Smart traps for automatic remote monitoring of *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae)

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Abstract: This work describes a novel solution to remote *R. ferrugineus* monitoring. Classical, plastic RPW traps containing aggregation pheromones for RPW are modified to include an optical sensor that senses adult pests falling in the trap. The counts of the pests are accumulated through the day and the counts are transmitted via the mobile phone network straight to a smartphone/tablet or internet address. The device is small and is attached internally in the trap carrying all necessary electronic equipment to allow optical detection, counting and transmission of counts through GSM. Smart RPW traps are expected to reduce the cost of monitoring and allow for reliable decision making as the wireless transmission is instantaneous thus allows the creations of real-time infestation maps. Our device has been tested extensively in real field delivering excellent detection results. We did not observe a single case that a RPW was not detected while being inside the trap and our trap delivers nearly zero rate false alarms.

Keywords: *Rhynchophorus ferrugineus*; Red Palm Weevil; *Scyphophorus acupunctatus*; electronic trap; remote monitoring; precision agriculture

1. Introduction

Rhynchophorus ferrugineus (Red Palm Weevil -- RPW) has been detected in several Mediterranean countries (Spain, Egypt, Greece, Cyprus and Israel). Its presence is confirmed by the official authorities of more than 30 Asian and African countries. RPW, is the most dangerous and deadly pest of date, coconut, oil, sago and other palms [1-3]. Date palm is an important crop in North African and Asian countries and ornamental palms are widely planted as amenity trees in the whole Mediterranean area.

The cause of the high rate of spread of this pest is human intervention, by transporting infested young or adult date palm trees and offshoots from contaminated to uninfected areas. Moreover, the pest demonstrates strong flying capabilities. The pest attacks palm trees and if left undetected, within a few weevil generations results in very severe overall damage in the plantation. If the pest is detected on time, the damage can be minimized. The infested trees once located are treated with biological or chemical means or removed. The treatment with insecticides or biological means has not been proven so far effective to the point of eradicating the pest. Most of the reported research focuses on means of treatment using biological or chemicals or early detection mainly based on the acoustic modality [4-9] and less on the logistics of its control. In order to make maps of infestation plastic traps with pheromone or food attractants are typically used. Manual counting of trapped insects is tedious as the pest manager must cover long distances since palms are dispersed in not always easily reachable areas especially in the Mediterranean basin. Due to the cost of deploying and examining traps manually, currently not many traps are being deployed, thus limiting the spatial and temporal resolution of collected data in large areas. In this work we report on a new remote monitoring tool that can change radically the way monitoring is carried out: a stand-alone electronic device that is easily attached inside the plastic conical black-colored traps (Picusan type traps [10]). Insects are attracted to enter the trap by a pheromone dispenser that hangs inside at the top of the trap. Generally the reverse movement of the insect out of the trap is impossible as the pests fall in water containing soap or detergent and are terminated. We attach and optical sensor that detects the fall of the insect inside the trap. The electronic circuits associated with the sensor count the pests and transmit results in text using the GSM network in a prescheduled basis. The time-schedule can be set by the user remotely by sending an SMS to the trap. Our electronics are very robust against illumination fluctuations and weather conditions and deliver near zero false alarms. The transmission of counts minimizes the labour inspection cost and movement of specialized personnel thus releasing valuable funds that can be used for the treatment of infested trees. The automatic monitoring task delivers data to base instantaneously thus allowing treatment policies to be scheduled. The transmission of counts through the mobile network using simple SIM cards (the same used by cell phones) takes no time and therefore results are available on-line on daily basis. Therefore the location and the extent of the problem can be quickly assessed and a response to the problem can be timely designed. This would be very difficult with typical manual delivery of counts as in the current human-in the loop process because of its cost is sparsely applied and once the data are manually delivered the problem has evolved to an unknown state due to the time-lag between inspection of the whole network and reality.

An automated trapping system that counts and transmits measurements from the field to a smartphone using the cellular mobile network increases data accuracy, reduces labor expenses associated with manual monitoring, improves capabilities for monitoring larger areas and potentially reduces the amount of chemicals. Our approach is cost efficient, robust (only simple numbers in a text message are transmitted not pictures nor audio) and power efficient as the state-of the art low power electronics employed allow functioning for two months unobtrusively.

