Artificial intelligence in crop protection

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Abstract: Artificial intelligence can be deployed effectively to leverage massive data sets to produce environmentally friendly crop protection products. The use of AI techniques can help to automate and speed up the process of providing farmers with timely and accurate decision-support on critical aspects of pest management such as pest identification, pest monitoring, selection of an appropriate pest management strategy and AI-based pesticide application. This new technology can safeguard biodiversity, including pollinators such as bees, which are vital to grow crops and also several beneficial insects such as ladybird beetles, which are a natural way to control pests. Additionally, the AI-based applications help to maintain soil health, enhances capacity of the soil to absorb carbon and thereby lowering the greenhouse gas emissions caused by agriculture.

According to the United Nations Food and Agriculture Organization, the global population will grow by two billion by 2050, while only 4% of additional land will be under cultivation by that time. Farmers face an increasing challenge in maintaining farm productivity in the face of rising agricultural debts and unpredictable weather patterns, as evidenced by the recent spate of farmer suicides. Biotic factors such as insect pests and diseases are major contributors to decreased farm productivity wherein reducing crop losses is the key way to enhance farm productivity. The use of emerging technologies such as Artificial Intelligence (AI) can certainly aid in the efficient and successful management of crop pests. The adoption of cognitive solutions is crucial for the future of farming.

AI is a branch of computer science that deals with computer systems simulating human intelligence processes. AI is rapidly becoming pervasive due to its robust applicability to solve a variety of problems that traditional computing and human efforts cannot solve. John McCarthy, an American computer scientist, coined the term artificial intelligence (AI) in 1956 at the Dartmouth Conference. Artificial intelligence is a subfield of computer science that seeks to develop intelligent machines. AI can identify patterns in data more efficiently than humans, allowing researchers to gain more insight into their data. Natural language processing, speech recognition, robotics, sensor systems, and computer vision are major applications of AI. Learning, reasoning, and self-correction are descriptions of these processes.

Artificial intelligence (AI) is a new technology in agriculture. AI-based technologies have the potential to strengthen crop production by more effectively managing pests and diseases in farmers' fields. Machine learning, a type of artificial intelligence that is trained on massive data sets and then learns on its own, can assist farmers in pest identification and monitoring, providing timely support for pest management decision-making. Machine learning is a subset of artificial intelligence in which supervised learning uses classification and regression algorithms to identify patterns in data and unsupervised learning uses clustering and association algorithms. Classification determines which category an object belongs to, whereas regression deals with obtaining a set of numerical inputs and discovering functions that enable the generation of appropriate outputs from respective inputs. AI-enabled agricultural solutions assist farmers in increasing crop productivity by reducing crop loss. AI, along with other digital technologies, will play an important role in modernising agricultural activities. Artificial intelligence has a wide range of applications in pest management, a critical area of agriculture. Plant protection is a critical aspect of agriculture in the face of numerous challenges. Plant protection challenges can be met with AI-driven techniques and tools. AI can learn from data and thus identify patterns in data more efficiently than humans, allowing researchers to gain more insight from their data.

Identification of specific pests in the field is critical for successful pest management. Growers must distinguish between beneficial and harmful insects in order to implement effective pest control measures. Another critical aspect of pest management is regular pest monitoring, which assists in determining the level of occurrence and the appropriate time to initiate pest management intervention. Following a thorough examination of the level of pest incidence, the appropriate pest management strategy must be chosen from among various pest management strategies such as biological, chemical, physical, quarantine, or cultural methods. Artificial intelligence (AI) has already been used in plant protection all over the world. Deep learning for pest identification, Artificial Neural Networks (ANNs) for pest modelling, and Internet of Things (IoT) for efficient farm management are some of the AI techniques used in plant protection. Researchers have also used AI approaches such as Fuzzy logic and Bayesian Network in the development of a pest management Decision Support System. Although the use of AI is promising, there are challenges in plant protection. Two major challenges in the process of developing AI-based plant protection tools and techniques are the development of innovative AI algorithms and the non-availability or limited availability of data for data learning. Pest prediction is still complex and elusive. The process of plant protection in agriculture is slowly becoming digital with AI showing promising potential.

