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Implementation of drone technology for precision pest management in advanced agriculture

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Abstract
Almost 73% of the Indian population is dependent on the agriculture sector directly or indirectly. Upcoming challenges accentuate the need for innovative and sustainable farming solutions. Drones are of great importance as early pest outbreak detection and treatment application are important to effective pest management, allowing management decisions to be implemented before pests are well-established and crop losses occur. Drones are designed to carry the sensors that can provide real-time information about the crop status so that decision on cultural operations and management is made efficiently and precisely. Farmers can take preventive action to cease the spread of pest to other crops. Timely actions can be taken to prevent losses from biotic stresses such as insect pests and diseases, optimize fertilization, rationalize irrigation, impact of climate change and unpredictable weather using analyzed insights from data collected by drones and satellite-based remote sensing.

Keywords: Precision agriculture, drone, remote sensing, integrated pest management, aerial spraying

Introduction
Agriculture represents the primary food source of the world (Friha *et al.*, 2021) [7] and it has been facing severe challenges due to the increasing demand for food products, food safety and security concerns, calls for environmental protection, water preservation and sustainability (Inoue, 2020) [10]. 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. Owing to the increment in population and corresponding decrement in rainfall amount, there is a substantial scarcity of food and water – which are the most basic needs of life. Hence, the importance of precision agriculture has become more pronounced leading to researches being conducted in the field over the recent decades (Naiqian *et al.*, 2002) [18]. The increasing consumption of fertilizers and pesticides coupled with the intensification of farming activities could lead to future environmental challenges. These challenges accentuate the need for innovative and sustainable farming solutions (Elijah *et al*., 2018) [5]. Prominent technologies in this field include Wireless Sensor Networks (WSNs), the Internet of Things (IoT), artificial intelligence (AI) techniques, including machine learning and computing technologies (Rejeb *et al.*, 2022) [22].

The Use of advanced technologies such as drone in agriculture offer potential for facing these challenges. Drones, popularly known as Unmanned Aerial Vehicles (UAVs), are of great importance as they have multiple advantages in comparison with other remote-sensing technologies. Drones can be leveraged in several agricultural activities, including crop and growth monitoring, yield estimation, water stress assessment and weeds, pest and disease detection (Srivastava, *et al*., 2020) [26]. Also, they can be used for precision irrigation, precision weed, pest, disease management and spray water and pesticides in precise amounts based on environmental data. On the other hand, drones face limitations as well. Pilot involvement, engine power, stability, reliability, sensor quality due to payload weight limitations, implementation costs and aviation regulation, are among them (Zhang and Kovacs, 2012) [32]. Major challenges for the use of drones in precision agriculture are the costs of drones and associated sensors and material, limited flight time and payload and continuously changing regulations.

Pest outbreaks are unpredictable and not uniformly distributed within fields. Early outbreak detection and treatment application are inherent to effective pest management, allowing management decisions to be implemented before pests are well-established and crop losses occur. Pest monitoring is time-consuming and may be hampered by lack of reliable or cost-effective sampling techniques. Precision pest management is twofold: first, reflectance-based crop monitoring (using ground-based or orbital remote sensing technologies) can be used to identify pest hotspots. Second, precision control systems, such as distributors of natural enemies and pesticide sprayings, can provide localized solutions. Both technologies can be mounted on equipment moving through fields on manned or unmanned aerial drones driving around in field (Filho *et al.,* 2019) [6].

