture sector in the last decade. The application of drones in the area of crop monitoring, and pesticide spraying for Precision Agriculture (PA) has been covered. The work done related to drone structure, multiple sensor development, innovation in spot area spraying has been presented. Moreover, the use of Artificial Intelligent (AI) and deep learning for the remote monitoring of crops has been discussed

INTRODUCTION

The population is increasing rapidly, which is making food security a challenging task. According to Food and Agriculture Organization (FAO) of the United Nation, more than 815 million people are chronically hungry and 64% of the chronically hungry are in Asia. The world needs to increase food production by approximately 50% by the year 2050 to feed a population of nine billion . On the other hand, the basic resources for agriculture production such as land and water are becoming scarcer every day . In a study done in 2018, it has been revealed that 9.2% of people on earth had extreme degrees of food availability problems . Any further decreases in the amount of food will result in a very pathetic condition. There was also a moderate level food insecurity problem (i.e. up to 17.2% of the total populace), which means that they did not have customary access to nutritious and adequate food. The combination of moderate and extreme degrees of food availability problem carries the approximate 26.4% of the total populace .

The crop production and food supply networks were severely affected by the COVID-19 pandemic . The basic requirements in the field of agriculture like labor, seeds, fertilizers, and pesticides were not available timely to many farmers and has resulted in less production. Many Asian countries are at a developing stage, and they are confronting with the issue of a high populace and their agrarian efficiency is much lower when compared with technologically advanced nations. India is facing a similar issue. This is due to its low-level agriculture technology, lesser power availability, and unskilled farmers, etc. Almost 73% of the Indian population is dependent on the agriculture sector directly or indirectly. Indian farming is still being done in a conventional manner. Farmers are using conventional techniques for seed planting, composts and pesticides application, etc. . The traditional techniques used for pesticides and fertilizer spraying require more time and are less effective, thus there is a need for technological advancement in this segment . COVID-19 pandemic made the monitoring of crop, fertilizer, and pesticide spraying very difficult for conventional farmers. The utilization of Drone in agriculture is a suitable solution to overcome these difficulties. Utilizing proper information collected by drones, agronomists, rural specialists, and farmers may improve their activities to increase the yields .

For smart farming and Precision Agriculture (PA), aerial remote sensing is considered to be one of the most important technology. Aerial remote sensing, with the help of drones, utilizes the images of different wavelengths and measures the vegetation indices to recognize the several conditions of crops. In the past decades, manned aircraft or satellites were used for capturing desired images that were utilized for precision agriculture . Capturing images by using manned aircraft is a very costly affair and the problem with satellite images is that image spatial resolution is not as good as desired in most conditions. Moreover, the availability and quality of images depend upon the weather conditions . An advancement in Unmanned Aerial Vehicle (UAV) technologies and reduction weight of payload devices has shifted the remote sensing of crops through this technology. This technology is less expensive, time-saving, and captures high-resolution images in a non-destructive way .

Drone monitoring systems help the farmers for observing the aerial views of the harvest. This gives information related to the water system, soil variety, pests, and fungal infestations. Crops images, collected by the drones, have information in the range of infrared and visual spectral. Different features from these images can be extracted, which gives information about the health of plants in a manner that cannot be seen with the naked eye. Another important feature of this technology is its capability to monitor the yield regularly i.e. on each week, or even at each hour. The frequent availability of crop information helps farmers to take corrective action for better crop management.

Applications of drones in precision farming can be studied based on the payload devices. Payload is actually the weight a drone can carry. The two main categories studied here are crop health monitoring, and pesticide spraying. In this paper, after a brief introduction about the use of UAV technology in the agriculture field, their different types used for agriculture monitoring have been reviewed. Further, a discussion about capturing high-resolution images and their analysis for crop health monitoring are done. Improvements in pesticide spraying drone and development of a drone capable for spot spraying has been reviewed.

LITERATURE SURVEY

Paper 1

Title : The Role of AI in Modern Farming: Precise Pest Management and Optimal Water Use.

Authors : Sonam Ahuja, Manjunath HR, Intekhab Alam, Ajay Rastogi.

Published on : 4 February 2024

Description : Sonam Ahuja et al in this paper, the transformative impact of artificial intelligence (AI) technology, particularly in precision farming using drones, is examined. With agriculture's pivotal role in the global economy, addressing the escalating food demand due to population growth necessitates innovative solutions. The integration of AI-driven drones in agriculture offers promising avenues for precise pest management (PPM) and water optimization.Drones equipped with AI-powered sensors gather data from various crops to accurately identify pests, enabling targeted control measures while minimizing pesticide and herbicide usage. This approach not only preserves soil fertility but also reduces environmental impact. Moreover, AI-driven irrigation systems, facilitated by drones, optimize water usage, preventing wastage and ensuring crops receive adequate hydration for healthy growth. The research underscores the transformative potential of AI in agriculture, particularly in pest management and water optimization. By harnessing AI technologies through drone applications, farmers can enhance productivity, improve crop quality, and meet the food demand sustainably. This paper highlights the crucial role of drones in revolutionizing farming practices, paving the way for a more efficient and environmentally conscious agricultural sector.