Status of research in the subject and advancement: The application of ICT in agriculture for information transmission began in the 1990s, particularly with the development of stand-alone and web-based applications. Many web-based agricultural databases, information systems, and expert systems have already been developed in India. Web-based expert systems were developed in plant protection to diagnose diseases and pests of various crops and provide management information. Web-based systems are now widely used in agriculture in many countries. This aided farmers in obtaining accurate information on crop varieties, pest identification, and pest management. CUPTEX, an application for managing cucumber disorders; NEPER, a web-based application used for managing the production management aspects of wheat crops; USDA developed an expert system for cotton crop management to provide appropriate management recommendations to cotton growers. Some of the web-based systems developed nationally are: eSAP (Electronic Solutions against Agricultural Pests) for crop health management, detection and advisories for insect pests, microbial diseases, nutritional deficiencies, and weed problems; AGREX, an expert system developed by the Center for Informatics Research and Advancement, Kerala for providing timely and accurate information. Mobile based information apps from ICAR-National Research Centre for Integrated Pest Management, New Delhi such as Pest Management Information System (PMIS) on Brinjal, PMIS on Tomato, PMIS on Okra, PMIS on Chilli, Rice IPM, Groundnut IPM etc.

The recent years have seen a significant amount of research on automatic pest identification. The majority of the time, computer vision, machine learning, or deep learning technologies are chosen and employed to identify plant diseases, but typically just one approach is chosen without comparing the other potential approaches in the same job. Numerous studies on the automatic detection and identification of pests concentrate on a single technological approach, while alternative technical approaches are not explored. In recent years, object recognition and computer vision have made significant progress. Prior to now, image classification challenges have been traditionally approached using features detection methods as DoG, Salient Regions, SURF, SIFT, MSER, etc.

Some learning methods are employed with the features after they have been extracted. Predefined features affect how well the approaches perform. The process of feature engineering itself is challenging and must be redone whenever the problem or dataset changes. This issue arises in all attempts to detect plant diseases using computer vision since they rely on manually created features and algorithms for image augmentation. Deep learning techniques can be used to resolve the problem of manual feature extraction because feature extraction is done automatically. Recent advances in deep learning enable significantly greater object recognition and detection accuracy. Deep learning techniques have been used, on the one hand, to find and cure the disease. Many of these techniques, including Artificial Neural Networks (ANNs), Decision Trees, K-means, and K-nearest Neighbours, have been used in agricultural research projects. One of these techniques that have been widely applied in the field of illness diagnosis is Support Vector Machines (SVMs). However, deep learning, a recent development in machine learning, advances the state-of-the-art in a number of areas, including the capacity to work directly with images without relying on manually derived characteristics. As shown in various applications, both machine learning and deep learning can increase computer vision accuracy. Deep learning may learn and make intelligent decisions using structured algorithms in layers, as opposed to machine learning, which bases its decisions on what it has learned from the incoming data.

AI companies use the new satellite images against pictures of the same using historical data and AI algorithm detects that the insects had landed at another location and farmers use such information after confirmation and timely eradicate the expensive pests from their fields. A deep learning-based programme called Plantix, created by German tech startup PEAT, can find probable flaws and nutritional deficits in the soil. You can use your smartphone to take a picture of the plant and check for faults thanks to this app's image recognition capabilities. On this app, you will also find short movies with advice and various ideas for soil restoration. Drone-based aerial photography was made possible by VineView, a business that acquired SkySquirrel Technologies. A round of data collection from the grape field is done using a drone, and all the data is then downloaded through a USB drive from the drone to a computer and examined by the experts. As these plants are highly susceptible to grapevine diseases like moulds and bacteria, the company uses algorithms to analyze the captured images and provides a detailed report with the current health of the vineyard, generally, the condition of grapevine leaves, helping farmers to timely control using pest control and other methods.

