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RESEARCH PAPER

Industry 4.0 Concepts in Pest Management

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ABSTRACT

Industry 4.0 otherwise called as Fourth Industrial Revolution, is the current trend of automation and data exchange in manufacturing technologies, including cyber physical systems, the internet of things, cloud computing and cresting the smart factory. In the earlier three industrial revolutions, introduction of steam powered engines, steel and electricity, electronics and computers, and conversion of analogue-mechanical technology to digital-automation software happened. In this fourth industrial revolution, emphasis on integration of digital technology with the new level of interconnectivity through IOT devices, cloud computing, robotics etc. is envisioned. As this Industry 4.0 concept overwhelms all walks of life, its role in modern agriculture in general and pest management in particular draws admirable attention. IOT devices in traps and other material will give an accurate data of collected pest up to date and enhance the pest management practices as integrated in Picusan trap for managing *Rhynchophorus ferrugineus*. In another example, based on the wing beat frequency, optical sensor differentiates *Ceratitis capitata* and *Bactrocera oleae* with 99 per cent accuracy. Automatic count system to monitor the dynamics of *Bactrocera dorsalis* in field level is also developed. Similarly, to monitor and trap various lepidopteran and dipteran insects, Trap view, Trap view Aura, Spensa z trap and Spensa sentinal traps are developed. GUPSY (Global Urban Positioning and Sensor system) bedbug monitoring system and RADAR (Rodent Activated Detection and Riddance) developed by Rentokil successfully embraced Industry 4.0 in pest management. Use of autonomous robots in pest monitoring and detection will give real time data there by achieving effective pest management. AI based neural networks used for image processing as done in Asian citrus psyllid monitoring and termite identification highlights the importance and practical use of this technology. 3D printed pod bug developed to release *Rhinoncomimus latipes*, a biocontrol agent of Mile – minute weed using unmanned Ariel Vehicle is successfully attempted. Cloud computing is mandatory for implementing such Industry 4.0 concepts, as it involves storage and retrieval of big data for further processing by different algorithms. This seminar highlights various components of Industry 4.0 in pest management and their successful utilization with the help of salient case studies.

HIGHLIGHTS

- The digitalization of agriculture, under the era of fourth Industrial Revolution through Internet of Things and Artificial Intelligence ,offers novel solutions that can achieve precise control.

Keywords: Pest monitoring, detection, management tactics, innovative techniques

With the internet era engrossing humans because of rapid developments in internet communication technology, smart production systems earlier undreamt of are becoming order of the day. These production systems aim for efficient production protocols through hyper-optimal utilization of resources using advanced automation and networking. It digitally transforms production

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systems as self-monitoring, diagnosing, analyzing, decision making, automated smart machine systems. These advancements are collectively called as "Industry 4.0".

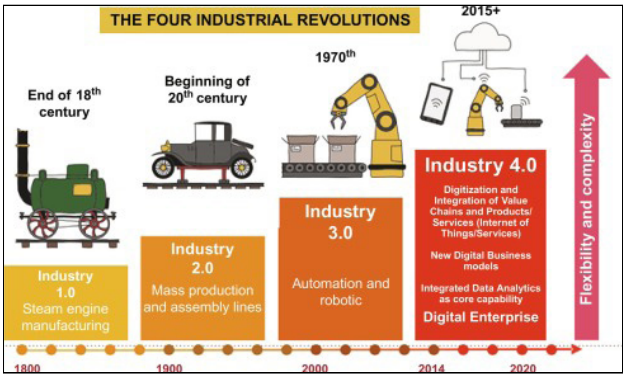
Industry 4.0 Definition

Industry 4.0 is defined as creating the smart production systems using the current trend of automation and data exchange in manufacturing technologies, including cyber-physical systems, the Internet of things, cloud computing, cognitive computing etc.,

Need of Industry 4.0 in Pest Management

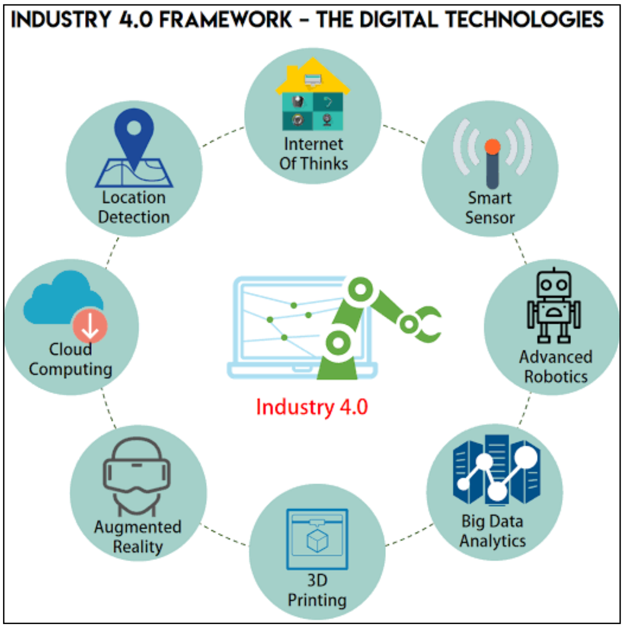
The need for these innovative technologies arises because, monitoring and survey of insect pest plays a major role in pest management. Based on these management will be effectively implemented. In traditional pest management it is time consuming and labor intensive. Hence, by using innovative technologies in pest management one can get timely precise data and can effectively enhance pest management program.