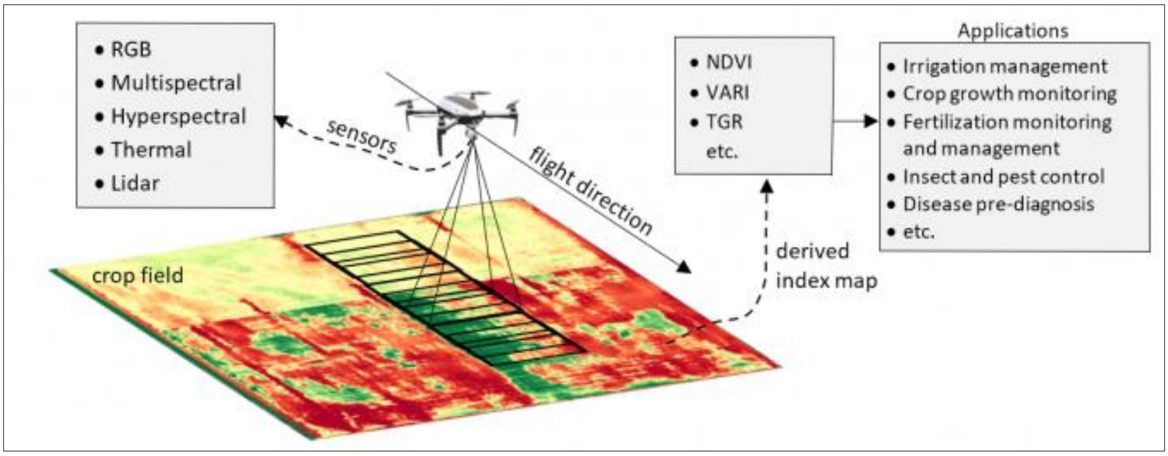

Fig 1: UAV Remote sensing for smart agriculture

In this review, we focus specifically on use of drone systems and remote sensing technology with entomological aspects. Therefore, keeping this in view, the present investigations is undertaken to achieve the following research objectives.

1. Application of drone systems for spraying pesticides in advanced agriculture.
2. Assessment of insect damage to crop using unmanned aerial systems.
3. Assessing the population of insect, pest and natural enemy by implementing drone technology.

Application of drone technology in pest management

There view pertaining to implementation of drone technology for precision pest management in advance agriculture are reviewed as under.

Application of drone systems for spraying pesticides in advanced agriculture.

The utilization of pesticides that are sprayed on the crops exceeds 20–30% and the remaining 70–80% goes as run-off, leaching, evaporation and drift that cause soil and aquatic pollution as well as deteriorating the quality of the crop produce (Markle *et al.,* 2016) [14]. The farmers in agriculture fields face health problems due to diseases caused by pesticides and insecticides. Thousands of cases result in adverse health effects when spraying pesticides manually onto crop fields. COVID-19 pandemic made the monitoring of crop, pesticide spraying very difficult for conventional farmers (Varshney *et al.,* 2020) [30]. The use of drones for spraying pesticides is a promising alternative to problems faced as above.The drone spraying system makes use of GPS coordinates to auto-navigate GPS coordinates to spray the pesticides on the infected areas in real-time as soon as the camera takes a picture of the spraying area (Borikar *et al.* 2015) [4].

Effective and timely spraying of plant protection measures are very important. For this, miniaturized unmanned aerial vehicles possess a wide array of benefits that include high efficiency, reduced labour requirement, saving of time and energy, quick response time, vast area coverage and environmental safety (Meng *et al.*, 2018) [16]. The design of UAVs should consider various parameters such as droplet size, wind speed, flight speed flight height, nozzle type, payload and drone type (Qin *et al.*, 2014) [21]. Further, meteorological parameters like wind speed, temperature and relative humidity can affect the efficacy of pesticide sprays under field conditions (Wang *et al.*, 2018) [31].

First UAV for pesticides application was developed by Yamaha Motor Co. Ltd., Shizuoka Japan in 1983. The stability and controllability of this helicopter were not suitable for utilization in the field. Many researchers have worked on the stability and controllability of UAVs as well as their spraying systems. In this sequence, Y. Huang *et al.* (2014) [9], had built a sprayer for UAV-based pest management in small fields.

Zhu *et al.*, (2010) [33] proposed a PWM regulator-based preprogrammed and remotely controlled helicopter for pesticide spraying in the agriculture field. A fixed frequency PWM (TL494), data acquisition system and software developed along with a guided system were used. PWM controller was tested on LabVIEW 8.2 software. After that, it was analyzed by using different control signals to get the optimum result. A designed spraying system with a PWM controller could enhance the efficiency of pesticide applications in the field. The system was remotely controlled. However, the telemetry system used for signal transmission was not precise.

