



Development of Automated Devices for the Monitoring of Insect Pests

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Abstract

The monitoring of insect pests based on adult trapping systems is part of integrated pest management (IPM) in many crops and of early warning detection programs used to set up appropriate management decisions or eradication responses. Using data obtained from traps to make management decisions is not an easy task and involves significant costs in equipment, transport and labour. Thanks to the spread and the low prices of information and communication technologies, innovative automated capture devices including electronic sensors and connecting components are increasingly being developed, allow facing some of the current monitoring constrains in a context of IPM. In this paper, we illustrated the state of the art of this field and provide insights on automated devices, consisting of traps equipped with sensors and other components for the collection of data in the field and their transmission to a remote server accessible online, with information stored in geo-referenced databases. Optical sensors are mainly used for detecting photo-interruptions, images or optoacoustic spectrum of wingbeats. The monitoring systems can be equipped with software for image interpretation and identification of the caught target insect pest (fully automated system) or a remote operator can count the trapped insects by watching the images coming from the e-trap (semi-automated system). The software can integrate a decision support system (DSS) module, which provides information on the risk of infestation and the actions to be taken (when, where, how to make a control application). The development and future prospects of automated devices are discussed in relation to the technical reliability of the system, ease of use and costs compared to traditional monitoring methods.



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Introduction

Monitoring of adult insects with traps is considered a standard activity in integrated pest management (IPM) and early warning detection,¹ helping to optimize control or eradication operations through observing the presence and/or variation of a pest population in the field. The data collected have been used to provide knowledge or warning to farmers and other agricultural stakeholders and allowed to incorporate spatial and temporal variability of the pest populations sampled in the field. This was key to accurately respond to the observed variations with precision treatments.^{2,3}

The increasingly widespread use of information and communication technologies (ICT) such as sensor networks, communication devices, internet things, and big data management and simulation software has opened many opportunities to modern agricultural production systems. In particular, automated or electronic traps (briefly e-traps or smart traps) have been suggested as part of ICT tools for pest monitoring.^{4,5}

The present paper provided an overview of the concepts and applications of automated traps in IPM and discussed the strengths and weaknesses of traditional versus automated monitoring tools.

Concept and Design of Automated Devices

In this paper, an automated trapping device is defined as a trap equipped with sensors for data collection in the field and hardware and software components for the transmission of the data to a remote server accessible online, where to store and/or process the information in geo-referenced databases.^{4,5}

Although the e-trap by itself is a stand-alone tool, usually the automated monitoring in the context of IPM is a multi-modular system. Moreover, it uses and produces digitalized and geo-referenced information, such as the geographical position of the traps and the link to GIS layers such as roads, houses, trees, field borders, land uses, so that the data arriving from the traps can also be visualized or elaborated in a GIS tool.

The catching module of the e-trap is adapted from existing or newly developed devices and can include

an attractant that increases attractiveness or make the trap more selective. It contains the sensor, which allows detecting and counting of the target insects. Most used sensors are optical but different types for example activated by acoustic vibrations or electric fields, were also used.

Photo-interruption sensors are activated by the modification or interruption of incident light (visible or infrared) due to falling objects such as moving insects and aim at counting the number of times a target insect entered in the trap. It was among the first systems to be used in combination with electronic components, transmitting the counts to a computer.^{6,7,8} In this case, the counted insects are not identified; therefore, the device must be specific to avoid erroneous counts caused by non-target specimens entering the trap.⁹

An image sensor detects and conveys light waves to produce an image. The camera must have a minimum resolution enabling correctly classification of the captured insect. It has been calculated the minimum resolution to be 2 megapixels to capture a recognizable image.²⁵ The number of photos is limited by the system's power consumption although for the here intended use here, one or a few photographs per day are easily supported.⁵

E-traps equipped with this sensor type can work at different levels of automation. In semiautomatic systems, the sensor collects the images at certain times and transmits them via internet to a remote operator who can check and count insects directly watching the image from a remote device and this can be done in real time.⁵ In case of a fully automated system, target individuals in the image are recognized and counted by image classifier algorithms, mostly based on machine learning or deep learning techniques.^{10,11,12,13} Various discriminating features, for example dimension or proportion of the body, can be used to differentiate the target species from other species.

Other optoacoustic sensors analyse the flow of light modulated by the wingbeats of an insect entering the trap. In this case, the wingbeat represents a sort of biometric signature that allows us to discriminate the target from non-target specimens.¹⁴

Various non-optical sensors were tested for insect trapping, able to recognize the bioacoustics vibrations or electric field modifications resulting from locomotion and feeding behaviours of the target pests.^{15,16,17} Additional sensors to measure temperature, humidity, rainfall etc. can be included in the e-traps.

