

# The electronic McPhail Trap

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**Abstract:** Certain insects affect cultivations in a detrimental way. A notable case is the Olive fruit fly *Bactrocera oleae* (Diptera: Tephritidae) that in Europe alone causes billions of euros crop loss/per year. Pests can be controlled with aerial and ground bait pesticide sprays, the efficiency of which depends on knowing the time and location of insect infestations as early as possible. The inspection of traps is currently carried out manually. Automatic monitoring traps can enhance efficient monitoring of flying pests by identifying and counting targeted pests as they enter the trap. This work deals with the hardware setup of an insect trap with an embedded opto-electronic sensor that automatically records insects as they fly in the trap. The sensors responsible for detecting the insect is an array of phototransistors receiving light from an infrared LED. The wing-beat recording is based on the interruption of the emitted light due to the partial occlusion from insect's wings. We show that the recording are of high quality paving the way for automatic recognition and transmission of insect detections from the field to a smartphone. This work emphasizes the hardware implementation of the core sensor giving all necessary implementation details needed to construct it.

Keywords: McPhail trap; automatic insect trap; precision agriculture

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## 1. Introduction

Olive cultivation is widespread throughout the Mediterranean and is vital for the rural economy but also for the world market. Approximately 2.5 million producers (one third of EU farmers) are

involved. The EU is the leading world producer, accounting for 80% (>2 million tonnes) [1]. However this sector is continuously under the threat of an extremely destructive insect pest: *Bactrocera oleae* (*Diptera: Tephritidae*), the Olive fruit fly. Each year it accounts for more than 30% destruction of all Mediterranean olive crops, i.e. losses of almost €3.0 billion [2-3]. In Europe the Olive fruit fly is controlled with aerial and ground bait pesticide sprays, but their efficiency depends on knowing the time and location of insect infestations as early as possible in order to initiate the spraying procedure. Producers set up traps in the field that lure and capture Olive flies to detect and manually count them. The producer has to inspect traps throughout most of half the year to identify and selectively count only Olive flies. The pest managers are instructed to disregard insects that have been trapped but are not Olive flies. Some of them however can look very much alike to the untrained eye (e.g. fruit flies). Manual counting is tedious as the pest manager must cover long distances since traps are dispersed in not always easily reachable areas. Manual counting is also rudimentary as occasionally hundreds of insects can be found in traps and the managers/farmers practically make only 'educated guesses'. Because of these limitations and the resulting cost not many traps are being deployed, thus limiting the spatial and temporal resolution of collected census data in large areas.

The monitoring task is based on manual counting of trapped pests and depending on the found concentration the spraying procedure is initiated. The timing of the spraying is critical as initiation prior to and after the optimal time-point returns suboptimal results. The fear of a serious infestation may lead inevitably the producers to compensate the faulty monitoring procedures with excessive spraying of pesticides, which affects natural enemies of the pests, as well as useful pollinating insects, contaminates water, and carries the risk of exposure to humans. An automated trapping system that would identify, count and transmit measurement from the field to a smartphone would increase census data accuracy, reduce labour expenses associated with manual monitoring, improve capabilities for monitoring larger areas and potentially reduce the amount of spraying.

Monitoring traps are plastic or glass boxes. Insects are attracted to enter the trap by either a pheromone dispenser that hangs inside at the top of the trap or by food baits and the light entering through the clear top. The most famous trap and probably the most widely used is the so called 'McPhail trap' consisting of two interlocking sections: a) a clear top and b) an inverted funnel. Insects enter the trap through a hole in the inverted funnel base in response to the chemical signals they receive [4]. Generally the reverse movement of the insect out of the trap though not infeasible is uncommon due to the movement patterns of insects and the inverted funnel design. The traps may contain water mixed with detergent or insecticide on their bottom and terminate the pest. We will embed our electronics in this widely known trap as a proof of concept but we do not imply that our approach is in anyway restrained to this trap configuration.