2. Embedding sensor and microcontroller in trap

2.1. The optoelectronic sensor

The sensor consists of an infrared light emitting diode that acts as an emitter of light and an array of phototransistors acting as receivers of light. The light path from emitter to receiver covers the entrance to the trap (see Fig. 1). The entrance is vertical and slippery and the heavy insect falls down the tube interrupting the path of light with its body. This interruption causes a large voltage fluctuation in the input of the microprocessor initiating an increase of counts by one.

In our configuration all components are firmly placed on a plastic disk cut to fit around the hole of the funnel (see Fig. 2). The disk base is thick enough to sustain deformations due to temperature variation in field conditions. The sensor is placed on the disk so that their relative position does not change in a possible displacement of the trap due to temperature variations and possible movements. Relative position stability of emitter and receiver is a crucial point of the electronic trap. The sensors are embedded in plastic shields to cut-reflections and illumination variations from the outside of the trap. The assembled device is attached internally on the funnel so that the light flow from emitter to receiver guards the entrance (see Fig. 3).

The microcontroller is in sleep mode, wakes up every 1 millisecond, emits a pulse of light for 32 microseconds and reads the answer from the phototottransistors' array. The GSM module is always in sleep mode and is powered on automatically following a time-table that is sent to the trap by an SMS once (normally every 1 to 5 days). These procedure are essential in order to ensure power sufficiency for two months of continuous functioning.

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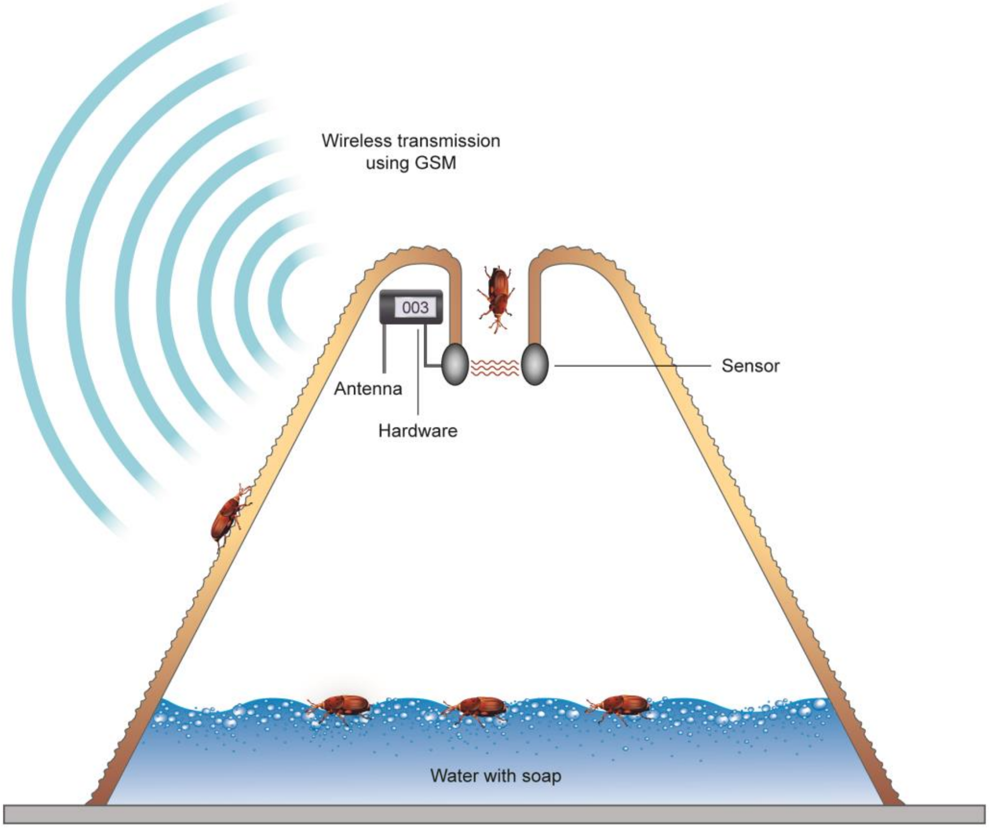

Figure 1. A typical plastic Picusan type trap with the optoelectronic detector embedded.