A microcomputer represents the core of the e-trap electronic system, collecting and recording the data from sensors and sending them to a network module. A unit for the remote connection is an important component of the automated trapping device to transmit data to the cloud usually using a 3G-4G-5G connection, secured by internet service providers. When many e-traps are deployed, costs for internet access can increase. In this case, e-traps can be connected to each other as nodes in wireless networks with various configurations and a central node transmitting data to the cloud.^{5,18} Different communication protocols have been used so far depending on the local conditions in the deployment of traps. For example, ZigBee had a long distance range but a low data transmission rate, whereas, Wi-Fi/WiMax had a higher data transmission rate but was more energy demanding.⁵ A source of electricity is necessary to sustain all electronic components; when power grid is not directly available, batteries and solar panels can supply power.

A graphical user interface (GUI) allows to read and interpret the information remotely. Additional software such as decision support systems (DSS), can be fed with data coming from automated traps and provide information on the selection of control tools or assist the operator in a spraying process.

Automated Devices: Practical Applications

This section contains some examples of automatic devices developed for insect trapping.

The first automated devices, equipped with bioacoustic sensors, image sensors or with light emitting diodes and the related receiving sensor have been designed for automatic trapping of Coleoptera. Earlier sensors were applied to passive grain probe traps to provide continuous monitoring of stored-grain beetles within large volumes of stored products.⁸ A modified automatic pheromone trap for

the boll weevil *Anthonomus grandis* Boheman was tested for the season monitoring of the weevil in cotton fields.¹⁹ Various traps baited with the specific aggregation pheromone were proposed for the monitoring of the red palm weevil, *Rhynchophorus ferrugineus* (Olivier) in urban environments or bark beetles in forests.^{4,15,20,21,22} A different approach was used for the early detection of alien wood-boring beetles.²³ In this case, a multi-funnel trap baited with a blend of generic lures attractive to many wood-boring species was equipped with a camera; the images were inspected remotely for insect identification with a different level of accuracy depending on family and genus of the trapped beetles.

Another example of automatic image-based trap was developed for small-bodied insects mainly aimed for greenhouses.²⁴ An automatic pheromone trap for counting the bean bug *Riptortus clavatus* (Thunberg) utilized a different detecting system consisting of two rollers placed at the same distance of the size of the insect, which upon entering touches both of them and generates an electric arc by striking the insect. The counts are transmitted by using a mobile phone connected to the trap.²⁵

Among Lepidoptera, various automated trapping devices baited with sex pheromones were established to monitor *Cydia pomonella* (L.) in apple orchards equipped with different type of sensors. An e-trap based on an optical sensor was developed based on a modified commercial model by allocating at the top of the trap a mobile phone with a camera taking images of the sticky surface placed at the bottom side and sending it immediately to the remote server for a visual evaluation.²⁶ Other developed traps used a visible or infrared light emitting diodes equipped with optoelectronic sensors able to count the trapped moths by detecting the light interruption caused by individuals falling through the funnel of a bucket trap.²⁷ Another device called z-trap was equipped with a metallic coil, which was able to identify the species of insect flying into the trap based on the amount of electric current discharged when an insect touches the coil.¹⁶ A monitoring automated device equipped with infrared sensors was proposed for counting *Spodoptera litura* (F.) moths entering in pheromone trapping tubes.²⁸

Many researches focused on the development of automated monitoring tools for fruit flies. An electronic device for *Bactrocera dorsalis* (Hendel) employed an infrared interruption sensor to count attracted flies entering the trap baited with the attractant methyl eugenol through an electronic funnel.^{29,30} A wireless automatic trap was developed by modifying a McPhail model baited with the specific pheromone attractants for the monitoring of *Ceratitis capitata* Wiedemann and *Bactrocera oleae* (Gmelin), equipped with a camera to capture images of insects; here a software automatically identifies and counts fruit fly entering into the trap along a transparent funnel.¹⁰

Other technologies for e-monitoring used a location-aware system based on a real-time wireless multimedia sensor network (WMSN). The system, through a semi-automatic trapping and insect counting, is able to acquire and transmit data to a remote server feeding a DSS that performed the final optimization of the control treatments.¹⁸ In particular, two of these e-trap models were based on the wireless transmission of images of trapped fruit flies on the glue surfaces of the e-traps, checked remotely by an entomologist.⁵ Their development and validation focused on following specific species in different agro-ecosystems: Medfly in peach orchards, cherry fruit fly in cherry orchards, olive fruit fly in olive orchards and the Ethiopian fruit fly in melons growing in plastic tunnels, modifying delta-type traps or yellow sticky panels, baited with different pheromone or food attractants, depending on the target fruit fly. The verification of the reliability of the data obtained was performed comparing the captures counted on the transmitted image with the captures checked by a human in the e-trap in the field. The captures of the flies checked remotely usually showed a similar numerical trend and the number of flies caught in the e-traps was similar to the number obtained with the standard manually-checked traps.⁵

Automatic devices based on infrared sensors were also developed for automatic trapping of *C. capitata* to optimize control applications frequency.⁹ A McPhail trap based on optoelectronic sensors detecting differences in the optoacoustic spectrum of insect wingbeat resulting from entering insects into the trap was developed for *B. oleae*.³¹

Current Constrains and Future Perspectives of Automated Devices for Insect Trapping

Traps, which frequently include attractants, are very powerful tools to attract and capture specimens of the target pest. Sometimes, these traps are species-specific but usually require trained personnel to discriminate target from similar-looking non-target species that can be captured indeed. In many standard IPM programs, especially in perennial crops, different trap types are used for the monitoring and control of specific insect species, deployed as grids in the fields, checked and serviced manually through periodic visits of human operators.

