Policy Research Journal
ISSN (E): 3006-7030 ISSN (P) : 3006-7022 Volume 4, Issue 3, 2026

AI-DRIVEN PRECISION PEST MANAGEMENT: INTEGRATING MACHINE LEARNING AND IOT FOR REAL-TIME MONITORING AND CONTROL

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DOI: http://doi.org/10.5281/zenodo.20504880

Keywords
Pest Monitoring, Pest Management, Machine Learning, Computer Vision, Smart Sensors, Precision Agriculture.

Article History
Received: 31 January 2026
Accepted: 16 March 2026
Published: 30 March 2026

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Abstract
Activities done with the assistance of software and algorithms that do not involve humans are called artificial intelligence. The aim of artificial intelligence is to find solutions like a person through experience. Artificial intelligence is making machines learn patterns, analyze data and take decisions and predict outcomes in ways that humans are not able to. It is also capable of solving problems and predicting problems before they happen. In the education sector, this technology, a breakthrough, can be impactful. Thus, the smart education system was developed. Artificial Intelligence analyzes & learns the images of pest species for machine learning from big data. Using a computer vision system, pest detection occurs from images. The machine learning system uses information derived from the camera, drone and smartphone to locate the pests on a real-time basis. Further, it does so without constant human intervention. The visual pattern recognition analytical tool detects damages caused to crop by insect pest. There are intelligent sensors that recognize pests using the seasonal behavioral patterns of pests and weather conditions. Sensors like temperature, humidity and soil moisture help in monitoring of changing condition. All these data help ascertain the scenario that causes pest development. AI tools can help classify and assess fruits and vegetables. The software determines the quality of produce by computing its shape, weight and colour. This helps in classifying the product under various grades as per specified quality parameters. To sum up, integrating artificial intelligence in pest monitoring can help recognize damage done to crops, thus reducing financial losses.

Introduction
Artificial Intelligence has become an essential agricultural technology for pest monitoring since its introduction. AI enables computer systems to analyze data and discover patterns which help users make decisions without needing human assistance (PG, 2023). The systems in pest management use their technology to enhance pest detection and tracking and control methods across agricultural land (Kamilaris & Prenafeta-Boldú, 2018). Farmers have traditionally depended on manual observation to monitor pest activity which often requires time experience and repeated field visits (Zhang et al., 2019). Early detection becomes more difficult because pest populations increase rapidly which creates problems for detection systems (Li et al., 2020). The existing situation prevents effective solutions from being implemented because crop damage already occurs (Kamilaris, 2018).

With AI-based monitoring tools agricultural pest tracking systems achieved more precise and effective monitoring capabilities. The systems enable operators to monitor their targets throughout all periods while the system alerts them to possible threats (Finlay, 2023). The new system improves all aspects of agricultural system management according to research by Li et al. in 2020.

The modern pest monitoring systems depend on machine learning as their primary technology. The system enables computers to enhance their performance by studying data which helps them achieve better results over time (Finlay, 2023). The agricultural sector uses machine learning to develop models which recognize various plant and pest species through analysis of crop and pest visual data (Li et al., 2020). The models use images from equipment that includes cameras and drones and mobile devices to achieve precise pest detection results (Zhang et al., 2019). The system identifies pests more efficiently because it requires less human monitoring (Kamilaris & Prenafeta-Boldú, 2018).

Machine learning functions as an essential technological component which enables contemporary pest monitoring systems to operate. The system enables computers to use data for improving their accuracy throughout their operational period (Finlay, 2023). Agricultural machine learning models require crop and pest image data for training purposes which enables them to automatically identify different species (Li et al., 2020). The models showcase their capability to analyze images which they collect from cameras drones and mobile devices while they successfully identify pests (Zhang et al., 2019). The system enables faster pest detection while reducing the need for continuous human monitoring (Kamilaris & Prenafeta-Boldú, 2018).

Pest monitoring has achieved its present condition because of computer vision technology and modern sensing systems. The system uses computer vision to process visual content that includes both images and videos for the purpose of identifying pest behavior patterns (Zhang et al., 2019). Smart agricultural field sensors have the capability to track various environmental conditions which encompass temperature and humidity and soil moisture levels (Kamilaris & Prenafeta-Boldú, 2018). AI systems use this information to determine which environmental conditions create optimal conditions for pest growth (Li et al., 2020).

The organization developed an advanced system to show complete field information by combining visual data with environmental data (Finlay, 2023). The system helps organizations to detect infestation problems early while planning their operations more effectively (Zhang et al., 2019).

