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Automatic trap for moth detection in integrated pest management

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Abstract

The codling moth *Cydia pomonella* (L.) (Lepidoptera Tortricidae) is one of the key pests in apple and pear trees and its high harmfulness on the fruits requires a strongly effective pest management. Among the pest control strategies adopted in the years, nowadays integrated pest management (IPM) represents one of the most diffused methods and it requires pest monitoring by means of sex pheromone traps regularly checked by the farmer. The aim of the work was to develop an automatic electronic trap designed to monitor the flight of codling moth males, to identify the pest and to forward the information on trapped males. The results showed how the modifications performed on the standard sticky traps did not causes a reduction of the trap capability to catch the males, and also that the photos taken by the system and sent to a remote unit allowed an easy moth identification and detection.

Key words: codling moth, pheromone trap, monitoring, integrated pest management.

Introduction

The codling moth *Cydia pomonella* (L.) (Lepidoptera Tortricidae) is one of the most harmful moths in fruit cultivation with respect to the entity of the infestation that it is able to cause (Witzgall *et al*., 2008). Indeed the codling moth is one of the key pests of apples and pears and several insecticide treatments are necessary to reduce the larval damage on fruits. Since the beginning of the '70s the codling moth has been sampled in apple and pear orchards using sex pheromone traps. The discovery of Codlemone (Roelofs *et al*., 1971; Beroza *et al*., 1974; McDonough and Moffitt, 1974), main component of the natural pheromone released by the codling moth female, allowed the deployment of the sex traps as the most used sampling system. The males captured allow not only estimate population size, but also the time course of the emergence period. It is so possible to execute more precise treatments, coordinate the interventions with the moth cycle and estimate the dimension of the following larval generation. The photoperiod is the main regulator inducing both sex pheromones released by females and the upwind flight response by males (Birch and Haynes, 1982).

The trap efficiency depends mainly on the shape of the trap and on the bait able to deliver the sex pheromone in extended and constant ways (Kehat *et al*., 1994). The trap opening width is an important factor with respect to the efficiency of the traps, indeed different researchers have demonstrated that a reduction of the width allows an increase in the number of captured males (Madsen and Vakenti, 1973; Charmillot *et al*., 1975). Finally a thin plume of pheromone in output from the trap together with the difficulties in the flight out caused by a small opening, allow an increase of the effectiveness of the codling moth traps (Accinelli *et al*., 1998).

Integrated pest management (IPM), based on the use of sex pheromone traps, relates mainly to the overcoming of the economic damage threshold evaluated by counting the trapped males. In the Emilia Romagna Region (Italy), for example, the execution of the codling moth treatments starts with the overcoming of the limit of two males captured per trap in a week (ERMES, 2011). This specification provides the use of at least two traps in one hectare of orchard surface, checked once or twice per week by technicians to verify the males caught and to decide the insecticide spray date.

Currently new environmentally friendly techniques are based on the codling moth control carried out not only by spraying chemical insecticides, but also by releasing beneficial insects and microbial preparations (the latter are usually less persistent in time with respect to conventional insecticides). Areawide pheromone mating disruption programs require the use of several traps to test efficacy (McGhee *et al*., 2011). Therefore, an efficient monitoring with pheromone traps becomes even more important in order to match all the different IPM techniques against the codling moth.

In the context of the problem addressed, the necessity for a more efficient monitoring of the codling moth is evident, with more frequent samplings. This would permit for more information on the moth flight and mating period and the possibility to correlate these data with biological, physical and environmental parameters. This necessity, that also covers other pest insects, has allowed for the development of monitoring systems with different solutions of automation.

In particular, pest detection and monitoring systems, based on acoustic transducers able to sense the sound of the insects and then to send electronic signals to a central station to identify the trap locations, have been developed (Beroza, 2002). Other systems based on an automatic counting of the captured insects fitted with crossing transducers (Kliewe, 1998; Beerwinkle, 2001), eventually integrated with transmission data systems have been designed (Tabuchi *et al*., 2006). A different approach has been implemented with automatic record systems using a camera designed to record the periodic-

