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Automated detection and monitoring of grain beetles using a "smart" pitfall trap

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Abstract

A smart, electronic, modified pitfall trap, for automatic detection of adult beetle pests inside the grain mass is presented. The whole system is equipped with optoelectronic sensors to guard the entrance of the trap in order to detect, time-stamp, and GPS tag the incoming insect. Insect counts as well as environmental parameters that correlate with insect's population development are wirelessly transmitted to a central monitoring agency in real time, are visualized and streamed to statistical methods to assist effective control of grain pests. The prototype trap was put in a large plastic barrel (120lt) with 80kg maize. Adult beetles of various species were collected from laboratory rearings and transferred to the experimental barrel. Caught beetle adults were checked and counted after 24h and were compared with the counts from the electronic system. Results from the evaluation procedure showed that our system is very accurate, reaching 98-99% accuracy on automatic counts compared with real detected numbers of adult beetles inside the trap. In this work we emphasize on how the traps can be self-organized in networks that collectively report data at local, regional, country, continental, and global scales using the emerging technology of the Internet of Things (IoT). We argue that smart traps communicating through IoT to report in real-time the level of the pest population from the grain mass straight to a human controlled agency can, in the very near future, have a profound impact on the decision making process in stored grain protection.

Keywords: pitfall trap, sensors, Internet of Things, stored grain, beetle pests.

Introduction

Low tolerance of the presence of insect pests in stored grain requires the development and implementation of detection and monitoring methods that are sensitive enough to detect early pest infestation to prevent quality and economic losses (Trematerra, 2013). Today, the innovative uses of sensors and networks targeting animals are starting to be translated into new ecological knowledge (Portet et al., 2009). Traps equipped with a detection sensor and wireless communication abilities have some distinct advantages against manual monitoring. They can monitor insect populations 24 h a day, upon their entrance to the trap, every day of the year, in dispersed nodes across a variety of fields, simultaneously, and all counts and recordings can be permanently stored in a cloud service. Another distinct advantage is the determination of the precise onset of an infestation. Real-time reporting, opens new grounds in stored product research and mainly in crop protection as – besides a timely control action in response to a pest infestation – it can help in the evaluation of the impact of a control treatment and therefore reschedule future actions if necessary.

Pitfall traps are typically used for monitoring several species of stored-grain beetles (Coleoptera) in silos, warehouses and processing plants (Reed et al., 1991). They are placed inside the bulk grain near the external surface. The cone-shaped device is made of clear plastic and has a removable perforated lid, which allows insects to enter, but not escape. Various pheromone lures targeting different species may be used. Many destructive beetle pests of stored grain may be monitored by this type of trap: the flour beetles *Tribolium* spp. (Tenebrionidae), the grain weevils *Sitophilus* spp. (Curculionidae), the lesser grain borer *Rhyzopertha dominica* (F.) (Bostrichidae), the cigarette beetle *Lasioderma serricorne* (F.) (Anobiidae) and the khapra beetle *Trogoderma granarium* Everts (Dermestidae) (White et al., 1990; Neethirajan et al., 2007).

Our approach aims at reducing the necessity of human-in-the loop in any intermediate processing stage of the workflow and reserve the need of expert entomologists only for the highest abstraction layer: the interpretation of the data received (trap catches) normally presented in the form of georeferenced maps and the corresponding decision making and action planning based on pest Economic Injury Levels (EIL) population thresholds that are applied in the frames of Integrated Pest Management (IPM). Our work focuses on leveraging the quality of service of remote surveillance of pest populations to a better and cost-effective status than sparsely applied human inspection.

Materials and Methods

We have embedded our electronics into the Pitfall trap (EDIALUX, Bornem, Belgium) for monitoring populations of beetle pests of stored grain. There is always an emitter of light opposite to a receiver of light and the path of the incoming insect passes in between. The interruption of the path of light effects a voltage drop that exceeds a threshold and constitutes a count. Both receiving and emitting elements are deployed as 1D linear arrays that are long enough to cover the entrance to the trap. In the pitfall trap, an insect can enter from any hole of the lid. In order to avoid blind spots in the field of view we need to have a uniform field sensing insect sizes ≤ 0.5 mm. We used 16 LEDs and the same number of photodiodes and both emitter and receiver have a light diffuser. All sensors are operated in pulse mode i.e. there is no constant flow of light from emitter to receiver but a pulse train is emitted.

For the purposes of our study, a prototype (Fig. 1) equipped with a linear array of five Light Emitting Diodes (LED) opposite to 5 receiving photodiodes was evaluated. The prototype trap was put in a large plastic barrel (120lt) with 80 kg maize. Adult beetles of various species were collected from laboratory rearings and transferred to the experimental barrel. In order to ensure trap catches a large number of adult beetles was used resulting in an infestation level of more than 15 adults per kg maize. Caught beetle adults were checked and counted after 24h and were compared with the counts from the electronic system.
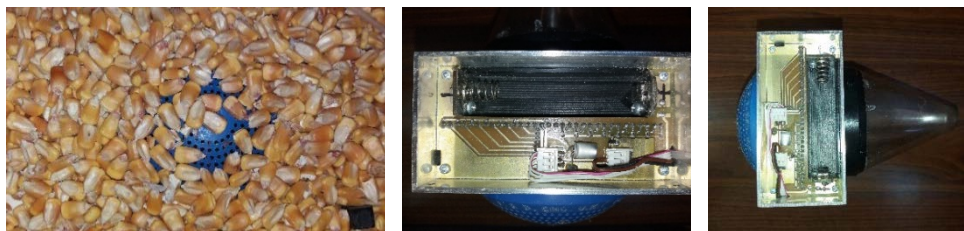
Fig. 1 The "smart" Pitfall trap. A sheet of light covers the lid entrance. Photo interruption due to a falling insect produces a voltage variation that is turned to a count. Counts as well as environmental parameters and a time stamp are transmitted wirelessly and uploaded to server.