Artificial Intelligence (AI) and its role in agriculture

The most valuable sector in the world *i.e.,* Agriculture, is experiencing a tremendous influence from artificial intelligence (AI), which is growing its ground-level footprint. Agriculture is gradually moving digital. Predictive analytics, agricultural robotics, and soil and crop monitoring are the three main areas where AI in agriculture is now being used.

Robots for agriculture: Many companies are creating machines to perform crucial agricultural chores, such harvesting crops more quickly and in greater quantities than people can.

Crop and soil monitoring: To analyze data obtained from drones or sensor-based technologies in order to monitor crop and soil health, organizations use computer vision and deep learning algorithms.

Predictive analytics: Machine learning models are being created to forecast how changes in the weather will affect crop productivity. Public and corporate organizations throughout the world have created numerous AI-based solutions for agriculture. The use of sensors and soil sampling by farmers is expanding, and the data they collect is stored on farm management systems for easier processing and analysis. The accessibility of these data and related data is opening the door for the application of AI in agriculture.

Practical application of AI and its role in agriculture

1. AI-based crop rotation and farm management: The majority of the UN sustainable development goals may be resolved globally with the help of straightforward AI-based expert systems assisting farms' decision-making for maximizing crop rotation. Crop rotation and agricultural management based on AI essentially work with nature rather than against it (Schoning and Richter, 2021).
2. Integration of Computer Vision and Applied Artificial Intelligence in Postharvest Storage Systems: An intelligent postharvest storage system can be created that is profitable, sustainable, and simple to deploy using vision-based adaptive controls in the storage chamber and vision-based quality grading of fruits and vegetables (Concepcion et al., 2021)
3. AI in agriculture for optimization of irrigation: The development of smart irrigation technology enables farmers to boost production without using a lot of labour by monitoring soil temperature, fertilizer content, water level, and weather forecasts. Turning the irrigator pump ON/OFF maintains the microcontroller to conduct the actuation. By creating remote sensors using Arduino technology, an automated watering system can enhance productivity by up to 40%. The placement of sensors is crucial to the effective application of irrigation robots. Multiple irrigation zones in the fields can be controlled by a single sensor (Shekhar et al., 2017; Jha et al., 2019; Savitha and Uma Maheshwari, 2018, Varatharajalu and Ramprabu (2018).
4. Unmanned aerial vehicles (UAVs) powered by AI: UAVs interact with the GPS and other sensors that are mounted on them. Drones are being used in agriculture for weed identification, cattle and animal monitoring, crop health monitoring, irrigation equipment monitoring, disaster management, and weed identification (Veroustraete, 2015; Ahirwar et al., 2019; Natu and Kulkarni, 2016). Agriculture is being greatly impacted by remote sensing using UAVs for image capture, processing, and analysis (Abdullahi et al., 2015)
5. Yield mapping and monitoring: A tone or shaded guide is often used to depict the ranges of yield within a field (Talaviya et al., 2020).
6. Yield calculation and calibration: Harvest weight or volume reaped per unit region, which is indirectly calculated by yield sensor while harvesting with combined harvesters or reapers (Talaviya et al., 2020).
7. Real-time crop and soil monitoring
8. Crop yield prediction and price forecast
9. Making resource allocation wiser
10. Improving food and environmental sustainability
11. Analysing market demand and managing risk
12. Protecting, feeding and harvesting the crops

Role of Artificial Intelligence in pest management

The use of AI-based technology helps to increase productivity across all industries and manages the difficulties faced by numerous fields in the agricultural sector, including crop monitoring, pest control, irrigation, and soil content sensing. Artificial intelligence (AI) has the potential to provide Agriculture with a much-needed answer, particularly in the area of pest management. By allowing farmers to produce more while using fewer plant protection inputs and even improving output quality, AI-based pest management technologies can ensure higher market prices for crop production. In addition to accelerating the process of pest detection, Application of AI approaches such as deep learning, in ICT based systems of decision support in pest management has started which not only speeds up the process of pest identification but also greatly facilitates pest surveillance and provides pest management advisories.