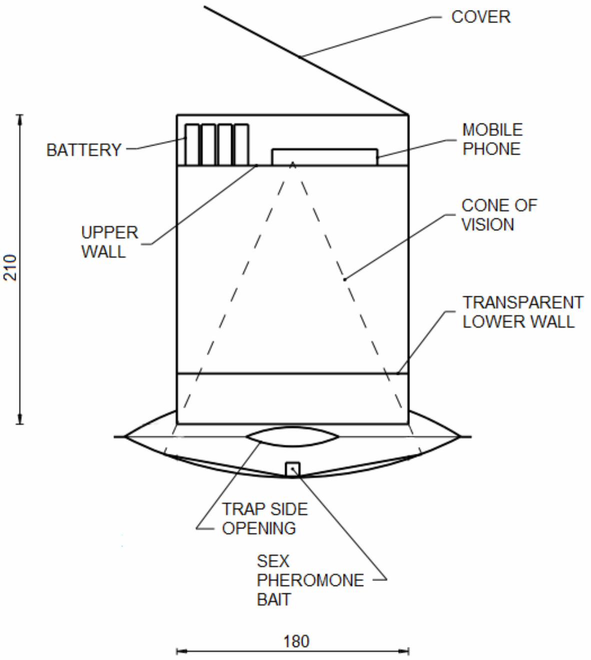


Figure 1. Schematic drawing of the electronic trap (measures are in mm).

ity of pheromone trap catches (Kondo *et al*. 1994) or to automatically transfer the images to a host computer where an image processing technique can count the insects (Shimoda *et al*., 2006). These technologies of identification and classification of the insects were also developed as demonstrated by specific research and patents (Wen *et al*., 2009a; 2009b; Landwehr and Agudelo-Silva, 2005).

The development of electronic technologies, their availability on the market and a progressive cost reduction make it possible to adapt commercial solutions to the aims of pest monitoring. Eventually ad hoc electronic circuits have to be developed to manage and control the system.

In the general context of the problems previously discussed, an automatic electronic trap for monitoring the codling moth has been designed and built adapting a commercial pheromone trap specifically studied for the codling moth. The performance of the electronic trap prototype has been evaluated in an apple orchard in comparison with traditional sex pheromone sticky traps.

Materials and methods

The prototype of the electronic traps has been designed modifying a commercial trap (Pomotrap, Sumitomo Chemical Italia, Milan, Italy) specific for *C. pomonella*. The Pomotrap consists of an envelope with a defined shape in which a sticky pad and the sex pheromone bait is inserted. Two side openings in the trap allow male moths to enter. The Pomotrap has been modified adding an opening in the trap top to fit a box with a square base. The parallelepiped has two internal walls, the lower one transparent, to redefine the capture zone, and the upper to support the image detection system and the power supply. The upper wall was fixed at a distance with respect to the sticky pad properly defined in order to get a complete vision of the trapping portion. The modified trap was covered with a top wall able to isolate the trap from environmental factors (figure 1).

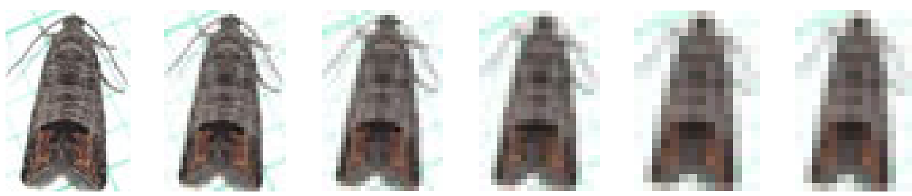
To realize the electronic trap, a commercial acquisition and data transfer system using wireless technology was selected. The system was composed of a programmable Smartphone, chosen in the class of the S60 3rd edition devices, with an integrated camera of 3 Mpixel and the operating system Symbian (Symbian, ver.9.0, Symbian Foundation, London, UK, http://licensing.symbian.org). The camera resolution was higher than the minimum resolution, equal to 2 Mpixel, to acquire a recognizable image with respect to the morphological characteristics of the codling moth (table 1).

To allow for a sufficient autonomy of the system, the Smartphone was integrated with an external power management unit consisting of: a microcontroller with a power of about 5 uW (Type: MSP430F2013); an ultralow power switch (Type: TPS2024); a voltage stabilizer (Type: TPS7333); polarization and interface components; 4 rechargeable lithium batteries of 4800 mAh.

To adapt the system to the monitoring needs, the following software modules were realized:

- temporized storage of the photos, in order to connect the camera at defined intervals, to fix the parameters in function of the brightness conditions, and to memorize the photos;
- data sent on an EDGE/GPRS network, to periodically transmit the data to a remote server, to save a local copy of the data, and to resend the data missed due to a temporary network breakdown.

Table 1. Pixel numbers of the camera and of the codling moth with the related image.

Camera resolution (pixel)	10 M	5 M	3 M	2 M	1 M	VGA
Image resolution (pixel/cm^2)	18750	9380	5620	3750	1875	630
Image						


a)


b)

Figure 2. a) Standard sticky Pomotrap and b) automatic electronic sticky trap.