History of Industrial Revolutions



- First industrial revolution — 1700s — Mechanized manufacturing process with steam powered engines and other machines
- Second industrial revolution — 1900s – Use of steel and electricity for enhanced productivity.
- Third industrial revolution — 1955 — analog machines transformed into digital automated ones.
- Fourth industrial revolution — 2014 — New level of interconnectivity using cyber physical systems, cloud computing and various IOT devices etc.

Various Components of Industry 4.0



The role of each component in pest management program with the help of several case studies is discussed in detail.

1. Internet of Things

It is connection between physical objects like sensors with the internet to make the Dump things smart. By using various IOT devices one can monitor the exact farm condition remotely. As a result of declining agricultural workforce, use of internet connectivity has been triggered to reduce the use of manual labor in the field. Intelligence survey have also mentioned strongly that use of IOT devices will reach 75 million in 2020 with annual growth rate of 20 per cent.

As basics of *Machine learning, Deep learning and computer vision* are needed for better understanding, the principle behind these technologies has been explained.

Machine learning

It is part of artificial intelligence technology and is generally divided into two types *viz.,* Supervised learning and Unsupervised learning

Supervised learning

In supervised learning, *data will be fed with labels.* For example, 10 images of aphids and 10 images of whiteflies will be fed to the algorithm and the algorithm will be trained to identify a test image uploaded as an aphid or whitefly.

Unsupervised learning

In unsupervised learning, *data will be fed without any labels.* Algorithm is trained with bulk images and it itself will be able to classify the images, as to what type and class of insect it belongs to, based on the training dataset.

Deep learning

It is part of machine learning and is divided into two types *viz.*, Two stage object detection method and One stage object detection method.

Two stage object detection method

When the data is fed, it will create a region proposal network to identify the type of object. In this type, accuracy is more. Convolutional neural network (CNN) and artificial neural network (ANN) comes under this category.

One stage object detection method

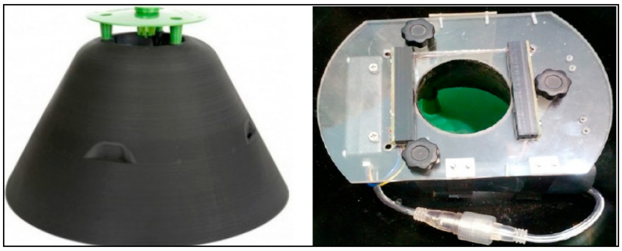
In this type, detection and identification can be done in a single process. Accuracy is low but data processing speed is high.

Computer vision

It is also a field of artificial intelligence, which make the computer to give information based on the digital data *viz.*, images, videos, and other files.

IOT in pest management: Case studies

Picusan trap for monitoring the *Rhynchophorus ferrugineus*



Black pyramidal trap which contains the aggregation pheromones along with optical sensor sense adult pests that enter the trap and count the number of pests as well. It also has the facility to measure the environmental parameters. This collected data are transmitted straight to the internet through GPRS (Potamitis *et al*. 2017).

Automated stored grain pitfall trap

The lid of the trap will contain five LED opposite to the receiving photodiodes. When insect fall in the trap it will interrupt the light thereby voltage variation may occur, and this is considered as insect count. This trap also has the provision to record the data regarding environmental conditions. Collected monitoring data are sent to the server for further processing (Potamitis *et al*. 2017).

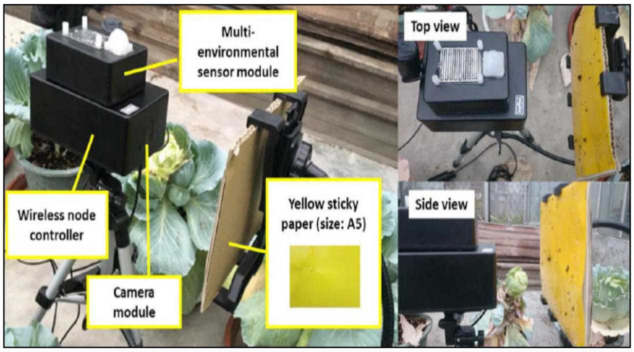
Tian *et al*. (2021) developed the *Distributed and Parallel Simulation Framework* to overcome the issue in single core graphical processing unit which is utilized in the many automated pest management systems. The developed framework uses multi-threading concepts as it shares the process (for e.g. insects' images) equally to each core thereby we can reduce the stress on single core graphical processing unit.

Rustia and Lin (2017) developed a IOT based imaging and sensor node system for monitoring greenhouse pest. This device consists of camera, wireless sensor node and multi environmental node. It continuously monitors the number of pests detected in the yellow sticky traps which is kept in multiple locations in the greenhouse. As it contains machine learning algorithm and image processing technique it can differentiate the whitefly and fruit fly with 98 per cent accuracy. Results highlighted that the light intensity is highly correlated with the number of pests detected in the trap.

Advantages of IOT

- As IOT devices give precise data, it can help in application of the management practice only in the required area thereby leading to efficient resource utilization with minimum time and human effort.

- Automatic precise data collection can be enhanced.