AI tools help in predicting future pest outbreaks which make them valuable for pest control. The systems use historical data together with environmental patterns to forecast pest emergence times and locations (Li et al., 2020). The predictive system enables farmers to implement preventive actions which protect their crops from damage (Kamilaris & Prenafeta-Boldú, 2018). The system enhances decision-making processes by delivering information which is relevant at the moment and matches user needs (Finlay, 2023).

Farmers can achieve lower crop losses through better resource management practices which they developed from their research findings. The research results show that the method improves agricultural practices which enable farmers to sustain their productivity.

Artificial Intelligence in Agriculture

Samal and his team have shown that (2023), artificial intelligence helps in identifying nutrient deficiencies and soil defects with the aid of data from smartphone camera images and soil sensors. For instance, there is an application known as Plan tix that assists farmers in computing the type and amount of organic materials that can be used to improve soil to support the growth of specified plants. The application offers video-based advice based on the farmer's situation. The farmer can simply take a photograph of the soil and submit it for analysis through Microsoft's Farm Beats application. The farmer is then given guidelines on how to improve soil quality and production

after identifying the problem (Sosnowski et al., 2020).

In order to monitor all the crops in the agricultural industry and ensure their compatibility, smart agricultural technology has been created using artificial intelligence (Deepika & Kaliraj, 2021). The technology helps in the identification and detection of pests and diseases that can affect the crops in real time. It also provides farmers and experts with warnings to enable them to identify any danger before it happens.

Moreover, this technology helps in attaining food and economic security and agricultural sustainability in the community. In addition, AI-based agriculture helps in the transformation of the digital environment in the agriculture sector and the generation of technical job opportunities in the agriculture sector (Vincent et al., 2019).

Disease and pest management techniques

It has been stated by Abbaspour-Gilandeh et al. (2022) that there is the idea that the implementation of AI in the agricultural sector will assist in addressing some of the challenges associated with agricultural crops.

The ways in which AI can assist in the management of diseases and pests are as follows:

Managing the control strategy into AI programs can assist in the evaluation of the data available and associate it with different pests in agriculture. AI can also assist in the development of models that guide the control of disease and pests in agriculture. AI can also assist in identifying the appropriate time to spray, fertilize, and administer medication.

Moreover, data integration allows for the accurate prediction of the spread of the disease through the application of the data input and directs the need to limit the use of fertilizer and medicine in a more effective manner.

Machine learning devices are given different kinds of data by a sensor network that consists of different sensors and monitoring devices that make use of smart sensors to periodically sense and monitor the farms and the crops. Signs of pest and disease infestation are found and detected by classifying the data based on the input obtained from the devices (Cardim Ferreira Lima et al., 2020).

Use of AI-powered satellites

The images are taken using satellites or through the air and are used for learning. The application uses AI to differentiate between images that are healthy and normal and the ones that are suspicious of illness or pests. With time, the application will be able to identify both the health and disease of crops and the existence of any danger (Teixeira et al., 2023).

This technology was capable of detecting diseases like Brown spot disease and bacterial leaf blight with 98.5% accuracy. Singh et al. (2017) state that tomato infections were detected by employing the AI-based method.

The accuracy of the system for detecting diseases like early blight and late blight was 96.8%.

The above research works prove the effectiveness of AI-based systems for the detection of diseases and pests. According to Harsha et al. In 2022, artificial intelligence is crucial for diagnosing agricultural diseases. It offers new and innovative ways to manage crop diseases effectively, especially by using chemical methods wisely in plant management and growth.

It has been recommended that artificial intelligence-based approaches can be used for effective management of diseases affecting agriculture and reduction of costs associated with monitoring diseases, despite the limitations associated with traditional approaches of identifying diseases affecting plants, like surveys (Mathenge et al., 2023).

Artificial intelligence uses in disease diagnosis

In order for the AI system to be effectively trained, certain image processing techniques have to be used. These techniques help the AI system to either identify plant diseases or distinguish healthy and diseased plants for a particular crop type. Using images for plants disease identification and controlled by some methods which can help in plans growth. Traditional image taken technology work for plant disease identification in agriculture is being replaced by AI systems (Das et al., 2022).

Acoustic sensors assist in identifying and locating insect infestation distribution patterns and density, and detecting cryptic insect infestations (Mankin et al., 2011).

Today, insect noises can be separated from other noises through digital signal processing techniques because of computer technology's advancement. Research on new acoustic vehicle technologies for detecting and identifying underground insect pests has been initiated.

In addition, the time taken for crop scouting can be minimized and the time taken for addressing problems like weeds, pests, and fungal growth can be improved with the aid of drones. This is due to the reason that the drones are capable of transmitting information in real time with regard to crop health, soil, and growth stages. The drones are capable of capturing pictures with the help of sensors like multispectral sensors.

In order to make use of image processing techniques for crop health and pests, the drones can be equipped with heat sensors.