Paper 2

Title : Drone-Based Intelligent Spraying of Pesticides: Current Challenges and Its Future Prospects.

Authors : Abhibandana Das, Kanchan Kadawla, Hrishikesh Nath, Sanjukta Chakraborty, Habib Ali, Shreya Singh & Vinod Kumar Dubey.

Published on : 25 January 2024.

Description : Abhibandana Das et al in this paper, the remarkable evolution of drone technology in agriculture is explored, underscoring its pivotal role in modern farming practices. From the inception of unmanned aerial vehicles to the emergence of sophisticated multi-rotor drones, significant strides have propelled drone technology forward. Ongoing research has led to advancements in sensor arrays, algorithms, and the diversification of drone models tailored for agricultural tasks. Modern drones boast advanced sensors and high-resolution cameras, coupled with robust processing algorithms, enabling precise detection of crop health indicators and pest infestations. This data aids in optimizing crop production and identifying pest hotspots, thereby enhancing farm management practices. Pesticide application, traditionally labor-intensive and hazardous, has been revolutionized by drone-mounted sprayers, ensuring quick, efficient, and safe operations. Despite challenges such as cost and weather dependencies, the long-term benefits of drones in agriculture are undeniable. Their integration into farming systems not only improves efficiency but also fosters innovation and sustainability. As drones continue to evolve, they are poised to become emblematic of modern agriculture, offering transformative solutions for the challenges faced by farmers worldwide.

Paper 3

Title : Advancements in variable rate spraying for precise spray requirements in precision agriculture using Unmanned aerial spraying Systems: A review.

Authors : Abbas Taseer , Xiongzhe Han.

Published on : March 2024.

Description : Abbas Taseer et al in this paper, the focus is on addressing the ecological damage caused by the overuse of pesticides through the exploration of a precise and adaptable technique called unmanned aerial spraying system (UASS)-based variable rate spraying (VRS), examining the current state of precision agriculture, discussing the application of UASS in variable rate spraying, highlighting the role of advanced sensors like multi spectral and hyper spectral technologies, addressing challenges and proposing solutions, exploring alternative solutions such as herbicides, emphasizing the advantages of VRS including increased yields and reduced resource usage, and delineating current challenges and envisioning future innovations such as sensor technology and AI-driven flow rate optimization for UASS based VRS, providing valuable insights into precision agriculture.

Paper 4

Title :Unmanned Aerial Vehicle-based Applications in Smart Farming: A Systematic Review

Authors : E Mehdi Raouhi, Mohamed Lachgar, Hamid Hrimech and Ali Kartit.

Published on :2023

Description : El Mehdi Raouhi et al in this paper, the focus is on the potential of cutting-edge technologies such as AI, Cloud Computing, and IoT in Smart Farming and Precision Agriculture, emphasizing their role in enabling real-time data collection through Unmanned Aerial Vehicles (UAVs). The emergence of these technologies holds immense promise for revolutionizing agriculture by facilitating faster decision-making, cost reduction, and increased yields. However, integrating UAVs in Smart Farming faces obstacles related to technology selection and deployment, particularly in data acquisition and image processing. The relative novelty of UAV utilization in Precision Agriculture contributes to the lack of standardized workflows, hindering widespread adoption and implementation. To address these challenges, the paper conducts a comprehensive review of recent UAV applications in Precision Agriculture, exploring common applications, UAV types, data acquisition techniques, and image processing methods. By gaining insights into the advantages and challenges associated with UAV-based applications in Precision Agriculture, the study aims to contribute to the development of standardized workflows and improve technology adoption.

Paper 5

Title : Using Remote Sensing and an Unmanned Aerial System for Weed Management in Agricultural Crops: A Review

Authors : Muhammad Huzaifah Mohd Roslim, Abdul Shukor Juraimi, Nik Norasma Che'Ya Nursyazyl Sulaiman, Muhammad Noor Hazwan Abd Manaf , Zaid Ramli and Mst. Motmainna.

Published on :2021

Description : Muhammad Huzaifah Mohd Roslim et al in this paper, the critical role of drones, artificial intelligence (AI), and advanced sensor technologies in weed management practices is examined. Weeds pose a significant threat to crop yields by competing for essential resources such as water, nutrients, and sunlight, necessitating effective control measures to ensure future food production sustainability. The integration of drones equipped with various sensors, including hyper spectral, multi-spectral, and RGB (red-green-blue), offers promising solutions for addressing weed infestation challenges. Remote sensing systems, enabled by drones and AI algorithms, provide a comprehensive approach to weed management in agriculture. This interdisciplinary approach encompasses spectroscopy, optics, computer science, satellite technology, electronics, and communication. By leveraging machine learning techniques, future challenges such as food security, sustainability, climate change, and herbicide resistance can be effectively addressed.