The key component in the electronic McPhail is the sensor. In our approach the sensor is a receptor array of 5 phototransistors in parallel connectivity and an infrared emitting LED. The use of an optoelectronic device mainly as an experimental instrument to monitor insect movements has been also reported in the past. The first encounter to our knowledge can be traced back to 1955. Richards [5] observed that partial occlusion of the wings of insects flying in front of a solar disk produce fluctuations in the receptor that when analysed reveal the wing-beat frequency and overtones of the insect and its harmonics. This idea was further developed in numerous publications using an optoelectronic device as a means to capture insect movement [6-9]. The use of microphones was also suggested [10]. There are clear advantages of the use of opto-electronics instead of microphones: a) the optoelectronic device records an event only when the path from the emitter to the receiver is

interrupted whereas a microphone picks up sound from all-directions, b) optoelectronic devices return a very high signal to noise ratio (are practically noiseless) whereas microphones record all sound sources (e.g. birds, cicadas, wind) and therefore can become very noisy, c) microphones although can be protected in several ways against weather conditions, are more vulnerable to open field conditions and finally cost much more. To our point of view, traps carrying microphones are very useful but only for in-lab research.

Though optoelectronic devices have been proposed for several insect applications [11], and their future embedding into traps was foreseen, a review of this literature leaves the reader with little information that could be easily integrated into a product. This could be due to immature technology at that time or the employing of computationally intensive classification techniques that cannot be routinely embedded into small, power-efficient devices [12-13]. The novelty of our paper lies in the following:

a) A new sensor is implemented using state of the art electronics and details of its hardware components and implementation are given, thus allowing replication. We show that our proposal is cost-effective reaching a total cost below 5.7 Euros (7.4 \$, d.l.v 20/8/2014).

b) The sensor is actually embedded in a widely used trap, thus solving many practical difficulties as encountered in devices operating in real-field, and its function as an integrated whole is studied on the task of recording in-flight the Olive-fruit fly wing-beat as well as other insects of interest.

## 2. Experimental Section

### 2.1. The optoelectronic sensor

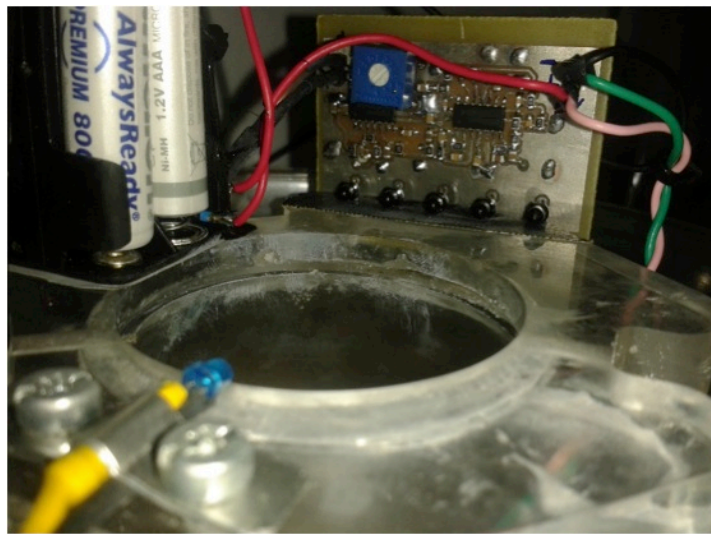
Although many configurations of the McPhail trap are reported in literature, the main components of the trap are the same. In Figure 1 (left) we present a typical plastic McPhail trap with the clear top and the inverted funnel detached. In Figure 1 (right) we show the same trap with all electronics embedded.



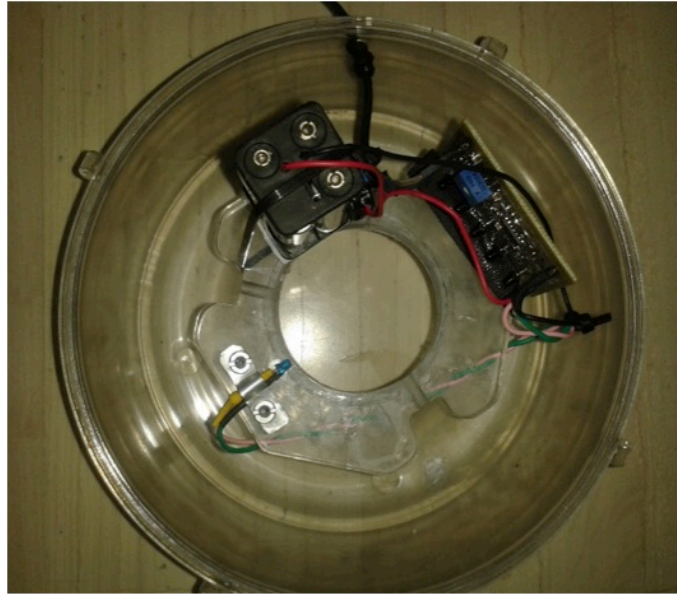
**Figure 1.** A typical plastic McPhail trap (left) with the optoelectronic sensor embedded (right).