The power management system allowed for a reduction of the Smartphone power consumption of an order of magnitude to assure an operating time of the electronic trap around two months.

After a preliminary check of the functionality of the monitoring electronic system, two electronic trap prototypes were built. The check of the monitoring effectiveness was performed in an apple orchard (variety: golden; planting layout: 4.0 × 2.5 m) of the Bologna University Experimental Farm. The test field was chosen because of the lack of specific control treatments of the codling moth in the previous three years. The traps were placed on the trees at a height of 1.7 m from the soil. On the 3rd row, two traps, one traditional Pomotrap (Trap A) and one electronic trap prototype (Trap B) were placed at a reciprocal distance of 60 m and both at a distance of 10 m from the orchard borders. On the 8th row, in the opposite positions with respect to the previous traps, the second electronic trap prototype (Trap C) and the traditional Pomotrap (Trap D) were placed. All the traps were placed with the openings oriented in the same direction, to reduce the effect of the wind direction on the captured moths (figure 2).

The tests were performed between April 12 and August 29, 2010. Treatments against the codling moth were not performed during this period, to assure a high infestation of the moth. The electronic system was set to acquire a daily photo at 8:30 a.m. and to send it immediately to the remote server for a visual evaluation of the captured moths. This adjustment was defined considering a possible operating condition of an electronic trap for the codling moth management. The visual inspection of the traditional traps was performed weekly, as in the normal practice when commercial pheromone traps are used, while the exchange of the sticky pad and pheromone bait was carried out monthly in all the four traps.

The results were analyzed using a multiple regression (Statistica, StatSoft Inc., Tulsa, OK, USA).

Results and discussion

During the field test period, malfunctioning in the different components, such as software, hardware and the external envelope, was not registered. The exposure to the environmental conditions did not modify the per-


a)

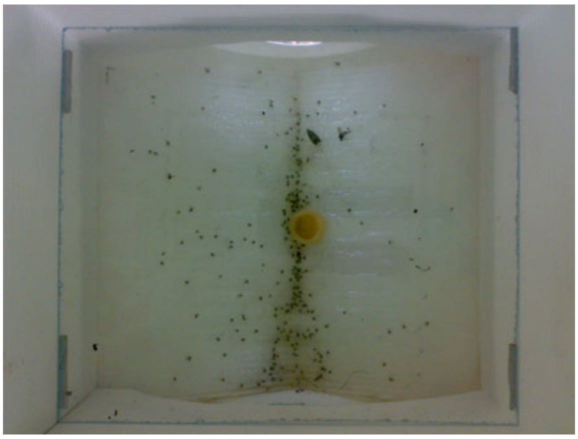

b)

Figure 3. Photos received from the automatic trap. a) Particular with two males and sex pheromone stopper; b) complete sticky pad inside the trap with one codling moth and other insects.

formance observed in the preliminary laboratory checks. In detail, anomalous effects caused by frequent rainfall events and high winds, which occurred during the first period of the tests, along with the fungicides spraying during all the test period, were not accessed.

The photos of the captured moths arrived daily at the remote server. In figure 3a an example of 2 males captured to show that it is possible to identify the moths trapped, also thanks to the high selectivity of the sex pheromone used. Indeed the traps captured other insect species as flies and midges, but with a dimension and a shape perfectly identifiable in the images (figure 3b).

The weekly control demonstrated a perfect agreement between the captures registered through the evaluation of the photos transferred to the remote system and those checked during the visual control on the field. The males captured were always located in the cone of vision of the camera (figure 3b).

The results of the moths caught in the electronic traps and in the standard ones, cumulated in the test period on field and reported on figure 4, show that the modifications introduced on the external envelope of the traps did not influence the capture efficiency of the electronic traps. The statistical analysis performed on the codling moths weekly captured by the four traps during the test period, does not show significant differences in the captures of the four traps (table 2). In total 325 codling moth males were trapped in the four traps and in particular Trap A: 94 specimens (29%); Trap B: 88 specimens (27%); Trap C: 69 specimens (21%); Trap D: 74 specimens (23%).

