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| **DRONE TECHNOLOGY: A NOVEL APPROACH IN PRECISION INSECT PESTS MANAGEMENT** |

 Senjaliya Tushar M., Dr. J. J. Patel, Patel Hiral G., and Chaudhary Lala S.

1. **Department of Entomology, N M College of Agriculture, Navsari Agricultural University, Navsari- 396 450 Gujarat,**

**Email** **t.m.senjaliya@gmail.com** **and Mobile no.9712055112**

**2 College of Agriculture, Bharuch, Navsari Agricultural University Gujarat, India**

**Email address** **jjpate@nau.in** **and Mobile no. 9426886513**

1. **Department of Entomology, N M College of Agriculture, Navsari Agricultural University, Navsari- 396 450 Gujarat,**

**Email address** **hiralpatel6078@gmail.com** **and Mobile no.97123695936**

1. **Department of Entomology, N M College of Agriculture, Navsari Agricultural University, Navsari- 396 450 Gujarat,**

**Email address** **lalabhai261999@gmail.com** **and Mobile no. 8511421905**

**Abstract:**

Drones, also known as Unmanned Aerial Vehicles (UAVs), have shown promising potential in revolutionizing pest control methods, offering enhanced precision, efficiency, and sustainability. By critically analyzing existing literature, we aim to provide valuable insights into the evolving landscape of drone-based pest management strategies. A reduction in global food grain production is majorly a result of the biotic stresses caused by diseases and pests which are well-known to cause devastating damage. It is therefore needs meticulous monitoring and genuine technology capsules to save the crops from devastation from these pests. Drones are semi-automatic devices that are continuously shifting toward fully automatic devices which have enormous potential for agricultural planning and pest management. The drone mediated technologies in pest management demonstrate great scope and promising alternative to conventional pest management approaches, should be positively promoted in Indian agricultural research and technology development, and encouraged widely for the effective utilization as a part of integrated pest management practices. We delve into the various applications of drones in pest management, highlighting their advantages, challenges, and future prospects.

**Introduction:**

The field of pest management plays a crucial role in ensuring the health and productivity of agricultural crops, natural ecosystems, and urban environments. The constant challenge of combating pest infestations and minimizing their detrimental impacts has driven the exploration of innovative and sustainable solutions. In recent years, the emergence of drone technology, also known as Unmanned Aerial Vehicles (UAVs), has sparked significant interest and potential in revolutionizing pest management practices. Drones offer a powerful combination of mobility, accessibility, and versatility, making them an ideal tool for addressing various challenges faced by traditional pest control methods. Equipped with cutting-edge sensors, cameras, and payload systems, drones are capable of performing a wide range of tasks with unmatched precision and efficiency. As a result, they have found applications across multiple stages of pest management, from early detection and surveillance to targeted intervention and data-driven decision-making. This paper aims to provide an in-depth review of drone technology in pest management, examining its transformative impact on the agricultural and environmental sectors. By exploring the diverse applications, advantages, and limitations of drones in pest control, we seek to shed light on how this technology has the potential to enhance the effectiveness and sustainability of pest management strategies. In the following sections, we will delve into the various applications of drones in pest management, including aerial surveillance for pest detection and monitoring, precision application of pesticides, data collection for predictive modeling, and dissemination of beneficial organisms for biological control. Moreover, we will assess the advantages of using drones over conventional methods, such as improved efficiency, reduced environmental impact, and cost-effectiveness. While the potential benefits of drone technology in pest management are undeniable, there are also challenges to address, including battery life constraints, regulatory compliance, data processing, and privacy concerns. We will critically evaluate these obstacles to provide a comprehensive understanding of the current state and future prospects of drone-based pest management. The integration of drone technology into pest management practices holds immense promise for revolutionizing how we approach pest control and monitoring. By harnessing the capabilities of drones, we can develop more sustainable, precise, and data-driven strategies that effectively mitigate pest-related risks while minimizing the environmental impact. As we explore the potential of this cutting-edge technology, collaboration between researchers, industry stakeholders, and regulatory authorities will play a pivotal role in unlocking its full potential and ushering in a new era of pest management practices.

**AGRICULTURAL DRONE:**

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 (Grammatikis *et al.,* 2020). 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. Nowadays, the application of small unmanned aerial vehicles (UAVs) is growing at a very fast rate in agribusiness (Ramirez and Galvez, 2019; Devi *et al.,* 2020; Giacomo *et al.,* 2018).