Herein we give implementation details on the opto-electronic sensor. In our configuration all components are firmly placed on a plexiglas disk cut to fit around the hole of the inverted funnel. The plexiglas base is thick enough to sustain deformations due to temperature variation in real-field conditions. All components are placed on the disk so that their relative position does not change in a possible displacement of the trap due to wind when operating in the real field. Relative position stability of emitter and receiver is a crucial point of the electronic trap.

Figure 2 shows an expanded view of the optoelectronic sensor. It is composed of: a) the emitter which is an infrared light emitting diode (LED), b) an array of 5 phototransistors acting as photoreceptors connected in parallel on the other side of the disk. The infrared LED and the phototransistors are in the same package and the part number is TCRT5000 with a cost of 0.78 Euros each. The remaining components are: An electronic circuit performing band pass filtering (60Hz – 4000Hz), and a 4.8 Volts power supply from rechargeable batteries and its accompanying switch.



**Figure 2.** Opto-electronic sensor embedded in the trap. (a): the array of phototransistors. A black tape is inserted underneath the phototransistors to cut reflections (b): the LED infrared source (blue bulb).

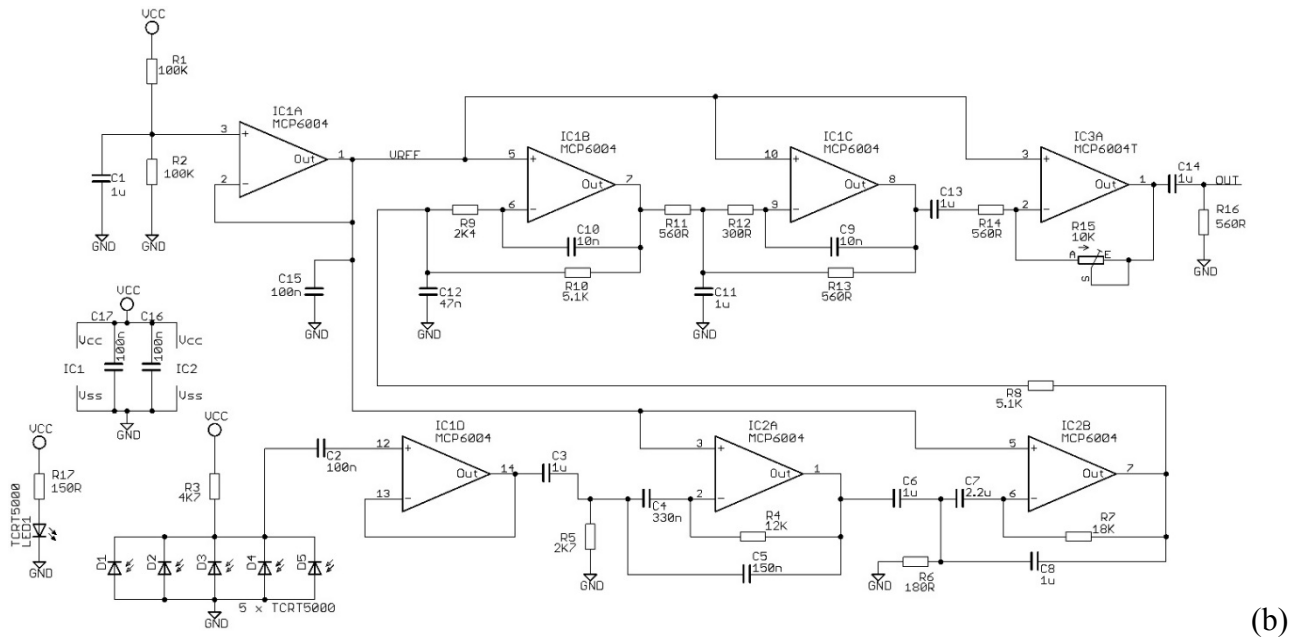
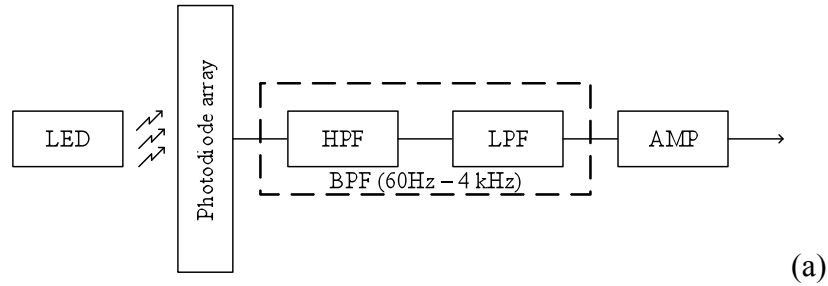