There are different ways of AI in pest management, which are described as follows.

1. A simple way for field scouting: AI can assist scouts by giving precise descriptions of pests and their locations in fields (Niranjan et al., 2022). The cost of crops lost each year will be greatly reduced by automated crop field surveillance utilizing computer vision, and the security of the field can be fully automated (Khare and Phadke, 2020).

2. Addressing challenges of pest diagnosis: Effective pest management depends on accurate field identification of a particular pest. Regular pest monitoring, which aids in determining the frequency of an infestation and the best time to start a pest control intervention, is another crucial component of pest management (Fig. 1).

3. Predicting pest issues in advance: Using AI approaches, farmers can receive timely and accurate decision-support on crucial areas of pest management, such as pest identification, pest monitoring, and the choice of an effective pest management strategy (Niranjan et al., 2022). AI is essential for increasing crop productivity and identifying plant diseases (Upadhyay and Gupta, 2021).

4. Spraying of pesticides with AI-powered drones:

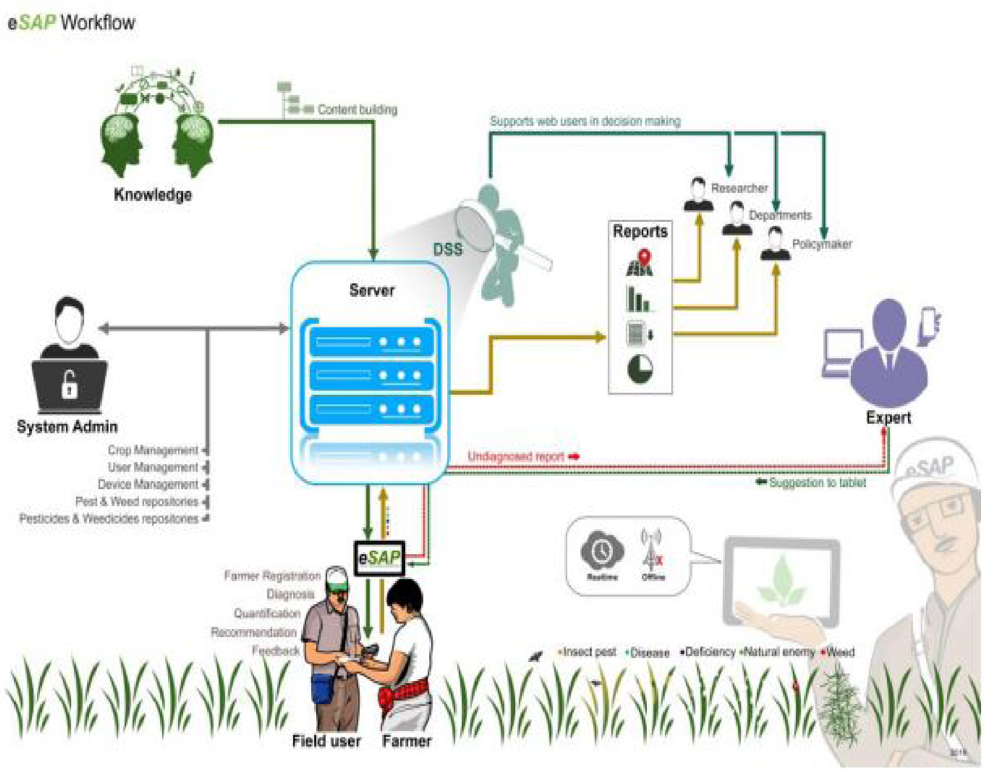

Fig. 1 Workflow of Electronic Solutions against Agricultural Pests (Aralimarad Prabhuraj, 2020)

Spraying pesticides with drones helps to manage pests effectively over a broader region by ensuring that crops are completely covered. Crop protection products are applied at the proper time, only where they are required, and at the best rate by utilising current breakthroughs in AI-aided spray timers, zone spray, buffer zones, and product recommendations. This improves the productivity and financial success of the farmer while also lessening the impact on the environment. The combination of AI-driven spray timing, variable rate application maps, and product recommendations in Europe has resulted in a 30% decrease in the use of fungicides on field trial cereal crops and a 72% decrease in tank residue, minimising environmental pollution. In Brazil the zone spray weed maps solution created using computer vision techniques resulted in a 61% average savings, cutting back on almost two-thirds of herbicide and water consumption (Shankar et al., 2020) (Fig. 2 and 3).

