

Smart Traps and Sensor-Based Insect Monitoring

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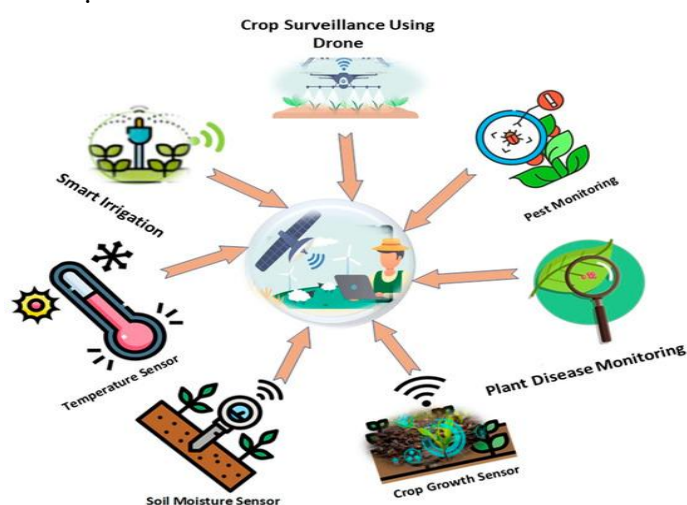
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INTRODUCTION

Insects are a major limitation for agricultural production globally, as both the quantity and quality of crops are related to defoliation by insect pests. Conventional techniques for pest monitoring are based on manual field scouting, visual inspection of pests and natural enemies, and trap monitoring at geographical sight intervals. However, these techniques tend to be highly laborious, time-consuming, and could be biased. The development of smart traps and sensor-based insect monitoring systems enabled by digital agriculture is currently revolutionizing pest management with the promise of offering real-time pest surveillance and precision pest management. These systems use sensor technologies, artificial intelligence (AI), Internet of Things (IoT), wireless communication networks, and data analytics to monitor pest populations continuously and provide information for farmers in a timely manner. Smart monitoring systems, which allow early detection of pests and reliable predictions, contribute to the reduction of crop losses, the optimization of pesticide applications, and the sustainability of agricultural production.



The Need for Advanced Insect Monitoring

Insect pests cause a 20–40% annual loss of crop yield worldwide. Climate change, global trade, and agricultural intensification have led to increased pest outbreaks and range expansions for many insect species. Conventional pest monitoring is time-consuming and costly, depending on manual field scouting and periodical observations. These methods might lead to late detection of pest outbreaks, a non-stratified evaluation, a limited coverage of the field and the difficulty to monitor large areas. To address these constraints, precision agriculture is growingly relying on automated insect monitoring systems which offer real-time information on the pest, enhancing surveillance precision, and enabling timely, data driven pest management decisions.

What are Smart Traps

Smart traps are non-contact, real-time insect monitoring devices that are furnished with sensors, cameras, communication modules, and artificial intelligence (AI) algorithms. Such traps use pheromones, light, colors, food baits or other attractants and also automatically detect, identify, count and send pest information to cloud platforms.

Types of Smart Traps

Pheromone-Based Smart Traps

Pheromone-based smart traps employ species-specific chemical attractants to draw the target insect pests, and integrated cameras and AI algorithms capture, identify, and count the insect population automatically. Such systems are now common for pests including cotton bollworm, fall armyworm, pink bollworm, fruit flies and diamondback moth. With accurate and real-time pest population estimation, the pheromone-based smart traps enable timely and effective decision making for pest management.

Light-Based Smart Traps

A number of insect species are drawn to specific wavelengths of light, which allows smart light traps to be used as very effective monitoring devices for nighttime pest species. The LED light sources in these traps are integrated with imaging and sensing technologies that enable automatic detection and recording of insect presence. They have multiple advantages such as 24-h monitoring, wide spectrum of pest detection, less laborious, and automatic data handling, which can enhance the efficacy and accuracy of pest surveillance system.



Sticky Smart Traps

Sticky smart traps with cameras take pictures of captured insects and apply machine learning algorithms to identify and provide an estimation on pest population. These systems find their application largely in greenhouses, vegetable

crops, horticultural production systems and finally protected cultivation systems, where they assist in providing a continuous and accurate pest monitoring to assist in timely management options.



Multi-Sensor Smart Traps

Advanced smart traps combine multiple attractants and sensor technologies to improve pest detection accuracy. These systems integrate environmental sensors, cameras, and AI-based identification models.