Disadvantages

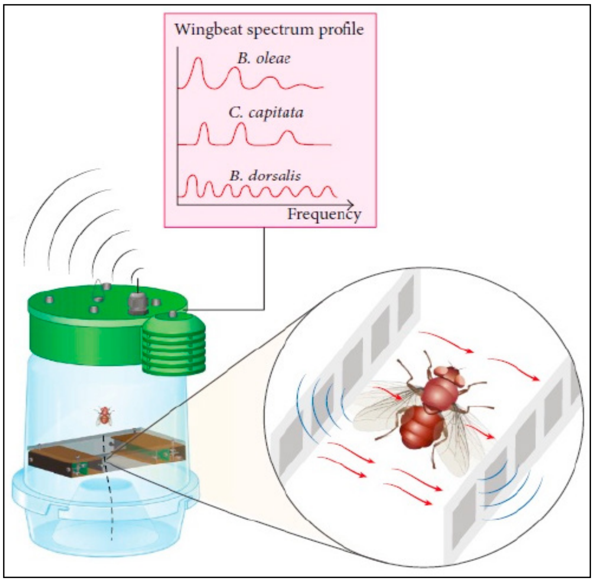
- Lack of infrastructure i.e., internet connectivity
- High cost
- Complexity – as it need basic technical skills to operate

2. Smart Sensors

Sensors are physical objects used to sense a particular item for more precise identification. There are various types of sensors *viz.*, hyperspectral, multispectral, and optical sensors. Each of these sensors will be utilized to do a specific task to get timely, accurate data. Normally sensors are attached in weather station, drones, and farm robots for monitoring diverse field conditions.

Sensors in pest management: Case studies

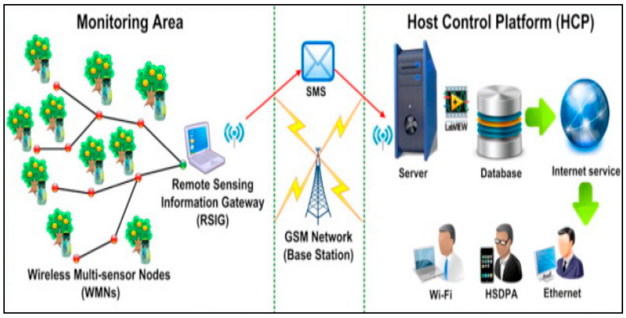
Automatic monitoring system for fruit flies



This novel bimodal system includes an optoelectrical sensor based on stereo recording device. When a fruit fly enters the trap, it records the wing beat frequency. This system can differentiate two fruit fly species *Ceratitis capitata* and *Bactrocera olae* with 98.99 per cent accuracy (Lima *et al*. 2021).

In another study, Okuyama *et al*. (2011) proposed *Automatic count system for fruit flies.* It contained an infrared device to count the number of fruit flies entering the methyl eugenol trap. The device also recorded environment parameters and transmitted it to the server.

Liao *et al*. (2012) develops the monitoring system to improve the above-mentioned method. It consists of Wireless Monitoring Node (WMN), Remote Sensing Information Gateway (RSIG) and Host Control Platform (HCP). Information was collected by WMN and it is passed to Remote sensing information gateway and finally reach the Host control platform for processing. The server classifies the data and deliver various events i.e., A normal status event, A pest outbreak event and Sensor fault event.



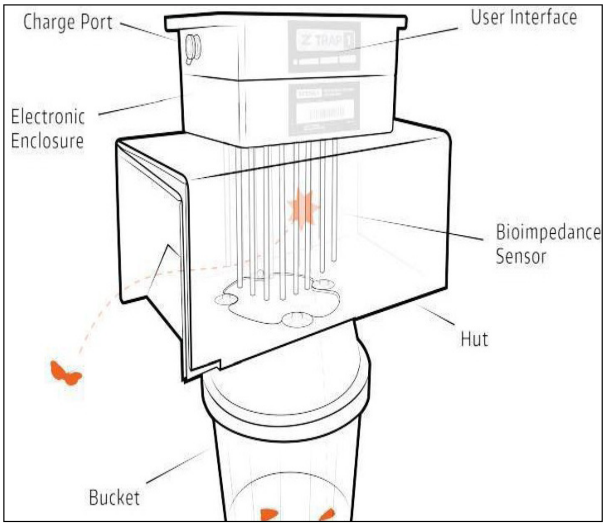
Various automated pest monitoring systems

One of most exploited and affordable system, Trap view which came into market in the year of 2013. The standard trap view system consists of four cameras to monitor the insect that enter the trap. Captured images were send to the cloud server for processing. The trap has internet enabled sim card to send data and GPS for tracking the location of the trap in the field. Pest images were classified by image processing algorithms and then final recommendations were send to user by using mobile applications. This system also come with the option of having temperature and humidity sensors.

Trap view Aura – Here uv polarized light is employed to get attract the insects

Trap view Fly – It has high resolution camera specially to monitor small flying insects like fruit fly and other sucking insects. By using trap view system, below mentioned pests are monitored successfully. The insect pests are codling moths, plum fruit moths, tomato leaf miners, cotton bollworm, grape berry moths, as well as diamondback moths. The trap also contains solar powered and lithium-ion battery for power management (http://www.trapview.com/en/).

Spensa z trap



This trap contains pheromone and series of electrified rods. Attracted insects when contact the electrified rods it gets electrocuted and collected in the bottom container. It also includes the bioimpedance sensor to measure the electric impedance of the insect. Collected data were send to cloud for further processing (https ://spensatech.com).