TECHNOLOGIES

1. Multispectral Imaging: Multispectral imaging involves capturing images of agricultural fields in multiple wavelengths of light, beyond the visible spectrum. Drones equipped with multispectral cameras can capture data in bands such as near-infrared, red-edge, and thermal infrared, providing valuable insights into crop health, stress levels, and nutrient status. By analyzing these images, farmers can detect subtle variations in vegetation vigor, chlorophyll content, and water stress, enabling targeted interventions for improved crop management and yield optimization.

2. LIDAR (Light Detection and Ranging): LIDAR technology uses laser pulses to measure distances and create detailed 3D maps of terrain, vegetation, and structures. Drones equipped with LIDAR sensors can generate high-resolution elevation models and terrain maps, allowing farmers to accurately assess soil topography, drainage patterns, and crop canopy structures. This information aids in precision farming activities such as land leveling, irrigation planning, and crop health monitoring, facilitating more efficient resource allocation and management decisions.

3.GPS (Global Positioning System): Global Positioning System (GPS) technology enables precise geolocation and navigation of drones during flight operations. By receiving signals from orbiting satellites, drones can determine their exact position in three-dimensional space, allowing for accurate mapping, route planning, and waypoint navigation. GPS-enabled drones are essential for conducting aerial surveys, crop monitoring missions, and pesticide spraying operations with high precision and reliability, ensuring optimal coverage and effectiveness in agricultural applications.

4. Machine Learning Algorithms: Machine learning algorithms play a crucial role in processing and analyzing the vast amount of data collected by drones during precision farming operations. These algorithms use statistical techniques to identify patterns, trends, and anomalies in drone imagery and sensor data, enabling automated decision-making and actionable insights for farmers. By leveraging machine learning, drones can detect crop diseases, predict yield outcomes, and optimize farming practices based on historical data and real-time observations, empowering farmers to make informed decisions and maximize agricultural productivity.

5. Autonomous Navigation Systems: Autonomous navigation systems enable drones to operate independently and perform predefined tasks with minimal human intervention. These systems utilize a combination of sensors, onboard computers, and algorithms to detect obstacles, plan flight paths, and execute maneuvers autonomously. Drones equipped with autonomous navigation capabilities can fly predefined routes, avoid collisions with terrain or obstacles, and adapt to changing environmental conditions in real-time, enhancing safety, efficiency, and reliability in agricultural operations.

6. Precision Spraying Systems: Precision spraying systems enable drones to deliver pesticides, herbicides, and fertilizers to crops with unparalleled accuracy and efficiency. These systems consist of specialized nozzles, pumps, and actuators that regulate spray droplet size, flow rate, and distribution pattern, ensuring uniform coverage and minimizing chemical drift. By precisely targeting pests, weeds, or nutrient deficiencies, drones equipped with precision spraying systems reduce agrochemical usage, minimize environmental impact, and optimize resource utilization in agriculture, leading to improved crop health and yield outcomes.

7. Remote Sensing Technologies: Remote sensing technologies, such as thermal imaging, hyperspectral imaging, and thermal infrared sensors, enable drones to capture valuable data on crop health, soil moisture, and environmental conditions. These sensors detect variations in temperature, reflectance, and electromagnetic radiation emitted by crops and soil, providing insights into plant stress, water availability, and nutrient levels. By analyzing remote sensing data collected by drones, farmers can identify areas of concern, assess crop performance, and implement targeted management practices to optimize agricultural productivity and sustainability.

8. Cloud Computing: Cloud computing technology facilitates the storage, processing, and analysis of drone-collected data in remote servers or data centers accessible via the internet. Drones upload captured images, sensor readings, and other data to cloud-based platforms, where they can be stored, analyzed, and visualized using advanced analytics tools and algorithms. Cloud computing enables real-time access to farm monitoring information, collaborative data sharing among stakeholders, and scalable computing resources for processing large datasets, enhancing the efficiency and effectiveness of precision farming operations.

9. Edge Computing: Edge computing refers to the processing and analysis of data at or near the source of data generation, such as onboard drones or edge devices, rather than in centralized data centers. By performing data processing tasks locally, edge computing reduces latency, bandwidth requirements, and dependency on internet connectivity, enabling faster decision-making and real-time responsiveness in precision farming applications. Drones equipped with edge computing capabilities can analyze sensor data, execute machine learning algorithms, and generate actionable insights autonomously, even in remote or offline environments, enhancing their efficiency and autonomy in agricultural operations.