**TYPES OF DRONES:**

**Single Rotor Helicopter Drones** – They look exactly like tiny helicopters and can be gas or electric-powered that can be used to survey land, research storms and map erosion caused by global warming.

**Multi-Rotor Drones** – They are usually some of the smallest and lightest drones on the market. These drones can usually spend 20-30 minutes in the air carrying a lightweight payload, such as a camera.

**Fixed-Wing Drones** – They look like normal airplanes, where the wings provide the lift instead of rotors- making them very efficient. These drones usually use fuel instead of electricity. Fixed-wing UAVs are used by the military to carry out strikes, by scientists to carry large amounts of equipment and even by non-profits to deliver food and other goods to areas that are hard to reach.

**Fixed-Wing Hybrid VTOL Drones** – They are a blend of fixed-wing drones and rotor-based drones, featuring rotors that are attached to the wings. Due to its hybrid approach, this technology offers users the endurance of a fixed-wing design and the vertical flying capabilities of a rotor-focused design.

**Working principle of Sprayer drone:**

A drone is made up of Brushless Direct Current Motors (BLDC), Electronic Speed Control (ESC), flight controller, Camera, Transmitter, and Receiver. The pump and its controlling system are the primary components of any spraying system. In accessories: Accelerometer, gyroscope, GPS are used for controlling the drone. To develop a drone for a sprayer application, the first step is to estimate the payload. Components of the drone are selected after the calculation of payload. The battery selection is determined by 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. First UAV (unmanned helicopter) for pesticides application was developed by Yamaha Motor Co. Ltd., Shizuoka Japan in 1983.

**APPLICATIONS IN INSECT PEST MANAGEMENT:**

Precision insect pest management is attractive because drone-based remote sensing technologies have several advantages. The coverage of vast areas is likely possible with sensing drones compared to handheld, ground-based devices. Particular biotic stresses, such as insect pest infestations, bring about physiological plant responses, lead to changes in the plants ability to perform photosynthesis and thus leads to changes in leaf reflectance spectral range. Drone can be equipped with an RGB (red green blue) sensor for aerial remote sensing, which is a multispectral sensor with between 3 and 12 broad spectral bands, or a hyper-spectral sensor with hundreds of narrow spectral bands (Keller and Shields, 2014). It is important to note that remote sensing does not detect pests themselves, but rather patterns of canopy reflectance that indicate plant stress caused by insect pests. Field observations are still necessary to confirm the presence of specific insect pests.

**Drone mediated aerial photography:**

 Drone-mediated aerial photography has enabled plant pest surveillance with clustering of wireless sensors and networks and precision agricultural design. Drone technology can give farmers a great aerial view of their agricultural field and enable them to make critical management decisions to resolve problems. The images captured by drones are transmitted to the cloud data centre for analysis of the degree of damage caused by pests using spectrum analysis technology. (Gao *et al.,* 2020).

**Drone mediated insect pest sampling:**

 A drone-attachable apparatus is available for trapping airborne insects either as position-fixed traps or freely movable traps can be sufficiently well developed and utilized for insect pests sampling. A DD-screen (double-charged dipolar electric field screen) is attached with drone which forms an electric field between to create an attractive force to capture the insects that enter the electric field. The electric field is sufficiently strong that it prevents the captured insects from escaping the trap (Takikawa *et al.* 2020).

**Drone mediated precision application of insecticides:**

An actuation drone could help control the pests at hotspots of the farm field through variable rate of application of insecticides. Novel types of drone fitted with crop dusters and/or spray equipments and available as commercial drones are currently being developed in different part of the world. Along with precision monitoring, precision application of pesticides could reduce the total number of sprays and thus contributing to reduced pesticide use and decreased resistance development in insects, as well as increased presence of natural enemies in the field.

**Drone mediated precision releases of natural enemies:**

Now a day, drones are useful tool for augmentative biological control, which depends on the extensive release of natural enemies for immediate control of pests. They could distribute the natural enemies in the exact locations where they are needed, which may level up the efficacy of bio-control agents and reduce costs of distribution.