Spensa sentinal

Spensa sentinel open ups the way for identification and counting of number of insects that attracted inside the pheromone based adhesive trap by utilizing deep learning algorithms in the cloud system.

Automatic system for monitoring bedbugs – GUPSY (Global Urban Positioning and Sensor system)

This automatic system (GUPSY) will attract the bedbugs by emitting CO_2. Numbers and stages of bedbugs that trapped inside were recognized by computer vision algorithms. This system holds the 3rd position in Lora Alliance Global IoT challenge in the year of 2016.

RADAR (Rodent Activated Detection and Riddance)

When mouse enter these traps, it will trigger the breaker beam sensors to activate thereby the entrance of the trap will close automatically. Simultaneously carbon dioxide is released to kill the mouse within a minute. Trap will send signal to Rentokil server which indicate activity and location of the trap (https ://www.rentokil.com/products/connectedpest control/radar -connect/).

Automatic detection and monitoring systems for lepidoptera

- Silveira and Monteiro in the year of 2009 developed a tool which automatically identify eyespot patterns of nymphalid butterfly *Bicyclus anynana* by utilizing the machine learning algorithm which contains circularity and symmetry pattern
- In another study, Wen *et al*. (2015) by using the suitable combination of shape, color, texture, and numerical features for extracting the moth description. Later, by utilizing the pyramidal stacked de-noising auto-encoder (IpSDAE) generate a deep neural network. The proposed system performs the moth identification at genus level of 98.13 per cent
- Combined ANN (Artificial neural network) with binary patterns were utilized to identify five butterfly species in the family Papilionoidea were done by Kaya *et al*. (2015)

Automatic detection and monitoring system for sucking insects with reference to white flies

Ghods and Shojaeddini, (2015) have created an algorithm based on texture and shape analysis for identifying whiteflies. The result showed the detection accuracy of 85 per cent. Automatic model based on color transformations for counting and measuring whiteflies in soybean leaves and yellow sticky traps were by Barbedo (2013), Cho *et al*. (2007) and Cho *et al*. (2008).

Benefits of sensors

- Simple to use and easy to install
- Cheaper
- Remotely controlled

Constrains of sensors

Internet connectivity in remote areas of developing country will be poor.

ROBOTICS

In the current trend of technology development farm robots were begin to emerge to do all the task done by humans. Five basic components which is present in all the farm robots are sensors, effectors, actuators, controller, and arms. To promote sustainable agriculture and food security we must include the automation in all major farm activities like weeding, spraying, irrigation, and harvest. For example: In Sweden, intra row weeding robots were developed for sugar beet crop. Multi-functional robot which is utilized for transplanting and spraying in Israel. In future, solar powered robots with battery inventor have been developed for maximizing the power management.

Robots in pest management: Case studies

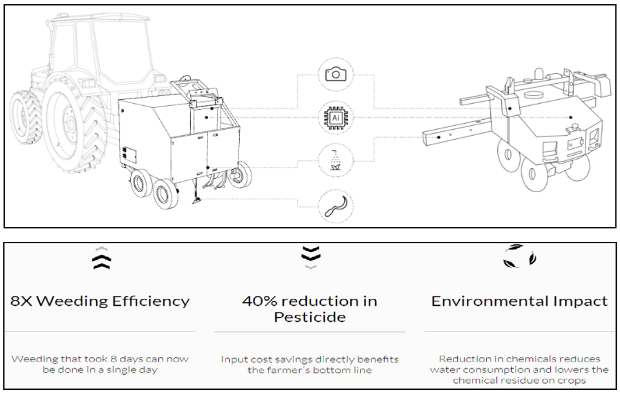
Vibhute *et al.* (2021) developed a multi-functional robot to reduce human effort and error in pest monitoring and survey process. It contains image processing algorithm and extraction process. Based on the density of the pest infestation the robot will decide to spray the recommended insecticide or it may cut the pest infected area by using the cutter which is placed in the robot arm. The proposed robot done the detection process with 93 per cent accuracy and 95 per cent in case of decision making.

Insect detection on an unmanned ground rover

Gutierrez *et al*. in the year of 2019 compare the two different approaches for conclude the accurate system for insect detection. The combination of machine learning and computer vision were tested against deep learning solution. To feed this algorithm a dataset was created which contains huge number of pest images (*Bemisia tabaci* and *Trialeuyrodes vaporariarom* infected tomato fruit. The result revealed that deep learning solution is better when compare to machine learning. Because deep learning algorithm able to differentiate the *Bemisia tabaci* and *Trialeuyrodes vaporariarom* and it can able to balance the speed between data processing and accuracy.

Farm robotic companies in India

- INDIAN ROBOTIC STARTUP 'TARTANSENSE' have raised the fund of five million dollars from omnivore, Blume ventures and FMC. They have two semi-automatic weed removal robots named BRIJBOT and BLADERUNNER. By using this robot for weed removal weeding efficacy up to 8 times and 40 per cent reduction in pesticide consumption can be achieved.



The future aim of this company is producing the small robots for small farms for accomplish all the major farming activities.

- Blue River Technology designed the See and Spray robots. Accurate detection of the weeds and spraying of pesticides precisely on weeds can be accomplished by this robot.