The moths captured started from the middle of April to the end of August. The first two males were captured (week 15 – Trap A) ahead of the forecast model indicated by ERMES (2011) that foresees the start of the flight of the overwintering generation in week 17. The

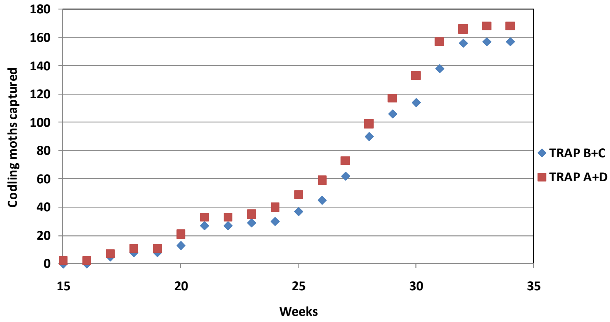


Figure 4. Accumulation of the codling moths captured in the electronic traps (Trap B + C) and in the commercial ones (Trap A + D).

flight periods of the three generations, consistent with the forecast model, were also identified and in particular: the overwintering generation with a flight period included between weeks 15 and 21; the first generation with a flight period between weeks 21 and 30, and the second generation with a flight period between weeks 29 and 34.

The analyses of the captures done on the basis of the daily detection with the automatic traps with respect to the traditional traps (figure 5) showed in the weeks 17 and 18, the starting of the captures in the second day of week 17 for the traps B and C with a moth each. The captures continued on the 3rd and 5th day in the same traps. Similar considerations can be done for the following week. This allows for a more accurate choice of the treatment time and demonstrates how electronic monitoring can be a valuable method to obtain an effective control. The electronic trap can also represent a valid support for territorial authorities to better calibrate the forecast models so as to better define the treatment timing.

Table 2. Multiple regression summary for dependent variable "codling moths captured" with respect to independent variables "trap" and "week" (R = 0.43).

	Beta	Standard error of Beta	B	Standard error	t (77)	p-level
Intercept			1.815	1.337	1.357	0.179
Trap	−0.104	0.103	−0.395	0.392	−1.008	0.317
Week	0.417	0.103	0.308	0.076	4.054	0.001

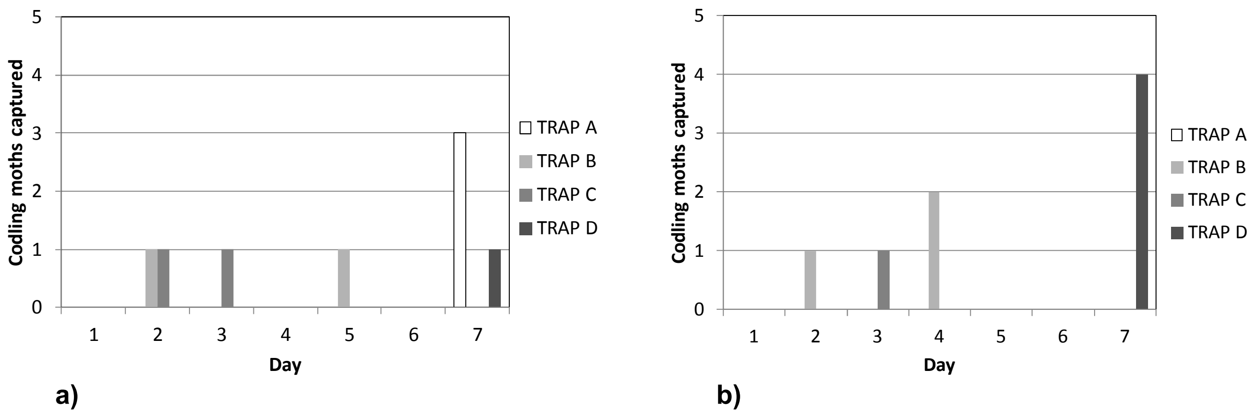


Figure 5. Weekly detail of the codling moths sampled: a) week 17, b) week 18.

Conclusions

The automatic electronic trap designed and built adapting a commercial pheromone trap proved to meet the objectives of the research in monitoring the codling moth from a remote server. The results obtained showed that the modifications introduced in the standard traps do not affect the capture capacity of the traps.

The traps, set to take and send a daily photo, allow for a more accurate choice of the timing of the control techniques and can represent a valid support for territorial authorities for an improved accuracy of the forecast models. The traps could allow for a reduction of staff costs due to a lower control of the traps on the field. The system flexibility also permits an increase of the monitoring frequency to use the system not only for field analyses but also for research investigations (i.e. better identification of hours for male flights in case of application of mating disruption with puffers or timing pheromone dispensers, etc.).

The trap efficiency, verified on the field with the codling moth in terms of number of insects captured, images transferred and easy identification of the moths, allows to a wider application of the system to other kinds of traps, like those used in the food industry context (Rajendran, 2005).

Technical and operating characteristics of the automatic trap allow finally to consider prototyping as a valid starting point for the development of commercial systems with a wide potential market, also favoured by the development of electronic technologies, their availability on the market, and progressive cost reductions.