5. Large-scale pest monitoring and surveillance: AI-based drones are employed for pest monitoring

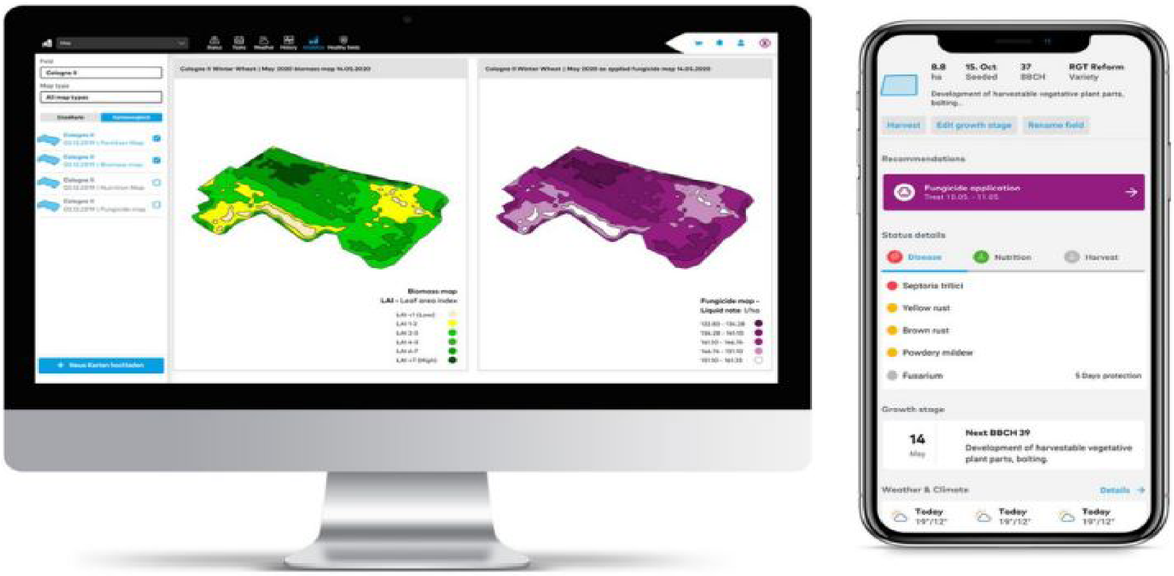

Fig. 2 Illustration of AI based xarvio Zone Spray and Spray Timer (Shankar et al 2020)