Balaji and Chennupati (2018) [2] designed a hexacopter using a Raspberry Pi controller to make the agriculture technologies farmer-friendly. Python language programming was used for disease and weed detection in crop monitoring applications. Various sensors like water level sensors, LDR and DHR were connected to get the data corresponding to the real condition of the crops. It was concluded that almost 20–90% saving is possible in terms of chemical, water and labor using this technology. However, this system needed an improvement in the payload of the drone.

Martinez-Guanter *et al.* (2019), [15] have designed and developed an aerial pesticide spraying system that considered the limitations of payload. It was designed using low-cost material to make a low-budget drone. UAV with approximately 6 kg take-off weight, with GNSS receiver and telemetry system was designed. The modular nozzle had two configurations, one with four nozzles (250 mm spacing) and the other with a single anti drift nozzle. Pump speed was controlled from a remote-control station. The pumping range was between 0.10 ltr/min to 0.22 ltr/min. A PWM based control system was used for autonomous application. The efficiency and reliability of the hardware system were tested in super-high-thick olive and citrus plants. The experimental results showed that the developed system was able to save approximately €7/ha in comparison to the previously used system.

Fig 2: Hexa copter spraying pesticides in rice fields of Tamil Nadu Agricultural University Farm in Tamil Nadu, India during October 2019.

Assessment of insect damage to crop using unmanned aerial systems.

Pests represent a major threat to grain production. Due to recent changes in farming system practices consisting of grain cropping with standing stubble and minimum tillage, these pests are being increasingly encountered. To implement optimal site-specific treatments and reduce control costs, new methods in biosecurity and pest surveillance must be investigated. Remote sensing applications in agriculture have focused on a wide range of endeavors for the past 25 years (Mulla, 2013) [17]. Aerial imagery is increasingly being adopted as a management tool in precision agriculture. A variety of sensors have been used for detecting and monitoring pests in agricultural environments (Lan *et al*., 2009) [13]. Artificial intelligence and machine learning can be combined with NDVI (Normalized Difference Vegetation Index) imaging technology-based high-resolution images captured by drones to develop understanding of soil conditions, plant health and crop yield prediction. Every individual plant can be located separately and analyzed using image processing algorithms, if it is stressed. UAV-based remote sensing offers a cost-effective sensor platform to acquire near-real time crop data to enhance farm management (Puig *et al.*, 2015) [20]. Supervised and unsupervised segmentation algorithms are greatly influenced by image quality, spectral bands, spatial resolution and the complexity of the scene. Furthermore, most of the available algorithms need to be fine-tuned by the user to extract specific objects of interest (Hay *et al*., 2008) [8].

Puig *et al.*, [20] conducted an experimental flight campaign in 2015 on a private sorghum farm in Australia. The system used in this experiment was the multirotor DJI S800 EVO (DJI, Hong Kong), owned and operated by the Australian Research Centre for Aerospace Automation (ARCAA). The imaging sensor deployed in this experiment was the Sony NEX-5R high-resolution camera. The spectral response of the camera is based on the Bayer pattern color filter array. A preliminary assessment flight was performed prior to data collection to assess the locations and distribution of pest damaged areas. A rectangular perimeter containing the area of interest was determined by flight planning roughly referencing on Google Earth. Three consecutive flights were required to complete the flight path. All flights were developed within line of sight covering the predefined area. An image processing pipeline was implemented to create a single orthoimage of the area of interest for further analysis. An accurate cluster for each crop health level is created by the decision boundary. In this experiment, the objective of image analysis was classifying the field in three crop health levels: healthy canopy, decimated crop and transition areas with lower plant density. This methodology is successful in situations of severe crop damage where bare soil, healthy canopy and transition areas are visible in the image.

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

Assessing the population of insect, pest and natural enemy by implementing drone technology.

Quick action must be taken to ensure that pest population is kept at bay to control the pest. Drone technology is useful to undertake spray quickly to suppress the pest population. This system provides a relatively fast alternative for manual and time-consuming studies. The accurate spatial mapping of pest complexes within fields in a noninvasive way enables the study of spatial population dynamics over time. This approach will have applications in collecting evidence for better understanding the ecology of the pest species within agricultural environments.