10. Sensor Fusion: Sensor fusion involves integrating data from multiple sensors, such as cameras, LiDAR, GPS, and environmental sensors, to create a comprehensive and accurate representation of the agricultural environment. Drones equipped with sensor fusion capabilities can capture multi-modal data on crop health, terrain morphology, weather conditions, and other relevant parameters, providing farmers with a holistic view of their fields and enabling informed decision-making. By combining information from diverse sensors, drones enhance their situational awareness, navigation accuracy, and data quality, facilitating more effective and precise precision farming applications.

WORKING PRINCIPLE

Agricultural drone

Initially, the drone was originated as a military tool and was given different names such as Unmanned Aerial Vehicle (UAV), Miniature Pilotless Aircraft, or Flying Mini Robots. Nowadays it is being utilized in the business sector, infrastructure sector, farming, security, insurance claims, mining, entertainment, telecommunication, and transport sector, etc. The drone has a powerful market opportunity as is evident from the data given in Table 1. Such a broad application of drones has resulted in a very fast improvement in drone technology, thereby making it more user-friendly day by day.

Table 1. Utilization of drone in different sectors .

S.No.	Industry	Drone application
1	Infrastructure	Investment monitoring, Maintenance, Asset inventory
2	Agriculture	Analysis of soils and drainage, Crop health monitoring, Yield prediction, Pesticides and fertilizer spot spraying
3	Transport	Delivery of goods, Medical Logistic
4	Security	Monitoring lines and sites, Proactive response
5	Entertainment and Media	Advertising, Entertainment, Aerial Photography, Shows and Special Effect
6	Insurance	Support in claims settlement process, Fraud detection
7	Telecommunication	Tower maintenance, Signal broadcasting
8	Mining	Planning, Exploration, Environmental impact assessment

Nowadays, the application of small unmanned aerial vehicles (UAVs) is growing at a very fast rate in agri business, Drones are semi-automatic devices that are continuously shifting toward fully automatic devices. These devices have an enormous potential for agricultural planning and related spatial information collection. In spite of some innate barriers, this technology can be utilized for productive data analysis .

Initially, UAVs were radio-controlled devices operated by a pilot from the ground, however, modern drones are GPS-based autopilot aerial vehicles. The type of cameras, sensors, controlling devices depends on the application of a drone. The three main types of UAVs platforms are Fixed-wing, Helicopter, and Multi-copter .

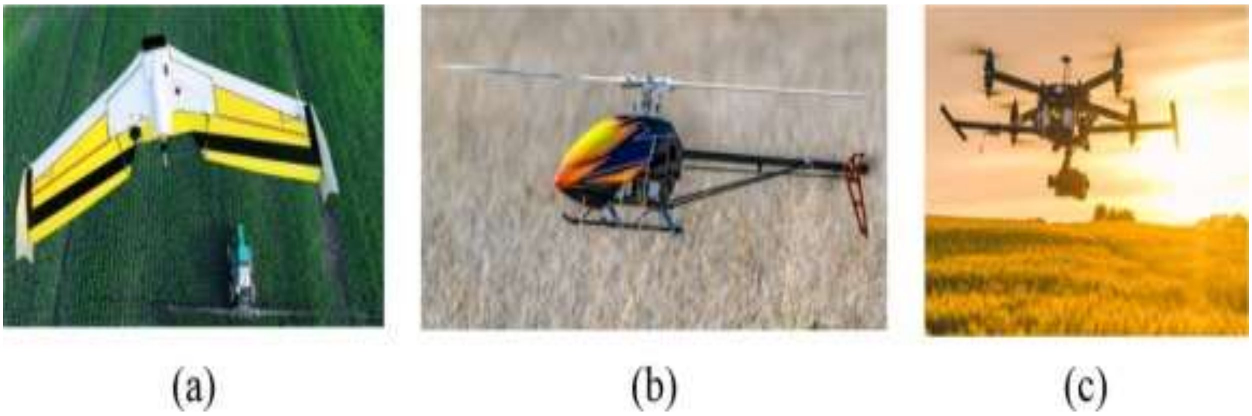

Fig. 1. Types of UAVs (a) Fixed wing drone (b) Helicopters (c) Multi-copter drone.

Fixed-wing UAV: These UAVs have stationary wings in the shape of an aerofoil which creates the lift needed when the vehicle reaches a certain speed. A commonly used Fixed-wing UAV is shown in Fig. 1(a).

Helicopters: It has a single set of horizontally rotating blades attached with a central mast for producing lift and thrust. This type of UAV is shown in Fig. 1(b). A helicopter is capable of vertically take off and land, fly forward, fly backward, and hover at a particular place. These features allow the use of helicopters in congested and remote areas where fixed-wing aircraft are unable to operate.

