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Real-Time Monitoring: A New Era in Insect Population Surveillance

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Abstract

The reduction of biodiversity is a major threat to the world and the rate at which insects are substantially depleting is a great cause of concern also. It is estimated that insect species may lose about 65% of their populations in the next century and this can devastatingly affect the activities of an ecosystem including pollination, nutrient maintenance and food haunting. This crisis can be effectively addressed by real-time insect population monitoring that allows the constant evaluation of the number of species, their diversity and behaviour. Such methodology will help obtain crucial, time-sensitive information that is needed to guide informed conservation strategies and eventually, facilitate the sustainability and resilience of an ecosystem.

Keywords: Acoustic, Radar, Real time monitoring, Survey

Introduction

Insects are small creatures, however, their contribution to the planet. The pollination of crops and recycling of nutrients and being the basis of numerous food chains all belong to the number of vital functions which insects perform in terms of achieving the balance between different ecological units. But recent reports have set red flags as insects are dying at an alarming level and some researchers even mentioned that within the next 100 years, up to 65% of insect species will be facing extinction. This massive decline is a dire warning to both natural ecosystems and food security and economic stability of people. The need to be aware of and preserve insect biodiversity has never been higher. However, conventional methods of managing insect prevalence, which may involve manual effort and identification of the insects, are cumbersome, time-consuming in nature. Science requires tools that are quicker and more exact in an era when the environment is changing at a rapid rate. This modern scenario is paving way to truly-real-time insect monitoring: the latest strategy providing automated technologies capable of monitoring and tracing insect abundance and diversity in real-time. Real-time monitoring is an impactful new approach to observing insect populations at the scale because it combined innovations, including the use of smart traps, remote sensors and artificial intelligence (Stepanian *et al*., 2020).

Important Electronic Devices to Aid Real-Time Insect Surveillance

1. Computer Vision Image-based Analysis

Conventional manual insect monitoring practices consume a lot of time and are hectic in terms of effort applied in the identification of species. The researchers in Denmark came up with an intelligent camera system that uses computer vision and deep-learning with the capacity to detect, track and classify insects in real time in the natural setting (Bjerge *et al*., 2021). The software used in the system that was created using the commercial off-the-shelf component, such as a CPU, GPU and web camera is capable of image capture, insect identification and storage of data. ICT tracks insects automatically. The Insect Classification and Tracking (ICT) algorithm is used to fully automate classification and tracking and can generate data on species identity, movement patterns, residence time and behavioural patterns. The system documented 2,634 images at various angles to increase the accuracy of detection during four

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months in the field study and activity of main pollinators including honeybees, bumblebees, hoverflies and butterflies. Findings revealed the best honeybee season to be August and July with the abundance of more hover fly. This strategy allows observation of populations of insect pests in high resolution without destroying them and this can provide important information on pollinator phenology and ecology of movement.

2. Radar Remote Sensing

Radar (Radio Detection and Ranging) remote sensing involves use of electromagnetic waves of radio or microwave frequencies to locate and track atmosphere objects. Radar is also becoming common in entomology to monitor flight of the night-flying and migratory insects to include moths, locusts and aphids. The most helpful resources in identifying the biomass and swarm movement activity of insect swarms are doppler weather radar systems and vertical-looking radar (VLR). These systems are always on which enables scientists to get real time data on insect altitude during flight, direction, speed and their density across large geographical coverage. The novel reflectivity and motion signatures allow radar to separate insects in the air against other air particles. The advantage of radar is that it operates through all weather and covers a large area of ground; and therefore, is suitable in long-range monitoring of migratory species of pests. As an illustration, the radar has been applied to track the movements of locust swarms in the desert areas and to predict the possible.