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References

ACCINELLI G., MAINI S., CAPIZZI A. 1998.- Effetti del tipo di trappola e dell'innesco feromonico sulla cattura di *Cydia pomonella*.- *Informatore fitopatologico*, 48 (1-2): 70-75.

BEERWINKLE K. R., 2001.- An automatic capture-detection, time-logging instrumentation system for boll weevil pheromone traps.- *Applied Engineering in Agriculture*, 17 (6): 893-898.

BEROZA M., 2002.- More efficient and environmentally-desirable means of detecting insects entering lure-baited traps or attractive areas.- U.S. Patent No. 0144452.

BEROZA M., BIERL B. A., MOFFITT H. R., 1974.- Sex pheromones: (E8, E10)-Dodecadien-1-o1 in the codling moth.- *Science*, 183: 89-90.

BIRCH M. C., HAYNES K. F., 1982.- *Insect pheromones*.- Ward Arnold Ed., London, UK.

CHARMILLOT P. J., BAGGIOLINI M., MURBACH R., ARN H., 1975.- Comparaison de differents pieges à attractif sexuel synthétique pour le controle du vol du carpocapse (*Laspeyresia pomonella* L.).- *Schweizerische Landwirtschaftliche Forschung*, 14 (1): 57-69.

ERMES, 2011.- Disciplinari di produzione integrata. Edizione 2011.- Regione Emilia Romagna, [online] URL: http://www.ermesagricoltura.it

KEHAT M., ANSCHELEVICH L., DUNKELBLUM E., FRAISHTAT P., GREENSBERG S., 1994.- Sex pheromone traps for monitoring the codling moth: effect of dispenser type, field aging of dispenser, pheromone dose and type of trap on male captures.- *Entomologia Experimentalis et Applicata*, 70 (1): 55-62.

KLIEVE V., 1998.- Elektronisch gesteuerte zeitfalle zur untersuchung der tageszeitlichen aktivitat von bodenarthropoden.- *Beitrage zur entomologie*, 48 (2): 541-543.

KONDO A., SANO T., TANAKA F., 1994.- Automatic record using camera of diel periodicity of pheromone trap catches.- *Japanese Journal of Applied Entomology and Zoology*, 38 (3): 197-199.

LANDWEHR V. R., AGULEDO-SILVA F., 2005.- Method and system for detecting and classifying objects in images, such ad insects and other arthropods.- U.S. Patent No. 0025357.

MADSEN H. F., VAKENTI J. M. 1973.- The influence of trap design on the response of codling moth (Lepidoptera Olethreutidae) and fruit tree leafroller (Lepidoptera Tortricidae) to synthetic sex attractants.- *Journal of the Entomological Society of British Columbia*, 70: 5-8.

MCDONOUGH L. M., MOFFIT H. R. 1974.- Sex pheromone of the codling moth.- *Science*, 183: 978.

MCGHEE P. S., EPSTEIN D. L., GUT L. J., 2011.- Quantifying the benefits of areawide pheromone mating disruption programs that target codling moth (Lepidoptera: Tortricidae).- *American Entomologist*, 57 (2): 94-100.

RAJENDRAN S., 2005.- Detection of insect infestation in stored foods.- *Advanced in Food Nutrition Research*, 49: 163-232.

ROELOFS W. L., COMEAU A., HILL A., MILICEVIC G., 1971.- Sex attractant of the codling moth: characterization with electroantennogram technique.- *Science*, 174: 297-299.

SHIMODA N., KATAOKA T., OKAMOTO H., TERAWAKI M., HATA S., 2006.- Automatic pest counting system using image processing technique.- *Journal of the Japanese Society of Agricultural Machinery*, 68 (3): 59-64.

TABUCHI K., MORIYA S., MIZUTANI N., ITO K., 2006.- Recording the occurrence of the bean bug *Riptortus clavatus* (Thunberg) (Heteroptera: Alydidae) using an automatic counting trap.- *Japanese Journal of Applied Entomology and Zoology*, 50 (2): 123-129.

WEN C., GUYER D. E., LI W., 2009a.- Automated insect classification with combined global and local features for orchard management.- ASABE Paper No. 095865, American Society of Agricultural and Biological Engineers, St. Joseph, Michigan, USA.

WEN C., GUYER D. E., LI W., 2009b.- Local feature-based identification and classification for orchard insects.- *Biosystems Engineering*, 104: 299-307.

WITZGALL P., STELINSKI L., GUT L., THOMSON D., 2008.- Codling moth management and chemical ecology.- *Annual Review of Entomology*, 53: 503-522.

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