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AI-Powered Insect Monitoring with Smart Traps: Transforming Pest Surveillance in Modern Agriculture

Sapna[1], Sajiya Quadri[2], Himani Pundir[1], Arshi Zeba[1] and *Jatin Kumar Singh[1]
[1]Ph.D. Scholar, Department of Entomology, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand
[2]Ph.D. Scholar, Department of Entomology, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha
*Corresponding Author's email: jatinksento@gmail.com

Insect pest monitoring is a key component of Integrated Pest Management (IPM), yet conventional methods are labor-intensive, time-consuming, and prone to observer bias. Recent advancements in artificial intelligence (AI) have enabled the development of smart traps that automate pest detection and monitoring. These systems integrate trapping mechanisms with imaging sensors, machine learning algorithms, and IoT connectivity to provide real-time data on insect populations. AI techniques, particularly deep learning models, enhance species identification and counting accuracy under field conditions. AI-powered smart traps have been successfully applied across diverse agricultural systems, improving early pest detection and supporting threshold-based interventions. Compared to traditional methods, they offer higher accuracy, scalability, and reduced labor requirements. However, challenges such as high initial costs, environmental variability, and data requirements persist. Overall, AI-enabled smart traps represent a promising tool for precision agriculture, contributing to sustainable pest management through improved decision-making and reduced pesticide use.

Keywords: IoT, Pest surveillance, Precision agriculture, Machine learning, IPM

Introduction

Insect pests are one of the major constraints to agricultural productivity, causing significant yield losses and economic damage worldwide. Effective pest monitoring forms the backbone of Integrated Pest Management (IPM), enabling timely and precise interventions. Traditionally, insect monitoring relies on manual methods such as sweep net sampling, visual inspection, and the use of sticky or pheromone traps. While these methods are widely practiced, they are often labour-intensive, time-consuming, and prone to observer bias, resulting in inconsistent and sometimes unreliable data.

With the rapid advancement of digital technologies, agriculture is undergoing a transformation toward precision and automation. Among these innovations, Artificial Intelligence (AI)-powered smart traps have emerged as a promising solution for real-time, accurate, and scalable insect monitoring. These systems integrate sensors, imaging technologies, and machine learning algorithms to automatically detect, identify, and count insect pests in the field.

This article explores the concept, working mechanism, applications, advantages, and challenges of AI-powered smart traps, highlighting their potential to revolutionize pest surveillance and support sustainable agriculture.

Evolution of Insect Monitoring Techniques

Conventional insect monitoring techniques have long been the cornerstone of pest management strategies. Various methodologies are their which proven to be effective but have limitations as discussed in the introduction. The transition toward digital agriculture introduced camera-based monitoring systems and remote sensing tools, allowing partial automation of pest detection. However, early systems lacked the intelligence to interpret data autonomously.

The integration of AI has marked a significant shift in insect monitoring. Modern smart traps are capable of not only capturing insects but also identifying species and estimating population density in real time, thereby enabling data-driven pest management decisions.

What is AI-Powered Smart Traps?

AI-powered smart traps are advanced pest monitoring devices that combine traditional trapping mechanisms with digital imaging, artificial intelligence, and wireless communication technologies. These traps can automatically capture images of insects, analyze them using trained algorithms, and transmit the results to farmers or researchers.

Key Components

- **Trap mechanism:** Sticky surface, pheromone lure, or light attractant
- **Imaging system:** High-resolution camera or optical sensor
- **Processing unit:** Embedded AI model or edge computing device
- **Connectivity:** IoT modules (e.g., GSM, Wi-Fi, LoRa)

Working Mechanism

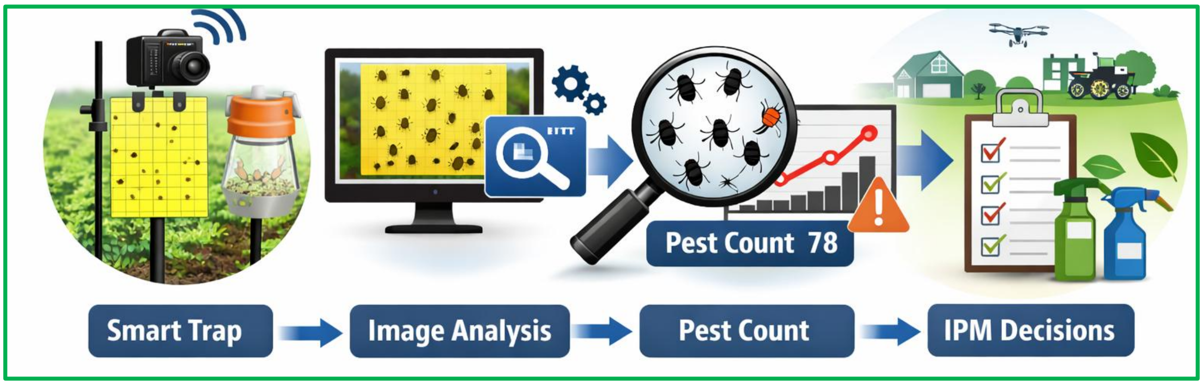


Figure 1. Working mechanism of an AI-powered smart trap

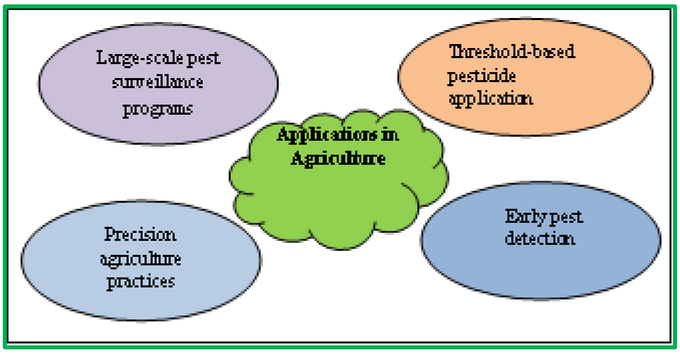
Insects are attracted using pheromones or light→Captured insects are imaged using an embedded camera→AI algorithms process images to detect and classify species→Data is transmitted to cloud or mobile platforms→Users receive real-time pest alerts and recommendations

Role of Artificial Intelligence in Insect Monitoring

Artificial Intelligence plays a central role in enabling automation and accuracy in smart traps. Machine learning (ML) and deep learning (DL) algorithms, particularly convolutional neural networks (CNNs), are used for image-based insect detection and classification.