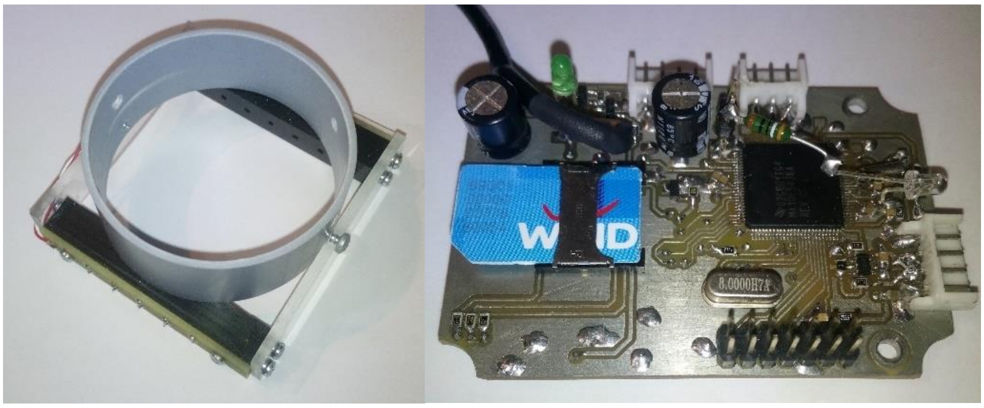

Figure 2. *Left*: optoelectronic sensor: A light gate guarding the lower part of the funnel. *Right*: microcontroller counting light interruptions, and message delivery.

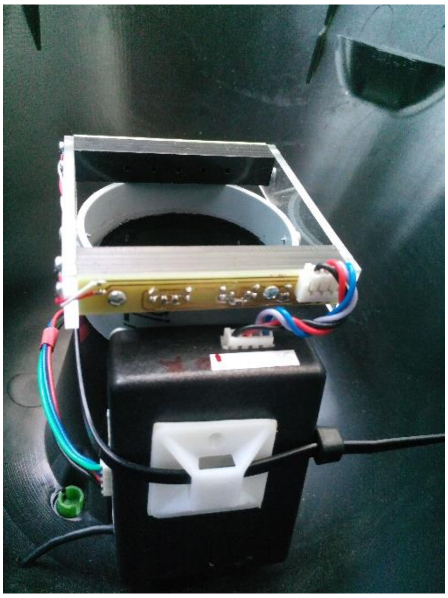

Figure 3. Detection device mounted on the funnel in the inside of the trap.

2.2. Controlling the device from distance

The device is controlled wirelessly through the GSM network by sending SMS commands to the trap. We control the time-schedule of SMS emissions to base or to the web server as well as the phone number of the receiver. A table with an overview of the data we receive is depicted in Table. 1 as follows:

Time:	21:38 02/06/2015
Device ID:	003
RPW counts:	5
Daily counter:	1
Battery:	75%
Mean Temperature:	26^{o} Celsius

Table 1: Data as reported from a single trap. *RPW counts* stands for insect counts since powering-on the device whereas *Daily counter* are counts since last measurements.

The SMS's are more comfortable for people that are not computer inclined and do not want to use web interfaces, and employ a single or few traps. The web interface however becomes indispensable in the case of a large number of traps deployed as it can be used for the automatic construction of infestations maps. The data can be loaded directly to internet for better workflow monitoring of several traps with the applicability of the GPRS functionality. We show a convenient and cost-effective way to exploit GPRS, in order to transmit results along with internal measurements of the state of the trap (e.g. battery status, temperature etc.). We use GPRS data transmission to post each sensor platform's data online (target counts, total counts, battery, GPS location etc.). More specifically, we used the dweet.io (https://dweet.io/) platform, a free web service that facilitates simple posting of data online from various internet-enabled devices. The data is then aggregated by another free service, namely Freeboard (https://freeboard.io), which allows visualization of the transmitted information. By combining the two platforms, we enable real-time monitoring of the status of the various platforms though a user-friendly