Song *et al.*, (2020) [24] have shown that the application of chlorfenapyr–chlorantraniliprole–lufenuron through drones had control efficacy of 94.94% and declined the pest population by about 94.86%. Tahir and Brooker (2009) [27] used drones to track populations of mobile insects that can be equipped with transponders.

Use of drone-based system can improve efficiency and cost-effectiveness of mark-release-recapture studies of insect migration. Stumph *et al.*, (2019) [25] described the use of drones equipped with a UV light source and a video camera to detect fluorescent-marked insects; Brown marmorated stink bugs (*Halyomorpha halys* Stal). Drone data were obtained at night and a software was developed to visualize individual insects. Although insects still need to be coated initially, the method eliminates the need to physically recapture the insects. Also, it removes the need for destructive sampling, so that insects could potentially be sampled over a longer period.

Biological control is a potential sustainable alternative to pesticide use. Biological control organisms include parasitoids, predators, entomopathogenic nematodes, fungi, bacteria and viruses. Drones may be a particularly useful tool for augmentative biological control, which relies on the large-scale release of natural enemies for immediate control of pests (Van Lenteren*et al.*, 2018) [29]. Various mechanical distribution systems have been developed to facilitate predator dispersal, such as the Mini-Airbug, a handheld appliance with a fan. They could distribute the natural enemies in the exact locations where they are needed, which may increase biocontrol agent efficacy and reduce distribution costs. Bio-agents like fungi and nematode can potentially be applied by drone equipment (Berner and Chojnacki 2017) [3].

A potential new area for use of drones in pest management as an important IPM tool is the release of sterile insects. sterile insect technique (SIT) is environmentally friendly, species-specific and compatible with other management methods (Simmons *et al.*, 2010) [23]. Judd and Gardiner have been successful in controlling codling moth (*Cydia pomonella* L.) population which is a major problem in apple orchards by using pilot programs to release sterile insects with drones. SIT produces sterile or partially sterile insects through irradiation. After mating with wild insects, there is either no offspring or the resulting offspring is sterile, resulting in reduced pest populations. Drone release of the sterile insects may be cheaper and faster than ground release, which occurs for instance by means of all-terrain vehicles (ATVs), or release by manned aircraft (Tan and Tan 2013) [28].

The detection of beneficial insect population can be done by using drones. Kraus *et al.* (2005) [12], used drones for estimating colony number by microsatellite DNA analysis of haploid males in *Apis*. They estimated the number of colonies of social insects rather than the actual number of individuals in the population. This primarily determines the effective population size. Here microsatellite data of haploid males is used to estimate the number of males producing queens in honeybee populations. Empirical data from microsatellite studies the Western honeybee *Apis mellifera* and the giant Asian honeybee *Apis dorsata*. This method is a simple approach to evaluate the number of males producing colonies in a population of social hymenoptera. It can be performed based on user friendly, menu driven, standard spread sheet and statistics software.

Conclusion

This review offers several contributions made by drones and remote sensing technology in pest management. When preparing the technological process of pesticide applications by means of unmanned aerial vehicles, it should be considered that conditions of UAV using may be different than typical sprayers.Drones are designed to carry the sensors that can provide real-time information about the crop status so that decision on cultural operations and management is made efficiently and precisely.

Using this, farmers can take preventive action to cease the spread of pest to other crops. Timely actions can be taken to prevent losses from biotic stresses such as insectpests and diseases, optimize fertilization, rationalize irrigation and reduce the impact of climate change and unpredictable weather using analyzed insights from data collected by drones and satellite-based remote sensing.

This application list is bound to undergo quite some growth in the near-future as more and more research takes place and will take place. Even though there are ample advantages attached to drone technology, every country has its own regulatory guidelines for the use of drones in agriculture.

Drone use is allowed in India, but there are several drone laws that need to be followed when flying in the country.

In conclusion, this paper demonstrates how UAV-based remote sensing and machine learning techniques can have a major contribution to biosecurity surveillance and pest management. Thus, there is an urgent need to develop innovative new nano formulations to improve the efficacy of drone technology while minimizing the cost and improving environmental safety. It could attract more and more farmers to spray pesticides by drone and increase crop yields in the coming years.

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