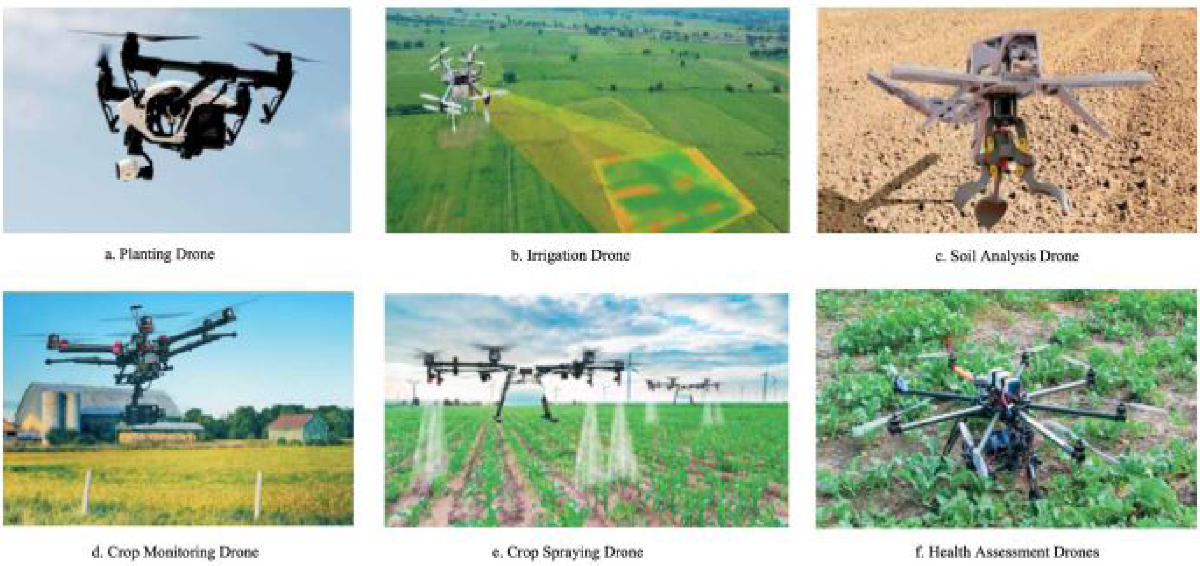

Fig. 3 Various applications of modern agriculture drones (Unpaprom et al., 2018).

and security (Fig. 4).

AI techniques for crop protection

1. *Machine learning:* Algorithms that can learn on their own from a set of input data in order to accomplish a certain goal are the subject of machine learning. New agricultural opportunities are made possible by its powerful computer. Machine learning and statistical pattern recognition have drawn a lot of interest in the agriculture sector because they have the potential to increase the sensitivity of disease identification and diagnosis. Farmer decision-making and action are aided by the plethora of recommendations and insights provided by machine learning-enabled technologies. Example: Classification of diseased or healthy leaves, fruit, plants, etc.
2. *Artificial Neural Network (ANN):* Among the several techniques used, artificial neural networks (ANNs) are one of the more reliable methods of recognising plant diseases. Neural networks are combined with various image pre-processing algorithms to enhance feature extraction. The biological neurons of the human nervous system are the foundation of ANN. Contrarily, ANN can extract meaning from complex data and identify patterns that are difficult for humans or conventional computers to find. Other advantages of ANNs include adaptive learning, self-organization, real-time operations etc.