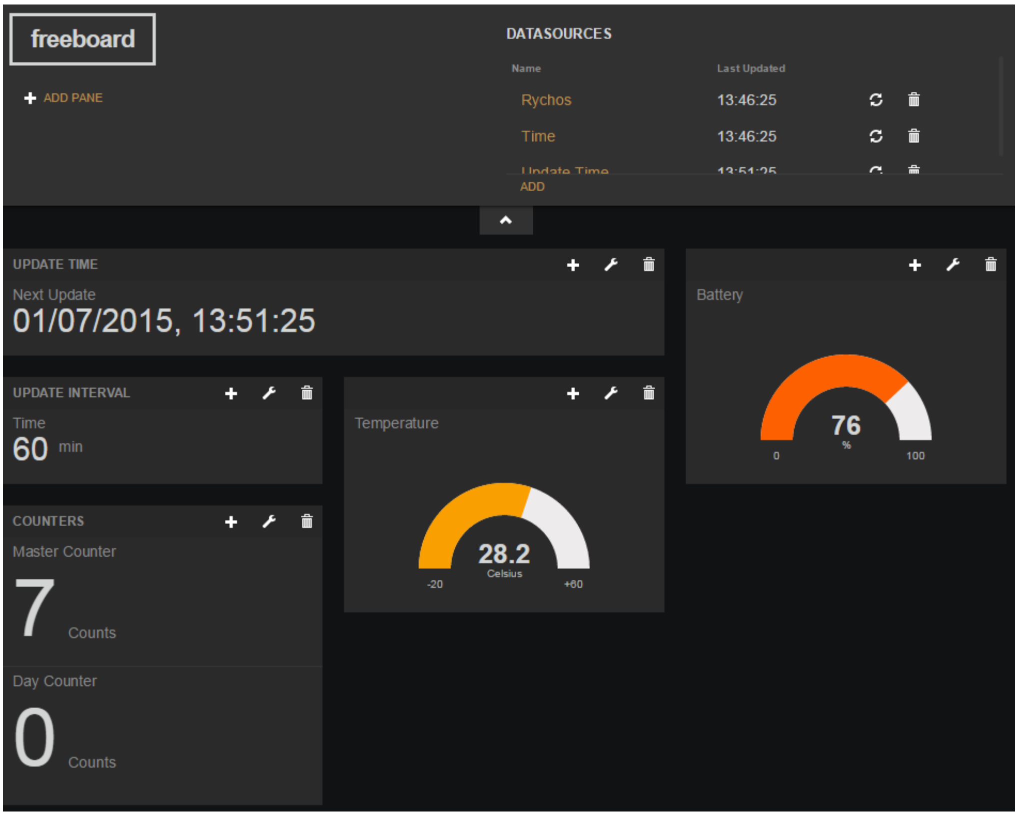

Figure 4. Detection and recognition results received from the GPRS module. The figure shows the online web interface that presents detected counts of pests.

online web interface, at no extra cost. The web interface we created for the purpose of this work is depicted in Figure 4.

3. Results and Discussion

We performed over a month of field experiments with daily inspections of traps in the island of Crete in Greece. We placed a smart trap in the capital of Heraklion in location with confirmed infestation of *R. ferrugineus*. In Fig. 5 we report results using a prototype smart trap and manual inspections on a daily schedule.

The trap performs simple counts due to abrupt light interruptions and not species recognition. We have placed time constraints to the microcontroller processing the pulse recorded due to the falling insect and we reject too short and too long in time measurements as outliers. The aggregation pheromone used to attract *R. ferrugineus* is specialized to attract this particular insect. We have found occasionally in deployed traps small butterflies that our system successfully rejects them as being *R. ferrugineus* cases.

The manual inspections confirm the validity of our approach as we did not observe any miss of event. Illumination variations (e.g. clouds, day-night change) do not effect false alarms and our device can work as effectively in day and night in contrast to camera vision.

Though it did not occur in our experiments it is known that the pest *Scyphophorus acupunctatus* can be attracted to the kind of traps and pheromone we used. *S. acupunctatus* is a significant pest of agave, yucca, and various other plants in the families of *Agavaceae* and *Dracenaceae*. In such a case the trap would not discern the incident of *S. acupunctatus* against *R. ferrugineus*. In case of palms absence the same smart trap configuration can be used for *S. acupunctatus*.