Results & Discussion

Results from the evaluation of the prototype traps are presented in Table 1 and Fig 2. As it is clearly concluded from our data, our system is very accurate, reaching 98-99% accuracy on automatic counts compared with real detected numbers of adult beetles in each trap. The accuracy of our system in detecting adult beetle catches is also shown by the very high ($r > 0.99$ in all cases) correlation between the generated signals and actual numbers of insects caught in the trap.

Tab. 1 Number of actually detected (manual inspection) and automatically counted (electronic sensors) adult beetles in "smart" pitfall trap

Species	Actually Detected	Automatically Counted	Correlation coefficient (r)
	59	62	
C. ferrugineus.	45	49	0.9912
	67	74	
	31	34	
O. surinamensis	11	12	0.9978
	24	25	
	15	15	
R. dominica	23	24	0.9976
	24	26	
	21	21	
S. oryzae	32	36	0.9900
	29	30	
	13	13	
T. confusum	26	30	0.9912
	34	36	
	14	14	
R. ferrugineus.	45	49	0.9999
	67	74	

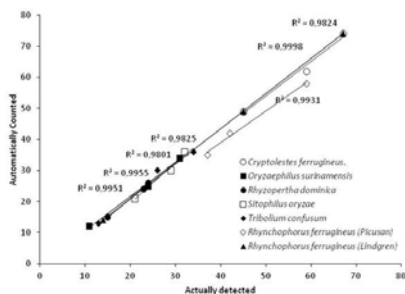Single trap inside grain mass, insect density >15 adults / kg grain

Fig. 2 Accuracy of the automatic counting in comparison with actual detection. The values of the linear regression coefficient R^2 prove that our system is 98-99% accurate (when detected and counted values are the same then R^2 equals to 1)

Only a few remote pest monitoring systems, based on wireless communication technology, have been evaluated in the past, with varying accuracy. The oriental leafworm moth *Spodoptera litura* (Fabricius) (Lepidoptera: Noctuidae) was effectively monitored by an ecological monitoring system combining GSM transmission technologies with mechatronics with accuracy ranging from 71 to 100 (Shieh et al., 2011). Average accuracies of 96.3% (Liao et al., 2012) and 94.9% (Deqin et al., 2016) were demonstrated by automatic monitoring systems counting the catches of the oriental fruit fly *B. dorsalis*. Other automated systems with image analysis technology also proved to be reliable in detecting mainly whiteflies and moths, with accuracies ranging from 70 to 100% (Xia et al., 2012; Ding and Taylor, 2016; Boissard et al., 2008; Lopez et al., 2012; Guarnieri et al., 2011). The accuracy of our system is higher than almost all of the abovementioned monitoring systems.

In this work we establish a connection between sensors' readings, pest population level and predictive models to ensure timely and effective control treatments. Acceptance of automated monitoring practices will raise doubts about the reliability of data collected without expert's intervention. The optoelectronics need to reduce their errors in order to reach comparable analysis to that done by experts. A long-term field operation is needed in order to identify the cause of possible false alarms and detection misses and sensor failures in sometimes harsh conditions before applying the output of such data-collection schemes to modeling and policy. We believe current results are sufficient to warrant further exploration on insect surveillance. Insect surveillance can provide insight into the effects of insecticide efficiency, reduce its use and shape our understanding of pest problems in agriculture. Provided we continue improving the reliability of devices and services and perform real-field, long-term trials we will upgrade automated practices to the level of being indispensable to farmers, policy makers and stakeholders.

Acknowledgement

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Detection and estimation of population density of bean weevils (Coleoptera: Bruchidae) in stored pulses via bioacoustic analysis

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Abstract

Stored product insects, produce acoustic emissions by moving, feeding or ovipositing inside the grain mass. These sounds can be used not only for detection purposes, but also for population density estimation. Acoustic emissions of adults of *Acanthoscelides obtectus* (Coleoptera: Bruchidae) and *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) were recorded infesting various pulses in varying population densities from 1 to 500 adults/kg product. The acoustic analysis system is being described. Population density, type of grain and pest species had significant influence on the number of sounds. The system was 100% precise in negative predictions and considerably successful in positive predictions. The system was very accurate (80-100%) in detecting insect presence even in the "critical" density of 1 adult/kg product, the most common threshold for classifying a stored mass as "infested" or "not infested". Our study suggests that automatic monitoring of the infestation state in bulk grain is feasible in small containers. This kind of service can assist reliable decision making if it can be transferred to larger storage establishments (eg. silos). Our results are discussed on the basis of enhancing the use of acoustic sensors as a decision support system in stored product IPM.

Keywords: Stored Pulses, Bioacoustic, Detection, bean beetles, Density Estimation

Introduction

More than 500 species of beetles have been reported to be associated with various stored grain products (cereals and pulses) and almost 100 of them may cause significant quantitative or qualitative losses. It has been estimated that between one quarter and one third of the world grain crop is lost each year during storage. The key for successful management of stored grain pests is not only early detection, but also an accurate population density estimation of the pest (Rajendran and Steve, 2005).

Acoustic detection is a very promising method for early detection of insects inside the grain mass (Eliopoulos et al., 2015; Hagstrum et al., 1996; Mankin et al., 2011; Potamitis et al., 2009 and others). Insects of stored grain generate sound by eating, flying, egg laying, or locomotion. Reliability and