Drones and smart sensors are being used to monitor pests in farming and other areas. A drone is a machine that can fly without a person on board. It can be controlled from a distance or fly on its own. These machines use GPS and computers to follow a planned path. Drones are used in places like mining, construction, and the military. In farming, they help look at crops closely, check the ground, and take pictures. They help manage pests by finding damage areas, finding where pests live, and even delivering special treatments (Saini, Singh, & Gouda, 2024). Radoglou-Grammatikis describes the use of drones in smart agriculture. The concept of hybrid drones which use fixed-wing features and multirotor' features is discussed in the video. This drone is capable of vertical take-off and long-distance travel. This means these drones are efficient. The research also manifests drone integration with IoT and AI systems for monitoring environmental conditions and predicting pest outbreaks. Radoglou-Grammatikis et al., (2020).

The existing literature on application of drones in agriculture extensively focusses on the use of drone for remote sensing in agriculture. According to Hunt and Daughtry (2018), drones can be used to capture images of crops that can identify pest damage and stress in plants. A novel study showcased how drones can be used for remote sensing of crops to monitor their state. Images of crops can easily be monitored because of studies of the crop with a drone (Hunt & Daughtry 2018).

There has been a growing interest in using drones for smart farming. People have been saying for a long time that using GPS and data can increase crop yields and help with food and water shortages. But until recently, drones haven't been used much in farming. Now, there are many new developments. Drones can take pictures of corn leaves from above, check soil moisture, and help with watering. These tools are changing how farmers and experts look after crops. At the same time, some promises made to farmers have not been fully realized even with proper research. (Verstraete, F, 2015).

Drones can help improve planting strategies and crop rotation. They also allow for daily monitoring of different parts of a field. Over time, more uses for drones will be discovered, and this will help make farms more efficient. Smaller farms may then be able to compete better with bigger farming operations (Verstraete, F, 2015).

In agriculture and forestry, insect populations are a big issue. Normally, people check traps in the field, which are in the large areas are time consuming and costly. A better system would be one that can do this automatically, quickly, and accurately. This paper suggests using a low-cost image sensor that can take and send pictures of traps to a control center. These sensors use very little energy, so they can work for months without needing a battery change. The images are tagged with time and analyzed in the control station to count insects in each trap. All the data is stored and can be accessed online (Lopez et al., 2012).

Sensor-Based Detection and Monitoring of Lepidopteran

Smart traps are being developed to detect certain types of flying insects automatically. These traps use sensors to detect insects without the need for

manual checks. Some of these sensors are expensive or not very effective for fast-moving insects. Currently, pest surveillance systems depend on manual inspection of traps, which increases operational costs. Although modern smart traps with automated detection are being developed, most existing systems rely on costly cameras or optoelectronic sensors that are more suitable for detecting fast-flying insects. In contrast, this study presents an optoelectronic sensor installed within a delta trap that can capture the slower wing-beat activity of Lepidoptera and transmit real-time data wirelessly. When combined with machine learning techniques, this system can assist in identifying insect species based on their unique biological characteristics (Welsh et al., 2022).

The global food supply and crop yield are significantly impacted by pests. The majority of conventional pest management is reactive and frequently heavily dependent on chemical pesticides. Prediction analysis, on the other hand, provides a proactive method of controlling pests by anticipating their attacks. Prediction models are essential to contemporary agricultural practices, and climate change plays a significant role in the shifting patterns of pests. Pest behavior is being impacted by climate change (Zafar et el., 2025).

To ascertain the dynamics of pest populations, predictive analysis relies on biological and environmental factors. Ti predicts pest outbreaks, it takes into account a number of variables, including temperature, humidity, rainfall, and crop development. Examining past pest data in conjunction with environmental monitoring can help farmers to make better decisions. The use of pesticides as well as utilizing environmentally friendly methods, predictive analysis AIDS in integrated pest management. Predictive analysis has been shown to reduce chemical applications (Ali and Qureshi., 2024).

Important predictive models and methods

Pest prediction models have made extensive for models through Factor Machine, as well as Artificial Neutral Networks. In rice - based farming systems, machine learning models can detect pest outbreaks earlier. Early warning tools can be designed using predictive models. Before pest populations become harmful, these systems will notify farmers. Crop damage will be lessened by these systems (Billeras et al., 2025). In a similar vein, it was noted that AI models are capable of processing massive amounts of data and recognizing intricate patterns of pest behavior (Reddy et al., 2025).

Climate- based models are used to predict pest life cycles based on specific temperatures, especially models for the accumulation of degree days. Additionally, it stated that temperature variations have a major impact on insect development and reproduction, making climate, based models useful for pest forecasting (Abduljaleel et al., 2025).