Multi-copters: Rotorcraft with multiple sets of horizontally rotating blades (typically 4–8) have the capability to provide lift and control movements of UAV as shown in Fig. 1(c).

In the past decade, the unmanned aerial vehicle (UAV) market was captured by fixed-wing and helicopters. Nowadays, the use of small drones in precision agriculture has shifted focus towards multi-copters that at present covers almost 50% of the available UAV model .

Performance of tiny sensors (accelerometers, magnetometers, gyros, and pressure sensors, etc.), used in drone technology, is continuously increasing and their size is reducing day by day. Moreover, the development of powerful processors, GPS modules, and increment in the range of digital radios is a continuous process, and thus drone technology is also improving. New innovations in embedded systems and motors have made it possible to reduce the size of UAVs and improved their payload capability. This further leads to a better controlling of the drone for monitoring of remote fields .

The integration of Artificial Intelligence (AI) has revolutionized the use of semi-controlled drones for farm monitoring . The decision of a semi-controlled drone was purely based upon the sensor output as shown in Fig.2. AI system has its own decision-making power, which has made it a useful tool for real-time data analysis. This decision-making power of AI is based upon previous training. Real-time data analysis has improved farm productivity through mapping spatial variability in the field. The crude data (of crops in agricultural fields) collected using drones are fed to the analytical models for analysis and further remedial actions are taken to improve the yield. Drones can perform soil health scans, assistance in irrigation, fertilizers application, crops health monitoring. Moreover, it provides useful data analysis to estimate farming yield .

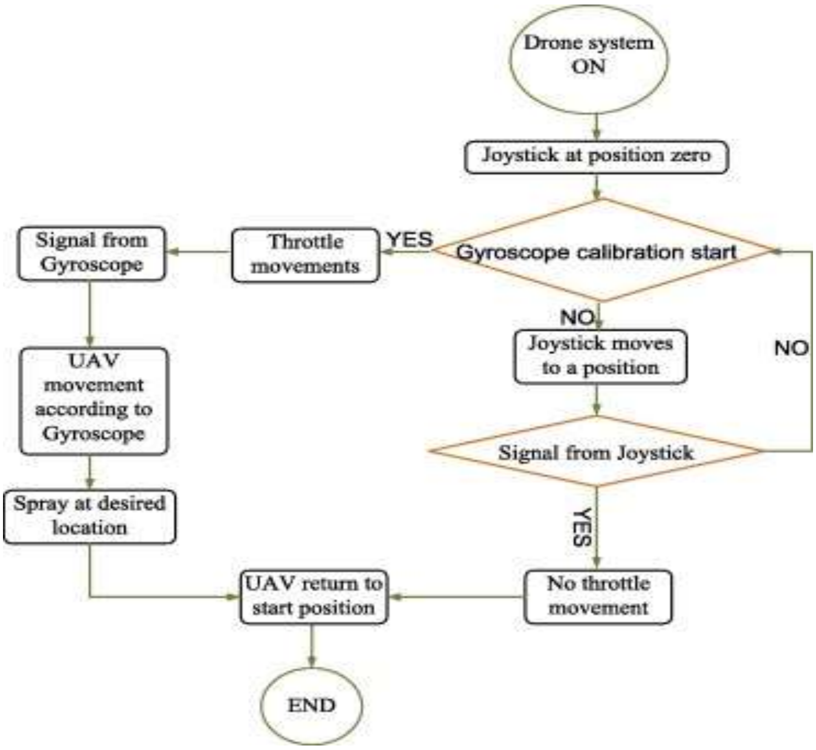

Fig. 2. Workflow diagram of sprayer drone.

Satellite image utilization for data analysis has its limitation in the case of small plants. Moreover, the availability of satellite images depends upon weather and light conditions. Unmanned Aerial Vehicle (UAV) provides a better solution for image data collection since they can capture desired location images from the desired height and at the desired frequency automatically. Moreover, drone-based technologies can analyze the data instantaneously and can be used as a fully automatic device for pesticide, and weed.

Crop health monitoring

Daily monitoring of crops is performed by the farmers to detect any potential threats such as diseases, pests, and slow rate of growth. The traditional methods for monitoring crops were visual inspection and collecting ground samples manually from random locations. For more than 50-years, color and infrared photography captured by different platforms have been used for monitoring crop growth . A camera-mounted drone identifies the crops with diseases or deficiencies using advanced image data analytical tools . Drones in the agricultural sector are mainly used for field mapping and crop monitoring, shown in Fig. 3. Investigation and analysis of UAV application for crop monitoring has been carried out in this section.

Fig. 3. UAV application in agricultural field (a) Field mapping (b) Crop monitoring.