Standard monitoring procedures involve the manual counting of trapped insects. The field survey of traps is done usually once a week, sometimes twice, for most insects. Each time, there are delays in data acquisition and analysis because inspectors must reach the trap in the field, count the insects from each device, enter data on paper then go back to the office, enter data in a spreadsheet and process them to send out to final users. This process has been in part shortened, inserting data directly in the field with a portable device that can communicate remotely with a server that stores the data automatically. However, assessing traps results in a delay that affect the time necessary to make a decision.

The biosecurity surveillance activities of alien insects also include an extensive use of baited traps both at points-of-entry for imported commodities to capture insects before they become established and in the context of post-border surveillance and containment.³² In these cases, traps must be monitored frequently as specific action must be taken immediately when a quarantine species is detected and delays can increase the chances for the establishment of a new invasive species.²³ Here, automated traps together with other technologies can play a major role in reducing the response times as explained above.

By themselves, manual traps are relatively simple tools to be managed and have a very low cost. However, intensive labour and transportations for installation, maintenance and periodic check of traps by skilled personnel represent most of the total monitoring costs. The service of large monitoring

networks can become very expensive, especially in areas where access to the traps is difficult. For this reason, often the number of monitoring traps positioned in the field is greatly reduced with a consequent loss of information on the spatio-temporal dynamics of pests and inaccurate control applications or missed alerts.

What are the potential advantages of automatic trapping systems? Data available on real time are easily represented in time and space and can automatically feed a DSS for the optimization of control methods. There is a reduction of human and transportation costs because traps are no longer checked every week but less often. The monitoring in remote or inaccessible areas is facilitated. When positioned the trap can remain for a long time without an operator going into the field to check it and can transmit data at desired time intervals. There is an increased efficiency in area wide programs, where many traps are located in a large territory: here e-traps represent an efficient method to get all needed information in real time. Coupled to a DSS, the automatic trapping may improve the applications of precision agriculture to pilot the operators in doing control interventions at the right time and place.²

Real time monitoring allows to be very efficient in some particular situations like early warning of invasive pests. E-traps producing images have the advantage that the operator can check frequently if suspected alien insects are in the traps and if a secure identification cannot be done remotely, go timely in the field for confirmation. In this case, the advantage of the e-trap is related to the possibility to give a remote secure identification. E - traps baited with a specific pheromone coupled with image analysis software, can be highly efficient in detecting correctly the target species. The same applies for other highly specific sensors such as those using wing beat frequencies¹⁶; on the contrary, low specific sensors giving simply a ping for something arriving in the trap are not useful, unless the trap is highly specific.⁹

From an electronic and informatics point of view, smart traps are a mature and reliable technology. Over the last few years, the electronic parts have

reached increasingly higher performances and lower costs, allowing the miniaturization of components. Therefore, the e-trap itself is not very expensive and labour costs are strongly reduced. Other benefits in terms of cost savings from reduced insecticide use and insect damages should be specifically assessed. However, possible economic constraints are costs for the development of a DSS or image analysis software. Furthermore, technologies should be tested in field conditions to prevent problems like insufficient battery capacity to make the device work properly, failure in data transmission to the cloud and weather conditions (rains or extreme temperatures) that can affect the e-trap field operation over time.

Modern agriculture is facing a huge technological transformation. Drones, remote sensing, intelligent decision support systems, internet of things introduced us in the smart agriculture concept and methodology in which we can place the automatic traps.³³ The development of automated monitoring devices requires specific skills and a multidisciplinary team with computer engineers, ICT specialists, entomologists and IPM professionals. For the dissemination of this type of technological applications the end users, whether they are agricultural companies, producer associations, private consultants or public bodies, must be willing to invest in maintaining the automatic monitoring networks including the costs for internet access and the data retention online. There is a big potential for the utilization of such an innovative tool, especially in high value crops or when high labour costs. Examples of fully automated traps mostly for moth or fruit fly pests using different sensor typology are currently available in the market.^{34,35,36} As for other ICTs, the perspective for smart traps to be widely used in the farming practice in the near future must be considered substantial.

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Conflict of Interest

The author(s) declare no conflict of interest.

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