- Sky Squirrel Technology, utilizing the Drones for various crop management programme

Pros of robotics

- Small in size, able to collect data close to crops
- Automatic self-control during change weather condition
- Spray on infected area has it reduces the pesticide consumption
- Perform task day and night without complaining
- Do not get sick or tired

Constrains

- Promotes unemployment
- Limited access to technology
- Energy cost and maintenance
- Could change the emotional appeal to agriculture
- High cost of R & D

ARTIFICIAL INTELLIGENCE

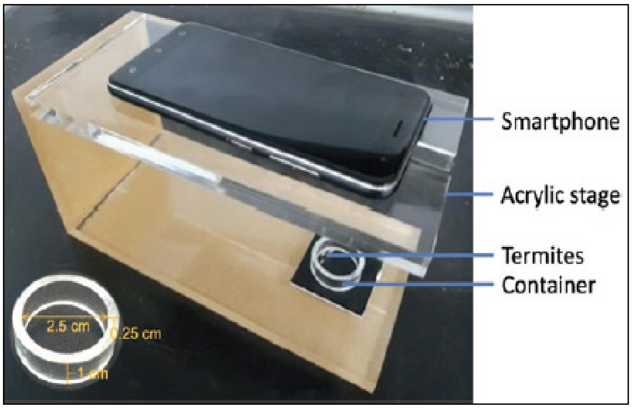
AI plays a major role in advanced farming. Farm robots do the all-major farming activities by utilizing AI. Monitoring of soil and crops can be done by various algorithms remotely. It will diagnose the insect and disease symptoms in advance and give more precise recommendations. In case of predictive insights, AI suggest the farmer to sow a right crop in perfect season to get more yield. Finally, prediction of crop yield and price forecast can be done by AI it will help the farmers to obtain maximum profit.

AI in pest management: Case studies

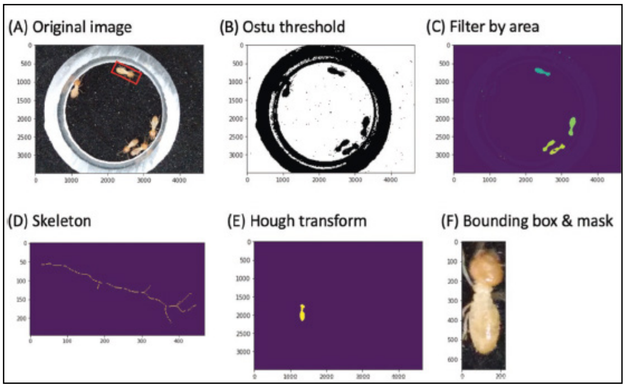
Automated vision-based system for monitoring Asian citrus psyllid using AI – (Partel *et al.* 2019)

In this case study, Robot utilize the tapping mechanism to collect the psyllids from tree branches and a board with grid of camera is there for image acquisition process. By using AI, it can able to differentiate the psyllids from other insects and other debris of trees. The designed system will have the precision and recall of 80 and 90 per cent in detecting the psyllids in sample of 90 citrus trees.

Termite identification using deep learning method - (Huang *et al.* 2021)



They have utilized deep learning method for termite identification. By using the above simple devices images of four termite species (Kalotermitidae: *Cryptotermes domesticus* (Haviland); Rhinotermitidae: *Coptotermes formosanus* Shiraki and *Reticulitermes flaviceps* (Oshima); and Termitidae: *Odontotermes formosanus* (Shiraki)) can be taken. Smart phone would be placed in the acrylic stage and focus the camera on termite ring which is placed below. Release the termites in acrylic ring. Termites are move freely inside the ring. To get individual termite images, five segmentation techniques have been utilized.

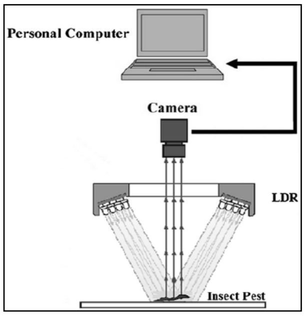


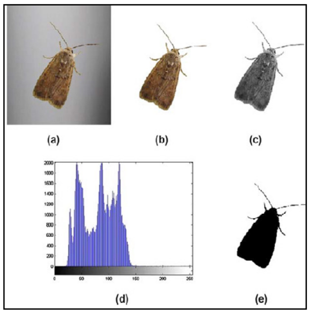
1. Conversion of RGB images to binary image by using **ostu threshold**
2. Filter the pixel size of termite utilizing **filter by area** method
3. Followed by **skeleton method** it will create a one-pixel bone represent the termite
4. **Hough transformation** to straighten the termite images
5. To get individual termite image **bounding box and mask** method is used

Obtained images were feed to faster region CNN for detection. Result showed the accuracy scores of 0.947, 0.946, and 0.929 in identifying soldiers, workers, and both castes.

Artificial Neural Network (ANN) based insect identification (Vakilian and Massah, 2013)

Device consist of CCD camera, LDR lightening module, dark chamber, and computer. Precise insect identification can be done by image processing algorithm and artificial neural network in the system. After image acquisition insect images were extracted from original image by using canny filtration. Then four morphological and three textural features were extracted from the obtained images.





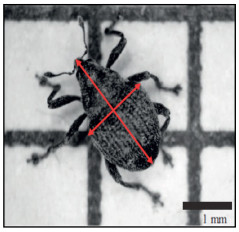
This system successfully able to differentiate the *Spodoptera exigua* from other insects. By incorporating this kind of technologies in robot's insect identification process at field level can be enhanced.