For effective crop monitoring, the selection of sensors to be used along with drones is very important. The sensor selection mainly depends upon their applications such as disease detection, nutrients detection, and water status identification, etc. Researchers have worked on the improvements of drones continuously and developed task-specific drones for crop monitoring. However, the UAV system made its breakthrough in the agriculture sector in around 2011, most likely because the drone technology, as well as payload devices, became affordable and easy to use.

A vegetation indices map can be created with the help of images captured by the drone-mounted camera. Crop information such as crop disease, nutrients requirements, and water stress can be estimated on the basis of these indices . Vegetation indices help in differentiating between healthy, unhealthy plants and weeds . These indices are based on the image spectrum of crops and the image spectrum is related to the health condition of the crop as shown in Fig. 4. There are solid relationships between harvest yield and vegetation indices estimated at certain harvest stages . These relationships play a great role to monitor the yield.

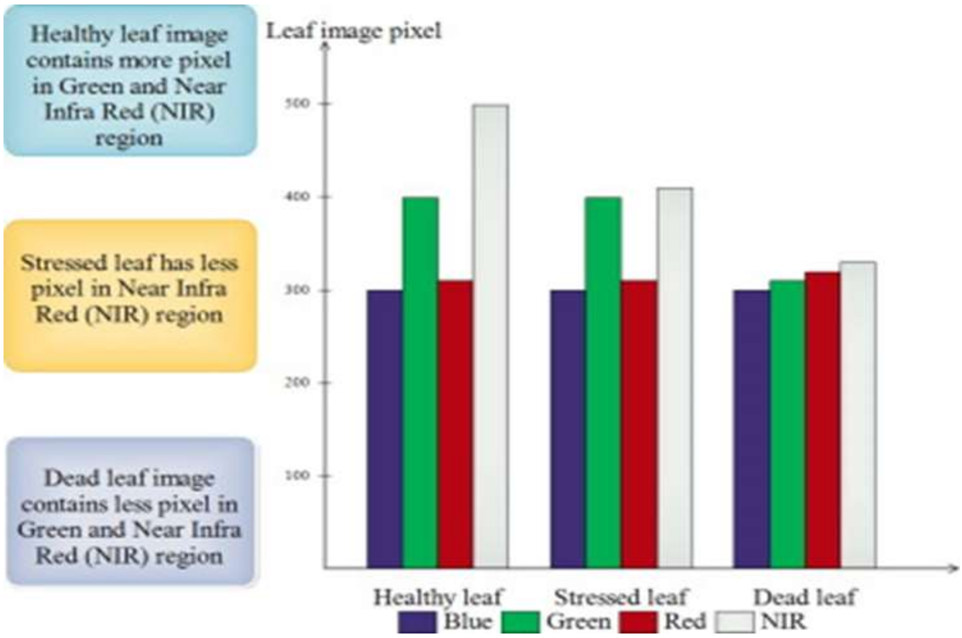

Fig. 4. Relation between plant health and image spectrum.

A multispectral camera has been used for the data collection. It captured the five different spectrum bands which are RGB, extra RedEdge, and NIR. The proposed system relied on U-Net for semantic segmentation. Image segmentation performance was improved due to extra band utilizations. The Random Forest algorithm-based deep learning process was used for the classification of the image data. Deep learning is Convolutional Neural Network (CNN) based Machine learning (ML) process. ML is a popular technique for visual data analysis and result prediction. A workflow diagram of this technique is shown in Fig. 5. The raw data collection using suitable sensors and processing of the collected data is done in the data acquisition and processing blocks. The collected data is converted into useful data through cleaning and grouping. Deep learning model consist of a well-written computer program.

The model was trained and validated with refined data for the collection of desired information from the crop. The trained system was deployed in the field for problem analysis. It was observed that the segmentation and disease detection capabilities of the system was improved. However, vegetation indices performance has been reduced. The performance of the system can be improved by using other deep learning networks and better data labelling.