3. LIDAR Remote Sensing

LIDAR (Light Detection and Ranging) is a three-dimensional scanning system based on laser pulses (usually these are near IR), allowing the high-resolution modeling of the environment. Entomological LIDAR systems are showing potential as tools in insect surveillance, which can be used to identify and identify the flying insects by the frequency of their wing-beat, size, shape and direction of flight. The temporal and spatial resolution of LIDAR is extremely fine and hence individual insects in flight can be detected. In comparison with radar, LIDAR has a high level of sensitivity to smaller insect species and can be focused within dedicated ecological areas: agricultural farms, forests, or even urban green land. It may also be used together with machine learning algorithms to automatically classify species or functional groups (*e.g.*, pollinators, pests). Other LIDAR may combine fluorescence or multi-spectral scanning to identify insect species, or to detect insect-vegetation interactions. This renders LIDAR quite applicable to pollination experiments, to pest control monitoring and to biodiversity evaluation landing points in order to prevent and manage the pests in advance.

4. Bioacoustic Acoustic Surveillance

Automatic species identifications and acoustic species notes recordings coupled with acoustic species recognition techniques are good avenues through which insect populations can be monitored on real time basis. The use of acoustic monitoring systems can facilitate non-invasive, constant in the time and cost-effective monitoring of the vocalizing insect species and, therefore, are an especially useful tool in monitoring the processes of biodiversity dynamics under the basis of changes in the environment. Such systems have the ability to pick up species-specific calls enabling a researcher to make high-resolution presence-, abundance- and temporal activity observations. This methodological approach has been shown to be useful through the study of Orthoptera diversity along roadsides in Northern France (Jeliazkov *et al*., 2016). They sought to assess efficacy of automatic species recognition to identify temporal trends in consideration to spatio-temporal variability and seasonal variability. They focused upon two species *Tettigonia viridissima* and *Ruspolia nitidula* and their acoustic surveys were done on a megascale 2006-2012. Their outcomes indicated that there were serious negative associations between the two species and time which indicated a possible population reduction over time. Climatic variations and swelling urban population were given as main contributors of these trends.

5. Near-Infrared Spectral Detection

Insect populations need to be monitored in order to conserve their biodiversity, sustainable agriculture and in the control of disease vectors to both humans and livestock. The conventional techniques that make use of manual trapping and identification of species tend to be time-consuming, labor-intensive and expensive. To overcome the obstacles, Rydhmer *et al*. (2022) came up with a new insect autopathological monitoring system through a network of miniaturized wireless near-infrared vessels. These field ready sensors capture the backscattered light by means of a pair of infrared light-emitting diodes at the forward-facing and aft-facing that makes use of dual wavelengths to determine the insects that enter a specified airspace. With frequencies of operation in the kilohertz range, the system has no moving parts and automatically captures important traits including wingbeat harmonics, direction of flight and melanisation. Every moment is matched with environmental data such as temperature, humidity and light intensity and sent in real-time *via* GSM to cloud-based databases. These weatherproof sensors are to be installed to work unsupervised, year around, so they are made with the use of GPS to identify their location, a situational camera and have flexible sources of power such as solar panels. This invention is an important milestone to the possibility of having fully automated and scalable insect monitoring through which ecological understanding and enhanced management interventions can be achieved in real-time.

6. Sampling Techniques of Environmental DNA (eDNA)

Conventional means of insect monitoring usually obligate the need to record physical samples which would prove time consuming and possibly damaging- in the case of rare and endangered insects. As an alternative tool, environmental DNA (eDNA) technology is non-destructive and can be viewed as a potent method of analysis of trace amounts of genetic material left by the life forms in question, *e.g.*, in the water, soil, or air. DNA may be lost in insects as it is released in the environment in the form of skin cells, waste-products or secretions. Such so-called relic DNA can be gathered by sampling the environment and replicating the samples on special genetic primers in order to determine if a species can be detected and even the relative abundance of a species without the necessity of sighting or capturing one. A prominent case is that of Doi *et al*. (2017), who relied on eDNA to detect the existence of an endangered aquatic insect Nap hoffmanni in wetland environments of Japanese environment. In this study, eDNA was found at more sites than hand capturing means to detect the species, with a number of sites where individuals were not physically present nonetheless found in eDNA. This shows the high sensitivity of eDNA and how it holds potential to transform conservation practice, particularly of the elusive or rare populations of insects. eDNA is efficiently identifying species across huge areas without disruption to ecosystems, a fact which is making it a powerful instrument in nature preservation and biodiversity monitoring.