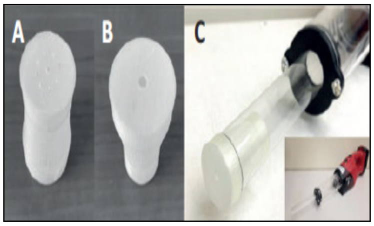
3D PRINTING

3D printing also known as additive manufacturing. Three dimensional physical objects can be designed by using 3D printing. It facilitates to produce the complex structures by using less materials when compare to traditional manufacturing process. In agriculture field, 3D printing is utilized to make the rare spare parts of farm machineries and customization of smart insect traps can be done.

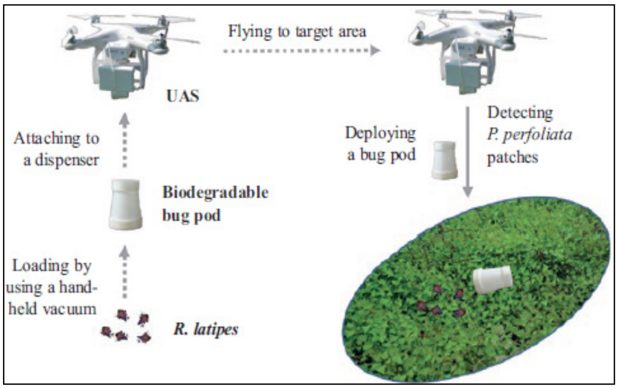
3D printing in pest management: Case studies

3D printed bugpod to release the biocontrol agent *Rhinoncomimus latipes* against weed, *persicaria perfoliata* by using drones (Kim *et al.* 2021)





In this case study, drone was allowed to fly at 15 different altitudes to check its ability to detect the weed patches. Followed by field evaluation of ability of the bug to escape from the pod, post release mortality and feeding ability of the bug were carried out. Biocontrol agent *Rhinoncomimus latipes* were loaded on biodegradable pod which is made up of poly vinyl alcohol. This pod was fixed to the drones. Drones fly to the weed detected area and release this pod. Bug release from the pod and feed on the weed. Results showed that more than 98 per cent of bug able to release from the pod within a 24 hrs after deployment.



3D Printed Drones

Soleon, an Italian drone company designed a 3D printed drone. By using laser sintering method, they have constructed the body parts of drones. Two materials were used, PA 12 (polyamide) it is light weight in nature and versatile material thereby it will automatically maximize the battery life of a drone and another material i.e., PA-GF (polyamide filled with glass particles it is high rigid in nature, it is utilized to make the parts which is close to motor of the drone to reduce the vibration. This 3D printed drones were effectively utilized to release the *Trichogramma* sp in various crop ecosystems.

AUGMENTED REALITY

Augmented reality superimposes digital data and images on the physical world to make understand the things much easier visually. Combination of IOT devices with augmented reality facilitate to see the data visually which help us for:

- Insect identification
- Pest control
- Assessment of soil quality
- Real time weather information

Augmented reality in pest management: Case studies

- Utilizing augmented reality, farmers were trained about the identification of beneficial and harmful insect, their feeding symptoms, nature of damage and appropriate management practices for individual pests in different crop ecosystems (Nigam *et al*. 2011).

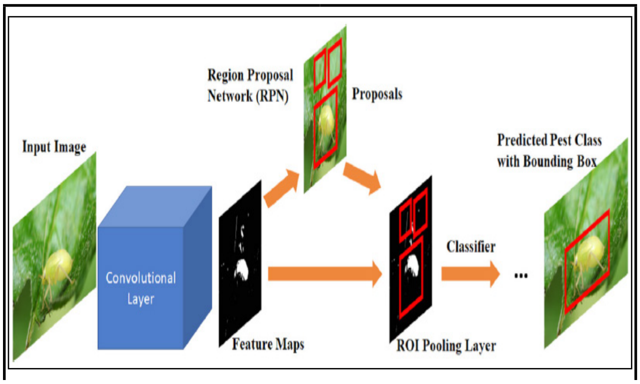
CLOUD COMPUTING

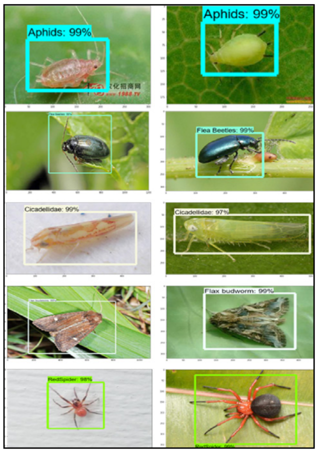
Usually, data from IOT devices will be large volume and need to be store this big data securely for further processing. Here cloud computing plays a major role to store this big data. Cloud computing Interlinks between IOT devices and user in transferring of raw data. Cloud computing as three services (Software as a Service (SaaS), Platform as a Service (PaaS) and Infrastructure as a Service (IaaS).