Sensor-Based Insect Monitoring Systems

Sensor-based insect monitoring systems make use of different technologies to improve monitoring of pests. Optical sensors operate on the principle of light reflection, and they employ imaging techniques for a fast, non-destructive determination and automated species identification. Acoustic sensors are also capable of detecting insects through their wingbeat and feeding sounds, with applications for wireless monitoring of mosquitoes, termites, storage pests, and pollinator activity without the need of capturing insects. Environmental sensors monitor temperature, humidity, precipitation, wind speed, solar radiation, and leaf wetness to forecast pest emergence and risk of outbreak.

Role of Artificial Intelligence in Insect Monitoring

AI is transforming insect monitoring, through automated identification of pests, estimation of their populations and prediction of outbreaks. The AI-enabled systems process the images taken by smart traps and match with extensive insect image databases to provide precise identification and classification of pests. They are: insect identification, pest counting, analysis of population trends, prediction of outbreaks, and support for decisions related to pest management. With more and more data, machine learning and deep learning algorithms are constantly enhancing their accuracy, enabling exact species recognition and less dependency on expert entomologists.

Internet of Things (IoT) Integration

The Internet of Things (IoT) combines smart traps, sensors, and communication modules into a unified pest monitoring system that provides live monitoring, remote access, automated notifications, cloud data storage, mobile apps, and decision support services. The

farmers can do timely and effective pest management interventions by receiving immediate alerts when pest populations go above economic threshold levels, which reduces crop losses and enhances the productivity as in the case of IoT-based solutions.

Applications in Precision Agriculture

The early detection of pests, which can be realized through the observation provided by smart monitoring systems before the occurrence of visible damages on the crops, allows management to be preventive and to reduce crop losses, therefore they are considered among the most important tools in precision agriculture for pest control. The real-time pest surveillance data enable precision pesticide application, so the chemicals are applied only in the time and place where they are needed, which results in reduction of pesticide use, production cost, environmental safety, and pesticide efficacy. By combining insect counts with weather data, such systems also enable pest forecasting, which aids growers with spray scheduling, resource management, risk management and crop protection management.

Benefits of Smart Traps and Sensor-Based Monitoring

Smart traps and sensor-based insect monitoring systems have many benefits compared to traditional methods of pest monitoring. Automated monitoring allows for higher-quality and more reliable pest population estimates while reducing the labor and scouting costs. Real-time pest data allows for informed decisions and immediate reactions to new pest threats. Through facilitating targeted applications of pesticides, these systems reduce the wastage of chemicals, the environmental contamination, and increase efficiency of pest control. Early detection and timely interventions allow for better crop protection, healthier crops and greater yield potential.

Challenges and Limitations

Although great advantages can be gained by using smart monitoring, there are some challenges such as the high cost for hardware and software installation and maintenance, the limited Internet access in the remote rural areas, energy supply and the technical knowledge that is required for using the system and interpreting output data. In addition, the accuracy of species identification may be reduced under complicated field conditions. Smart monitoring technologies will also require advancement in cost-effective technologies and the provision of training programs to farmers, so the overcoming of these barriers will be essential for these technologies to reach a wide audience of farmers, particularly those owning small holdings.

Future Trends in Insect Monitoring

A handful of nascent technologies are predicted to also bolster insect monitoring systems in the future. Sophisticated AI-based predictive analytics would enable better forecasting of pest outbreaks using historical pest, weather and crop data. Drone-based surveys will provide quick monitoring of vast farmlands, together with smart traps and ground sensors. Edge computing will allow processing of data in situ at monitoring devices, lessening the reliance on cloud connectivity and accelerating responses. Digital twins will build virtual crop environments to represent pest dynamics and test management options prior to field introduction, and autonomous pest management systems could potentially be triggered to start precision pesticide applications when pest numbers pass threshold levels.

CONCLUSION

Smart traps and sensor-based insect monitoring are a powerful step forward in the evolution of today's pest management. By leveraging sensors, AI, IoT, and cloud computing, these solutions enable real-time, accurate, and automated monitoring of pests. They enable early pest detection, precise

pesticide application, decision-making, and sustainable crop protection. Though barriers in terms of cost and infrastructure still exist, the pace of technological innovation is rapidly making these systems more and more viable.

With the digitization of agriculture, smart insect monitoring will be one of the pillars supporting precision farming and climate-resilient agricultural production.