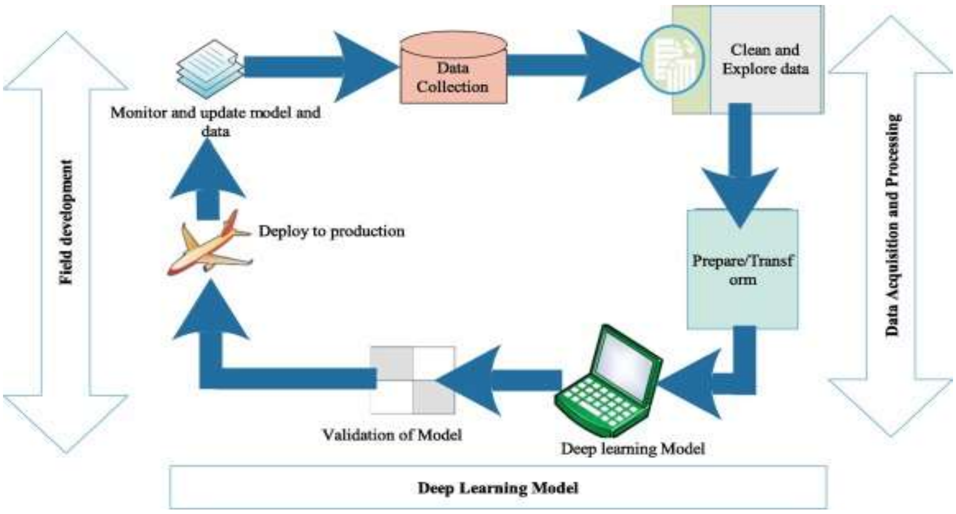

Fig. 5. Workflow diagram of deep learning-based system used for precision agriculture.

Some important outcomes have been extracted from research done in crop monitoring during the last decade. In recent years, many crop condition-monitoring methods were developed based on remote sensing data. These crop condition monitoring methods can be classified as direct monitoring methods, image classification methods, and IoT based crop monitoring.The direct monitoring methods are based upon crop condition monitoring indices (such as Normalized Difference Vegetation Index, NDVI and leaf area index, LAI, etc.). These methods are easy to use and needed fewer data. However, due to their short theoretic foundation, they are hard to use in complex areas.Image classification methods are based upon supervised and unsupervised learning algorithms. These methods visualize the results effectively and are user-friendly.

A continuous improvement in machine learning, computer vision, and AI technologies is making it more accurate and user-friendly. This technology needs good programming skills and latest equipment. Moreover, calibration is needed, for the classification model, in the case of real-time applications.IoT-based technology utilizes the different types of sensors for the collection of crop data and these data are analyzed using a simulation model. This technology is efficient in resource utilization, enhances data collection, needs less time, and minimizes human efforts. This technology has some drawbacks such as; complexity, security, and privacy.

Pesticide spraying

This section is about research and developments in UAV-based pesticide spraying systems. Till date, mostly conventional methods for pesticides application are being used in various parts of the world. The manual mechanical sprayer is the most common tool for conventional pesticide application. Manual spraying of the pesticides affects human beings and may lead to diseases like cancer, hypersensitivity, asthma, and other disorders . Additionally, conventional methods have several other shortcomings such as extra chemicals use, farm labor shortage, lower spray uniformity, environmental pollution, and less area coverage. These conventional methods cause a higher cost of pesticide application and are less effective in controlling pests and diseases.

To overcome these shortcomings, a drone-mounted sprayer is being employed. The application of drone-mounted sprayers in the field has enhanced the coverage ability, increased the chemical effectiveness, made the spraying job easier and faster. Nowadays, Drone is capable of carrying up to 40-liter pesticide tank and follow pre-mapped routes to spray crops according to the requirements. Drones are showing great potential in covering the fields with difficult access for tractors and aircraft. Some images of drone-mounted sprayer are shown in Fig. 6.

(a) (b) (c)

Fig. 6. UAV based Spraying system being used in (a) Paddy field (b) Tea crop and (c) Banana trees.

A flow chart of drones with an integrated spraying system is shown in Fig.7. The basic components of any drone are Brushless Direct Current Motors (BLDC), Electronic Speed Control (ESC), Flight controller, Camera, Transmitter, and Receiver. The main parts of any spraying system are the pump and its controlling system. In accessories: Accelerometer, gyroscope, GPS are used for controlling the drone.

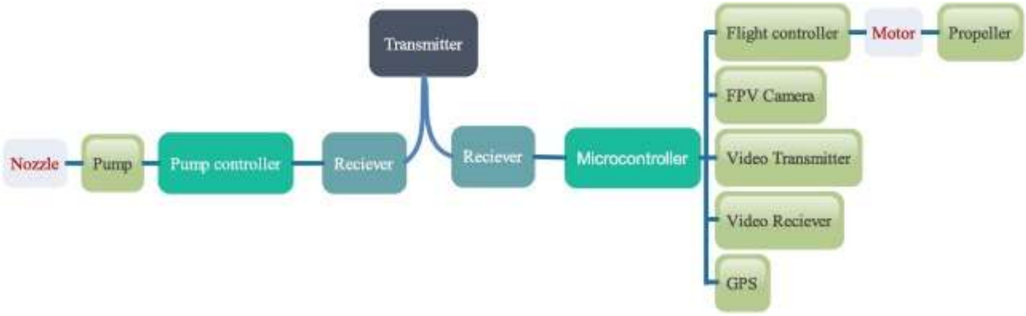

Fig. 7. Flow chart of Semi controlled UAVs for pesticide application.