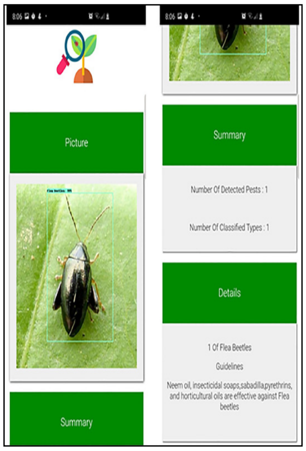
Cloud Computing in pest management: Case studies

Mobile app for insect identification using deep learning in cloud computing - (Karar *et al.* 2021)

In this study, faster region based Convolutional neural networks is utilized for identification of insect pest based on cloud computing. In convolution layer, pest images get reshaped and then feature maps are extracted. As early mentioned in the introduction part of deep learning method, CNN comes under two stage object detection method it will generate a region proposal to detect the object. Results from faster region proposal and feature maps are integrated in ROI pooling layer and finally transferred to the bounding box to know the exact position of the insect pest. This app also has the Database of recommended insecticides which is linked to detected crop pests to guide the farmers. Developed app is validated on five classes of pests: Aphids, Cicadellidae, Flax Budworm, Flea Beetles, and Red Spider mites. Proposed app will give the recognition results with accuracy of 99.0 per cent.





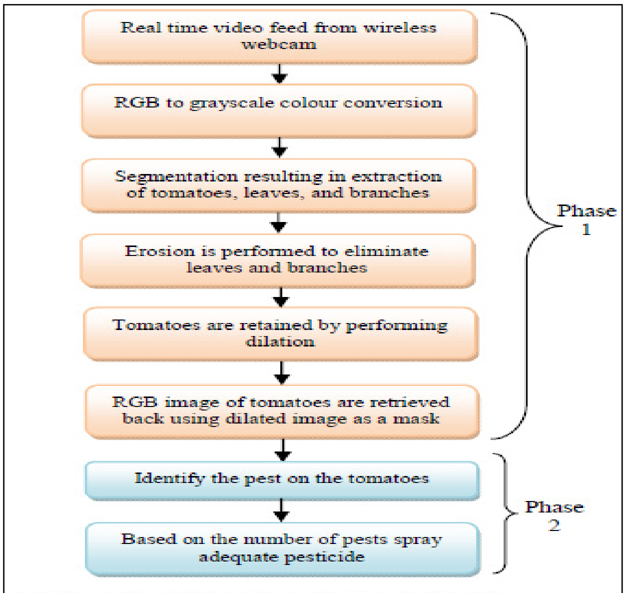


Various modes of cloud computing in pest management - (Chen, 2015)

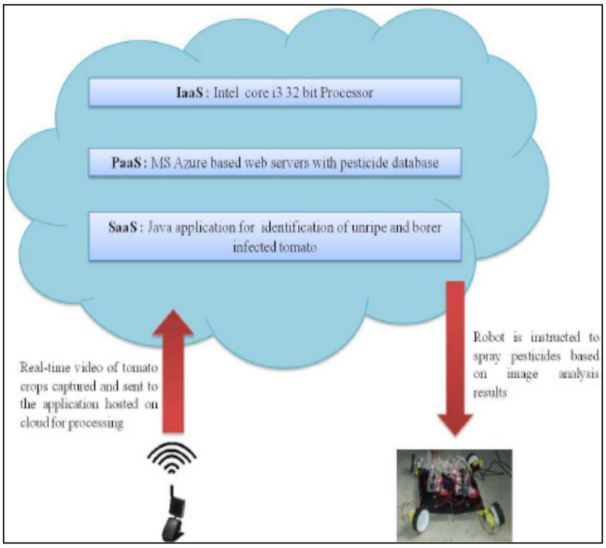
- Active mode - the pest monitoring component and virtual machine monitor in worker node collect information. virtual machines run the data and send to the master node
- Passive mode - master node send request to worker node, followed by data were transferred to master node
- Periodic mode – worker node sends information's to primary node at specific intervals
- Event-driven mode - worker node generate a series of events. Each event will trigger the corresponding collector to check the monitored pest status

Novel Cloud Computing based Smart Farming System for Early Detection of Borer Insects in Tomatoes – (Rupanagudi *et al.* 2015)

In this study the designed robot will record the real time video of tomato crop and the recorded video is send to the cloud for processing. Based on the recommendation from cloud computing contain software the robot will spray the specific insecticide on the pest infected area.



Flowchart depicting the steps involved in our algorithm

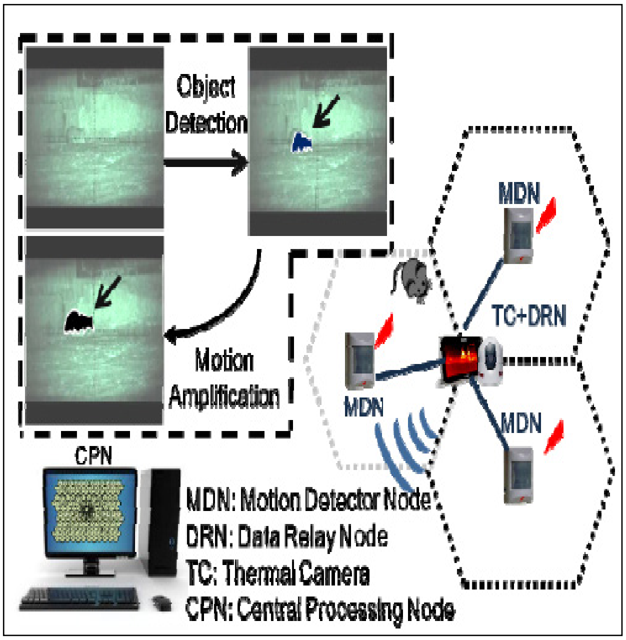


CYBER PHYSICAL SYSTEM (CPS)

- It is an integration of computation and communication technology

CPS in pest management: Case study

Designed programme will automatically detect the rodent's activity in field condition. It includes the motion detector node, thermal camera, data relay node and central processing node. Motion detector node in the field will activate the thermal camera when rodent activity is detected then the thermal camera start records the video. Recorded video is send to central processing node via data relay node. In central processing node based on various factors like rats' physiology, body temperature, body size and movement behaviour it will analyse and give the accurate results (Mehdipour, 2014).