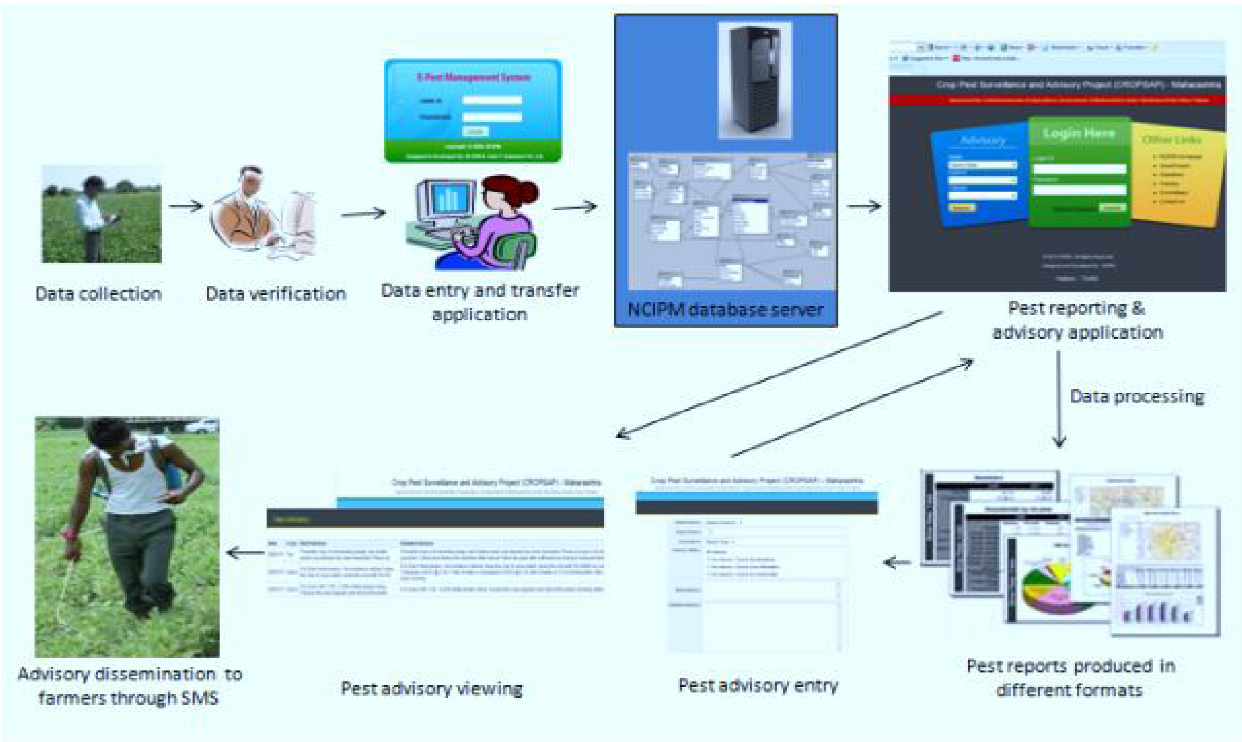

Fig. 4 Structure of ICT-based pest surveillance (https://ncipm.icar.gov.in/NCIPMPDFs/successstories/PestSurveillance.pdf

3. *Image processing techniques:* Image processing techniques were successfully and widely used for plant detection and classification. The data is organised into categories using a two-dimensional taxonomy. One dimension includes the following processes: object detection, data reduction/feature extraction, pre-processing, segmentation, optimization, and image interpretation. At several levels, such as the level of a pixel, an object set, and so on, inputs are received and tasks are carried out in a certain dimension. Several pre-processing techniques, including picture clipping, image smoothing, and image enhancement, are employed to increase the effectiveness of sickness diagnosis. A number of methods, such as the Otsu

method, k-means clustering, and converting RGB images to HIS models, can be used to segment images. Fourier filtering, edge detection, and other image pre-processing techniques were also used. Example: Image-based disease and weed identification.

4. *Support Vector Machine (SVM):* Support vector machines are supervised learning systems that are used to handle classification and regression issues. In SVM, the hyperplane is utilised to separate the classes. A hyperplane in N-dimensional space is analogous to a line in two dimensions. This hyperplane divides the plane into two halves, with each class on one side, in two dimensions. The SVM approach finds the best hyperplane for classifying new samples using labelled training data. As a result, SVM determines the hyperplane to classify each data point separately. For accurately diagnosing leaf diseases, the Support Vector Machine (SVM) has also been found to be very promising.
5. *Internet of Things (IoT):* Internet of Things (IoT): The internet of things, also known as IoT, is a network of interconnected computing devices, mechanical and digital machines, objects, animals, and people who are given unique identifiers and the capacity to transfer data over a network without the need for human-to-human or human-to-computer interaction. IoT includes robotics and sensors. Example: Robotics (Drones) helps to take the view or infestation survey of the field within a short span of time without manual power.

Conclusion

The foremost application of artificial intelligence is pest detection, identification, and timely recommendation of plant protection measures. It is the latest direction for farmers to adopt new technology in order to meet global food demands by managing insect pests using artificial intelligence techniques, thereby contributing to increased food security. Many mobile apps based on artificial intelligence have been developed by various ICAR research institutes for several crops to efficiently identify and manage crop insect pests. Although the use of AI is promising, there are challenges in plant protection. Two major challenges in the process of developing AI-based plant protection tools and techniques are the development of innovative AI algorithms and the non-availability or limited availability of data for data learning. Pest prediction is still complex and elusive. The process of plant protection in agriculture is slowly becoming digital with AI showing promising potential.

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