**Drone mediated Sterile Insect Technique (SIT) and mating disruption:**

Another possible area for use of drones in pest management is the release of sterile insects. Experimental programs to release sterile insects with drones have been successful in controlling codling moth populations in Canada, New Zealand and the USA. Furthermore, experimental programs for control of cotton pink boll worm and Mexican fruit fly in citrus, with drone-released sterile insects proved effective for control of these pests in the USA.

**Advantage:**

1.Precision and Targeted Application: Drones enable precise and targeted application of pesticides and beneficial organisms. They can deliver treatments to specific areas affected by pests, minimizing off-target effects and reducing chemical wastage. This precision helps protect non-target organisms and promotes environmentally friendly pest management practices.

2. Reduced Environmental Impact: By delivering pesticides and biocontrol agents only where necessary, drone-based pest management reduces the overall use of chemicals. This, in turn, minimizes the potential negative effects on beneficial insects, wildlife, and water bodies, fostering sustainable and ecologically sensitive pest control practices.

3. Increased Efficiency and Speed: Drones significantly enhance the efficiency and speed of pest management operations. They can cover large areas in a short time, enabling swift pest detection and intervention. The rapid response to pest outbreaks helps prevent further spread and reduces the risk of significant crop losses.

4. Accessibility to Remote and Challenging Areas: Drones can access hard-to-reach or hazardous locations, such as steep terrain, dense forests, or tall structures, where pests may thrive or be difficult to monitor. This accessibility ensures comprehensive pest surveillance and control, leading to more effective pest management strategies.

5. Data-Driven Decision Making: Equipped with various sensors, drones collect valuable data on pest distribution, crop health, and environmental conditions. The data collected can be analyzed using advanced algorithms and integrated with geographic information systems (GIS) to provide valuable insights. Data-driven decision making enhances the accuracy and effectiveness of pest control efforts.

6. Cost-Effectiveness: Although initial investments in drone technology may be significant, the long-term cost-effectiveness of drone-based pest management is often favorable. Reduced pesticide usage and improved resource utilization contribute to cost savings in the long run.

7. Safe and Labor-Saving: Drones eliminate or reduce the need for manual labor in hazardous tasks, such as climbing tall trees or navigating rough terrains. This minimizes the risk of accidents and injuries, ensuring safer working conditions for pest management professionals.

8. Real-Time Monitoring and Response: Drones equipped with live video feeds and telemetry data provide real-time monitoring of pest infestations. Pest control operators can make immediate decisions and adjust their strategies based on the real-time information, enabling more efficient and adaptive pest management.

9. Integration with Advanced Technologies: Drones can be integrated with cutting-edge technologies, such as artificial intelligence, machine learning, and autonomous navigation systems. These technologies enhance the drones' capabilities, allowing for autonomous pest detection, targeted interventions, and optimized flight paths.

10. Scalability: Drone-based pest management is scalable and can be adapted to various scales of operations, from small-scale farms to large commercial agricultural fields. It offers versatility in managing pest issues across different landscapes and sectors.

**Limitations:**

High costs

Requires skilled labours for operation

Complexity in collection of data, its analysis and interpretation

Can’t be used during adverse climatic conditions

Applicable only for large scale spray

Drone Crashes

**Future Prospects:**

There is a ramp in drone application for precision agriculture after 2017. This is due to the reduction of weight, cost of UAVs, and increment in payload capability. Drones used in crop health monitoring and livestock detection are mainly multi-copter and fixedwing types. The size and cost of these drones are continuously reducing day by day. Cameras are shifting from RGB to multispectral cameras and the operation has been shifted from semi-controlled to fully automated systems. But still the growth of drone technology is in its early stage and maybe a scope for further development in both the technology and the agriculture applications. The major challenges are the cost of technology, limited battery life of drones, vision destruction, literacy about technology to enduser, and shortcomings of image processing and data analysis.

**CONCLUSION:**

Drones are becoming progressively adopted as part of precision insect pest management. Drones with sensors (remote sensing equipments) are deployed to monitor crop health, map out variability in crop performance, and detect outbreaks of pests, insecticide application, and release of natural enemies. Despite progress in drone mediated technologies in precision agriculture in the past decade, the commercial use of drone in agricultural fields or forests has been limited to a few countries including the United States, China, Japan and South Korea. The drone mediated technologies in pest management demonstrate great scope and promising alternative to conventional pest management approaches, should be positively promoted in Indian agricultural research and technology development, and encouraged widely for the effective utilization as a part of integrated pest management practices.

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