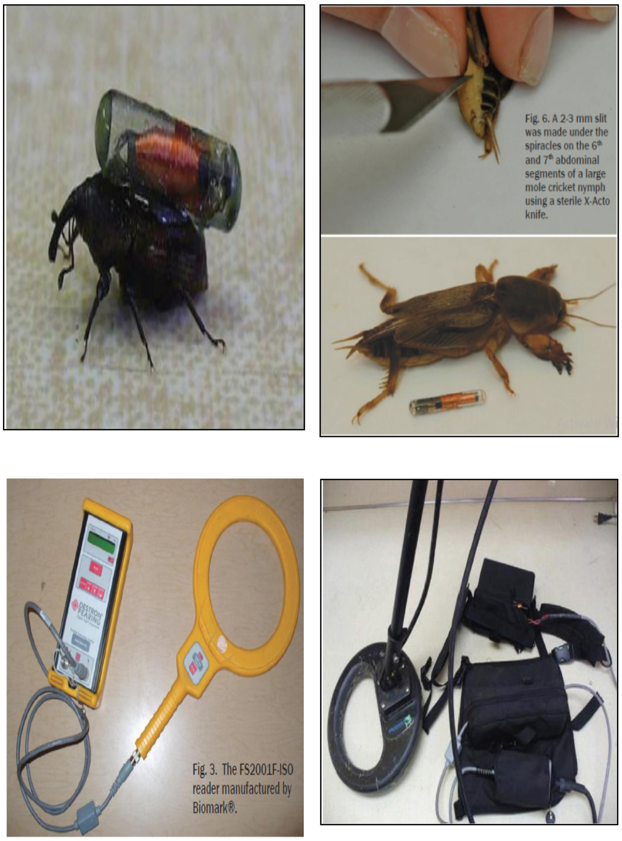


RADIO FREQUENCY IDENTIFICATION TAGS

In entomological research, these tags are used to monitor the movement of the insects. In honey bees, this tag is fixed in the abdomen and the RFID reader in the hive entrance. RFID tags fixed in the bee will give a signal whenever it crosses the reader. Based on this researcher able to identify the total trips in which a bee undergone in a single day to collect the nectar, pollen, and other resources.

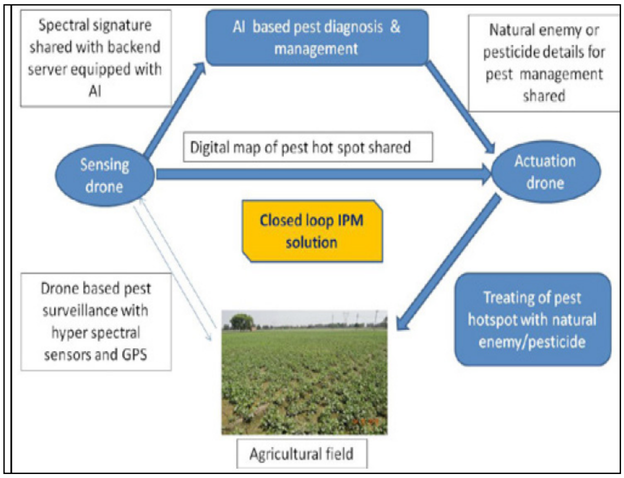
RFID in pest management: case study (Silcox *et al.* 2011)

In this case study, RFID tags were utilized to monitor the movement of two pests Billbug, *Sphenophorus venatus vesticus* and tawny mole cricket, *Scapteriscus visinus.* In billbug they have attached the tag in dorsal side by using the adhesive material. In tawny mole cricket, they make the 2 – 3 mm slit in the 6th and 7th abdominal spiracle and insert these tags. Bleeding haemolymph were cleaned and fix with the glue. Tag inserted insects were released in the field and location were noted. In next morning by using RFID readers detect the released insect around 15 m radius. By using RFID tags exact distance travelled by the insects can be identified accurately.



DRONES

Also known as Unmanned Aerial Vehicle (UAV). Drones that are used for commercial spraying was first time developed by Yamaha motor co ltd for dusting and spraying of rice and soybean crop. Drones is the one of the main innovations now a days used in pest management programme for monitoring and surveying of insect pests.



There are two types of drones:

- Sensing drones
- Actuation drones

Sensing drones: Used to detect the pest hotspot in the field i.e., to create a digital map of pest infected area.

Actuation drones: Information regarding the pest hotspot were received from the sensing drone. After that actuation drones fly to the infected area and release the management practices (Insecticides or biocontrol agents) precisely.

CONCLUSION

- By utilizing this kind of innovative technologies in farm level, farmers can manage the pests effectively by precise data thereby timely application of required control measures can be feasible
- But it involves high cost and technical skills to operate
- We are in the emerging stage, and it takes time to implement all these techniques at field level

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