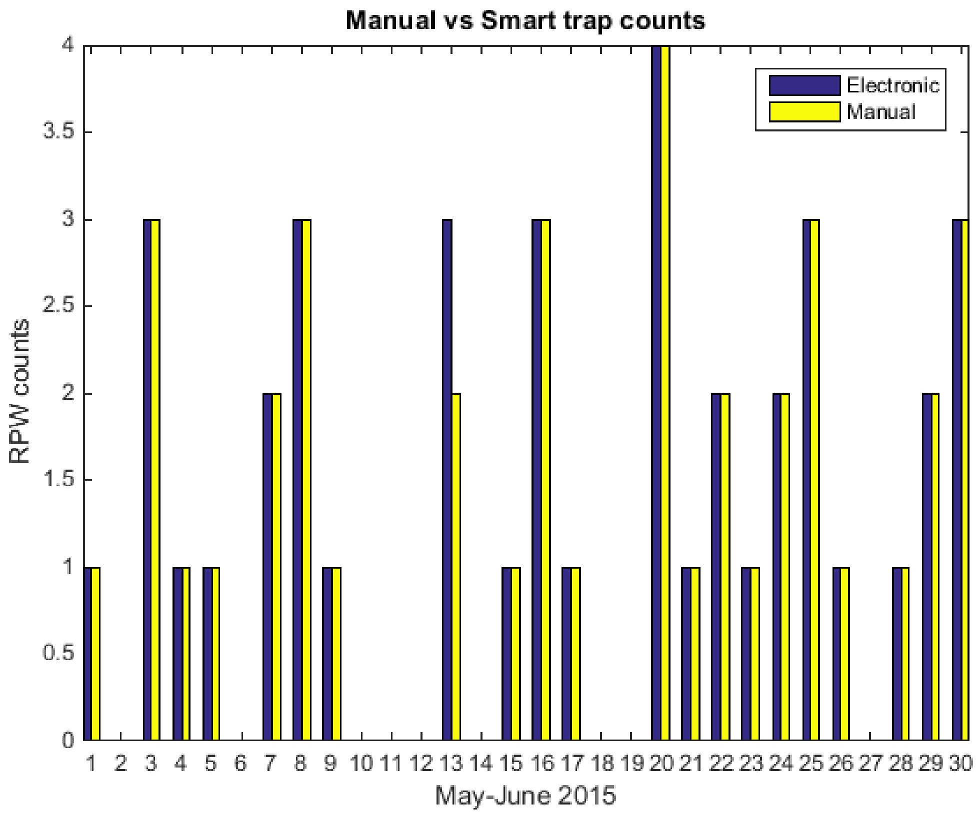

Figure 5. Counts of RPW in an electronic trap. *Manual* corresponds to human inspection and logging and *electronic* to the proposed automatic device. The two means of monitoring are in perfect accordance.

4. Conclusions

Detection and localization for agricultural tasks using sensors are becoming popular and valuable components of what is referred as precision agriculture. In this work we focus on the detection and localization of a devastating for palms pest, namely *R. ferrugineus.* We modified a typical plastic RPW trap into an electronic one that can count *R. ferrugineus* and transmit counts through the GSM network. The device is composed of an optoelectronic sensor coupled to a microcontroller platform capable of accurate sensing the falling insect.

Our device has been extensively tested in the field and was found immune to illumination variations, weather conditions and power sufficient for unobtrusively functioning 24/7 for 2 months. In our monthly experiments the device achieved a false alarm rate 1/30 and 100% hit rate. We attribute this fact to the simplicity and robustness of our system: There is no way that the insect can go down the funnel of the trap without interrupting the light gate. The low false alarms are under investigations and are probably due to electromagnetic noise during emission. We suggest that the additional cost of the device is compensated in short-time as the manual trips to the traps are greatly reduced thus allowing the transfer of budget from monitoring to treatment procedures. The insect counts are transmitted wirelessly and instantaneously from the field to the pest manager therefore one can have real-time infestation maps of large land areas that allow for better design of policies and interventions. Due to the global acceptance of the GSM network our smart traps allow collecting, analyzing and monitoring of *R. ferrugineus* spread with information systems that model and predict infestation spread and risk that maybe located as far as to another continent.

Acknowledgments

We acknowledge that we performed our experiments using *Picusan* ® traps for the attraction of *R. ferrugineus*. We acknowledge Dr. D. Kontodimas from Benakio Phytopathological Institute of Athens (http://en.bpi.gr/) for supporting all our enquiries regarding insect's lifecycle and feeding habits.

Author Contributions

Ilyas Potamitis has written all text and carried out all measurements and experiments. Iraklis Rigakis implemented the hardware of the optoelectronic sensor.

Conflicts of Interest

The authors declare no conflict of interest.

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