Applications of Real-Time Monitoring

1. Early Detection

The real time monitoring systems facilitate accurate identification of the insect population the moment they appear or move into a given habitat. There are such technologies as a smart camera trap, acoustic sensors and radar systems that immediately warn about the existence of invasive species or pests prone to outbreak. This will enable it to intervene at the right time before populations can reach harmful levels. Early diagnosis is very essential in terms of limiting extensive destructions of crops and preventing vector-borne diseases.

2. Increased Accuracy

Customary manual approaches tend to be affected by observer bias and misidentification. Conversely, computer vision, machine learning and DNA based tools like environmental DNA (eDNA) techniques can be used to precisely detect species of insects in real-time. Such upsurge in accuracy helps in advancing the assessment of the biodiversity and also makes sure that the non-target species are not hurt in the measures of controlling pests because this involves the application of the control in the right and target species.

3. Constant Data Measurement

The continuous monitoring can be used in a 24-hour time frame to observe insect behavior and population swings not necessarily seen in periodic monitoring. Automating light trap and its image capture systems or LIDAR enables researchers to monitor changes at both day-night cycles and seasonal highlights, thus getting a less disorganized sense of ecological interplay.

4. Cost-Effective

The initial establishment of the real-time monitoring tools can be costly though it can greatly slash the expense in the long run insofar as it imposes on the minimization of investment in manual field surveys and labor-intensive process of identification in laboratories. Automation frees manpower and information is accessible and mining without travelling to the location.

5. Ecological Research Support

The kind of data available by real-time monitoring is priceless to ecological modeling and the behavior, migration patterns, pollination of insects and predating and victimry relationships. Data obtained in the longitudinal type by these technologies are used in studies of the climate change effects, habitat fragmentation and the distribution of species, contributing to the conservation biology-related studies and ecosystem health assessment.

6. Early Control of Pests

Among the most important advantages of real-time insect trackers is that they can help make the immediate actions of pest control. To give an example, IoT sensors placed on pheromone traps can notify farmers as soon as the threshold population is reached, which will initiate the targeted use of pesticides or the launch of a biological control agent. This enhances integrated pest management (IPM) that becomes precise in its interventions.

7. Enhances Food Production

Insect Control Monitoring of fields continuously will help a farmer to implement site-specific control measure of crops against pests and as such, prevent excessive use of pesticides and harmful effects to the environment. The data in real-time are also useful in predicting seasonal pest outbreaks, more efficient timing of crop treatment and keep records of traceability in sustainable farming systems.

Challenges and Limitations of Real-Time Insect Monitoring

i) Substantial Initial Capital Investment: Advanced monitoring systems may be expensive to install initially, more so when it is to be implemented large scales through farms or forests.

ii) Requirement for Species-Specific Training Data in AI Models: Artificial intelligence models applied in detecting insects need lots of trainer information, which can be spice and genus specific. In the absence of this the identification and analysis may be inaccurate.

iii) Sensitivity to Environmental Variables: In the case of rain, wind, or dust, the work of sensors and cameras may be obstructed and obtaining the stable measuring data will be more difficult on a regular basis.

Conclusion

Technologies may be combined with various real-time monitoring programmes and adhere to the latest standards on data curation and transparency. Open systems, most of them are only at a proof-of concept stage and might be deployable on a large scale in the future. Even though these technologies have the potential to save time in species identification and are able to realize non-lethal real time surveillance, they cannot substitute specialist taxonomic knowledge that is essential to be accurate. To conclude, referring to the benefits and constraints, in the future, entomology will not be a human process, but a human working along with a machine to know more about insects.

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