To design a drone for spraying application, the first step is to estimate the payload. Components of the drone are selected after the calculation of payload. Battery selection depends upon the current and voltage requirements of the drone modules. Finally, the frame of the drone is designed that depends upon the number of arms and payloads.

This system gave satisfactory results in vector control applications. Moreover, it was suitable for use at tough reachable sites.During recent years, a lot of changes can be observed in the drone flight controllers as well as in the spraying systems. The spraying system upgraded from a semi-controlled device to AI-based fully automated system. The blocks used in a fully automatic pesticide spraying system is shown in Fig. 8. A fully automatic pesticide spraying system is capable of spot spraying by analysing the real-time data. It does not require any human efforts in chemical spraying, that makes it a great choice toward safer and more economical system .

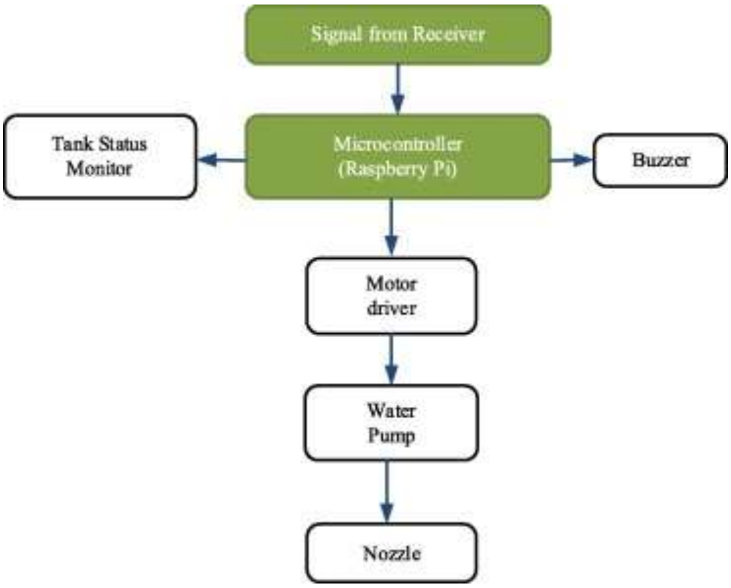

Fig. 8. Blocks of a fully automatic pesticide spraying system.

CONCLUSION

The transformative impact of drone technology on precision farming, particularly in the realms of crop monitoring and pesticide spraying, signifies a paradigm shift in modern agriculture towards heightened efficiency, productivity, and sustainability. The evolution of drone structures, sensor technologies, and integration with artificial intelligence (AI) has ushered in a new era of precision agriculture, characterized by real-time data acquisition, analysis, and decision-making. The surge in drone adoption within the agricultural sector post-2017 underscores industry recognition of their potential to optimize resource allocation, mitigate environmental impact, and enhance yield outcomes.

The rapid advancements in drone technology have led to significant improvements in farm management practices, enabling farmers to monitor crop health, detect pest infestations, and implement targeted interventions with unprecedented precision and effectiveness. Moreover, the versatility and scalability of drones have facilitated their integration into diverse farming operations, from small-scale family farms to large commercial enterprises, driving operational efficiencies and cost savings across the agricultural value chain.

Despite the remarkable progress achieved thus far, several challenges persist on the path to widespread drone adoption in agriculture. Issues such as cost constraints, limited battery life, regulatory complexities, and the need for specialized expertise pose significant hurdles that must be addressed through collaborative efforts among stakeholders. Furthermore, the effective utilization of drone-collected data relies heavily on robust image processing algorithms, data analytics capabilities, and user-friendly interfaces, highlighting the importance of ongoing research and development in these areas.vision destruction, literacy about technology to end-user, and shortcomings of image processing and data analysis.

FUTURE SCOPE

Looking ahead, the future trajectory of drone technology in agriculture holds immense promise for further innovation and advancement. Key areas of focus include continued efforts to drive down costs, improve battery efficiency, and enhance user education and training to promote broader acceptance and adoption of drones among farmers. Additionally, ongoing research in image processing algorithms, sensor technologies, and AI-driven analytics will unlock new opportunities for data-driven insights and decision-making in precision farming.The integration of automation and AI technologies is poised to revolutionize agricultural practices, enabling autonomous drone systems capable of adaptive, data-driven management tailored to specific crop requirements and environmental conditions. Moreover, advancements in regulatory frameworks and standards will be essential to ensure safe and responsible drone operations, addressing concerns related to privacy, airspace management, and environmental protection.Collaborative research initiatives, spanning academia, industry, and government sectors, will play a pivotal role in driving interdisciplinary innovation, fostering knowledge exchange, and accelerating the pace of technological advancements in drone technology for agriculture. By harnessing the collective expertise and resources of stakeholders, the agricultural sector can harness the full potential of drones to address pressing challenges, promote sustainable food production, and contribute to global food security and environmental stewardship.

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