The pattern of pest population growth can be investigated using time series models like ARIMA and SARIMA. Forecasts of pest population outbreaks can be generated by time series models, which can also help with the planning of suitable pest control measures. When the data is consistent, time series models can be used (Loona et al., 2025).

The pest prediction system has changed due to the incorporation of AI and big data with lot sensors and satellite imagery. Pests have been accurately identified by image recognition systems (Reddy et al., 2025). In a similar vein, the use of remote sensing for forest pest monitoring was discussed (Choi et al., 2025).

Benefits and Challenges of AI in Pest Management

The recognition and observation of pests have improved significantly due to artificial intelligence. AI-driven applications evaluate images taken from drones, cameras, or sensors to determine insect pests, damage to the plant, or disease symptoms. For this purpose, convolutional neural networks (CNNs) are trained using machine learning algorithms. The models that were trained subsequently perform inference on the images for pest and disease detection. In the event that a pest outbreak occurs and damage is identified, farmers can undergo damage

inspection training. Typically, in pest scouting, human personnel can visually inspect the fields to note the presence of and damage caused by pests. Unfortunately, this process takes considerable time, doesn't give accurate result and is inefficient for large application area. Using the monitoring system gives better results. They will application can process large volumes of field information in real time and transmit the information. The provision of enhanced monitoring of pests and timely distraction support decisions that are more effective in pest management (Srilatha, P 2025).

The use of pesticides can be significantly reduced due to trials and identification of new methods through AI technology. Our AI tools for precision agriculture have the capacity to detect where and how much pesticide to use to treat affected plants only. It reduces unnecessary use of chemicals and prevents environmental pollution. Studies show that AI-enabled pest management systems can cut down use of pesticides by nearly 90% and improve yield by 20-30% AI technology can help reduce surplus use of pesticides as well as protect beneficial insects, soil, and neighboring ecosystems (Mishra, M. M., & Paliwal, A. 2026).

Artificial intelligence is essential for precision farming. It incorporates data produced by drones, IoT sensors, satellite imagery, and weather monitoring systems. Also, it can analyse environmental condition, pest population trend and crop health data at the same time. It forecasts pest outbreaks and recommends the most effective pest management measures. Farmers can receive automated alerts and recommendations via a mobile app using Artificial Intelligence (AI) based Decision Support Systems. Most importantly, this increases the effectiveness of farm management. Also, this could assist the farmers in a proper implementation of the IPM strategy and pesticide usage management (Barbados, 2025).

AI technology now makes pest management systems more effective. It can also automate agricultural tasks. Robots, smart traps, and artificial intelligence drones can install permanent monitors on farms without the need for human intervention. Particularly for extensive crop rotation, automated farming systems greatly increase the efficiency of farming operations and minimize the need for labor. For pest control, AI systems also consider environmental trends and additional historical information. As a result, you won't need to pay for labor and pesticides. According to some surveys, when properly adopted and implemented, AI systems can reduce pest management costs by 30–40% while also improving quality and productivity. (Shoaib et al., 2025).

Data Availability and Quality Challenges

Artificial intelligence is slowly making its entry into pest management in the makeup industry and agricultural science. The main user of the drone is the designer who is changing designs of crops as well as a drone. The cosmetics sector is always looking for a perfect ingredient for their desired colour while AI is proving to be effective at it. Aside from the field that requires 3D design coding development a to z knowledge about the industry. The makeup industry is also finding a better ingredient for their perfect color while AI is being effective in the process. In an industry that requires complete knowledge from developing codes, designing and developing equipment in 3-D, the drone is being efficiently utilized (Wen, G. 2025).

In Conclusion, AI technology now makes pest management systems more effective. It can also automate agricultural tasks. Robots, smart traps, and artificial intelligence drones can install permanent monitors on farms without the need for human intervention. Particularly for extensive crop rotation, automated farming systems greatly increase the efficiency of farming operations and minimize the need for labor. For pest control, AI systems also consider environmental trends and additional historical information. As a result, you won't need to pay for labor and pesticides. According to some surveys, when properly adopted and implemented, AI systems can reduce pest management costs by 30–40% while also improving quality and productivity. (Shoaib et al., 2025).

Another significant obstacle is the high cost of technology. AI systems need a high degree of

technological sophistication; they need devices like cameras, drones, IoT sensors, and cloud computing. Small farmers might not be able to afford these technologies. Additionally, a lot of rural farming areas that lack power, digital infrastructure, and reliable internet connectivity. As a result, farmers cannot operate AI systems. Wider adoption of AI-based technologies in developing nations and other small farming communities is hampered by financial and technical barriers (L. Li and Wang, 2024; Shoaib et al., 2025).

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