AI models can:

- Identify insect species with high accuracy
- Count individuals even in dense populations
- Differentiate between pest and beneficial insects
- Analyse temporal trends in pest populations



Advanced systems also integrate predictive analytics, using historical and environmental data to forecast pest outbreaks. This allows farmers to take preventive measures rather than reactive ones, reducing pesticide use and crop losses.

Advantages of AI-Based Smart Traps

- Reduced labour and human effort
- Improved accuracy and consistency
- Real-time monitoring and alerts
- Scalability across large agricultural areas
- Reduction in unnecessary pesticide applications
- Contribution to environmentally sustainable farming

Table 1. Comparison of conventional and AI-based insect monitoring systems

Parameter	Conventional Methods	AI-Based Smart Traps
Data collection	Manual	Automated
Accuracy	Variable (observer-dependent)	High and consistent
Time requirement	High	Low
Real-time monitoring	Not possible	Possible
Scalability	Limited	High
Cost	Low initial cost	Higher initial investment
Data storage & analysis	Minimal	Advanced analytics and cloud storage

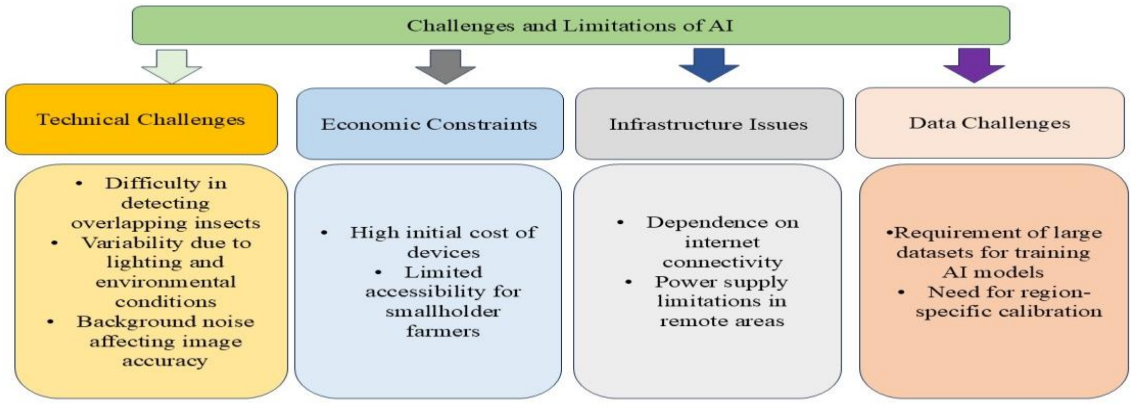
Case Study

Table2. Case Study: AI-Based Smart Trap Applications

Crop/System	Target Pest	Technology Used	Key Findings	Reference
Mango & Maize (Pakistan)	Fruit flies (*Bactrocera spp.*), Fall armyworm (*Spodoptera frugiperda*)	AI-enabled smart trap with camera + YOLO model + IoT	Achieved ~94% detection accuracy; real-time pest alerts reduced need for manual scouting	Schneider and Srivastava, 2025
Livestock (Cattle farms)	Hematophagous flies (*Stomoxys*, *Hippobosca*)	CNN-based smart trap with environmental sensors	High precision (96%) and recall (98%); autonomous monitoring improved pest management	Santaera *et al.*, 2025
Open-field agriculture (Mexico)	Nocturnal insects (moths, flies)	Neural network-guided smart trap with sensors and automated gating	Selective trapping improved efficiency and reduced non-target captures	Hinojosa-Dávalos et al., 2025
Orchards (Europe)	Brown marmorated stink bug (*Halyomorpha halys*)	Edge-AI smart trap with image processing and IoT connectivity	Continuous seasonal monitoring; reduced manual inspection and improved IPM decisions	Wilk et al., 2021

Challenges and Limitations

Despite their advantages, AI-powered smart traps face several challenges:



Future Prospects

The future of AI-powered insect monitoring lies in integration and accessibility. Emerging trends include:

- Integration with drones and satellite systems
- Development of low-cost, farmer-friendly devices
- Use of mobile applications for real-time advisory
- Region-specific AI models for improved accuracy
- Integration with weather data for pest forecasting

Advancements in edge computing and IoT are expected to further enhance the efficiency and affordability of smart traps, making them more accessible to farmers worldwide.

Conclusion

AI-powered smart traps represent a significant advancement in insect monitoring, bridging the gap between traditional pest surveillance and modern precision agriculture. By enabling real-time, accurate, and automated pest detection, these systems support informed decision-making and sustainable pest management. While challenges related to cost and infrastructure remain, continued innovation and policy support can facilitate wider adoption. Smart traps have the potential to transform agricultural practices by reducing pesticide use, improving crop productivity, and promoting environmentally sustainable farming systems.

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