**Figure 3.** Top view of electronics' placement. (a) A 4.8 Volt battery supply on the left, (b) the hole in the middle is the entrance of the inverted funnel, (c) the array and the LED in their final positioning. All parts sit tight on a plexiglas disk mounted on the lower part of the McPhail trap.

## 2.2. The electronics

The optoelectronic system block diagram is shown in Figure 4a. It consists of an emitter, a receptor array, a band-pass filter based on a low-pass and a high-pass filter and an adjustable gain amplifier. The electronics board utilizes seven low voltage operational amplifiers (see Figure 4b) for signal buffering and the band-pass filter implementation. Specifically, the IC1A is a buffer of half of system's power supply ( $V_{cc}/2$ ), creating the reference voltage in order to operate the other amplifiers with a single supply. The IC1D is a buffer for the photoreceptor array signal. The IC2A and IC2B function as a high pass filter with a cutoff frequency of 60Hz. The IC1B and IC1C function as a low pass filter having a cutoff frequency of 4 kHz. The IC3A is a variable gain amplifier with a maximum gain of 25 dB.

The signal output is a clear zero-mean recording in the absence of photo path interruption and can easily follow the frequency of wing-flapping in case of insect's presence. The output can be fine-tuned through variable gain amplifier using the potentiometer (R15 in Fig. 4b, blue square in Fig. 2) to be in the range -1 and 1 in order to be treated as line-level audio signal. The device can operate in daylight as well as in total darkness and the battery supply ensures a steady input that is required for such delicate measurements. This prototype should be operated away from artificial light as the photodiodes are prone to picking up interference.



**Figure 4.** (a) Block diagram and (b) Schematic Description of the filters and operational amplifier attached to the phototransistors. HPF, LPF stands for high-pass, low pass filters respectively and AMP for amplifier.

We are currently looking into a series of design and optimization strategies of photonic devices for sensing applications [14] in order to optimize our sensor in terms of SNR and power consumption.

### 2.3. Capturing of live adult specimens for controlled and in-flight experiments

In this work we focus on the sensor but the electronic McPhail will finally include a recognizer built to its electronics that will classify insects from their wing-beat as they fly in the trap. It is well-known in pattern recognition that, in order to achieve optimal classification results, the training and test conditions must be matched. Therefore, we did not use insects that are grown in captivity as we noticed a great difference in their behavioral patterns. Insects grown in captivity are generally reluctant to fly and not as vivid as the naturally grown counterparts. Moreover we did not know if captivity affects other parameters of flight. Therefore we used custom-made traps in order to capture alive

*Bactrocera oleae* adults from olive orchards as illustrated in Fig. 5. The custom-made traps were filled with either pheromone or food baits and hanged from trees. Once inside the trap, the insects have the tendency to fly upwards and therefore we found large numbers of them in the detachable container (Figure 5 right). The detachable container was capable of capturing the pests alive otherwise they would be typically drowned in the bait. Once a number of insects are trapped, the container is manually sealed and detached from the main trap while a replacing container is locked in. Subsequently, the removed container is placed in a common freezer for about 1-2 minutes. *Bactrocera oleae* (as well as *Musca domestica* and several mosquito species we tried) are ectotherms meaning that their body temperature is controlled by their outside environment. By putting them in the freezer we instantaneously decrease their activity levels and this allows us to manipulate them and remove other species possibly collected in the trap. Then the detachable container is placed under the Electronic McPhail Trap powered on. After the insects attain the normal temperature of the environment they fly towards the open inverted funnel of the McPhail trap and, therefore we achieve an in-flight recording.

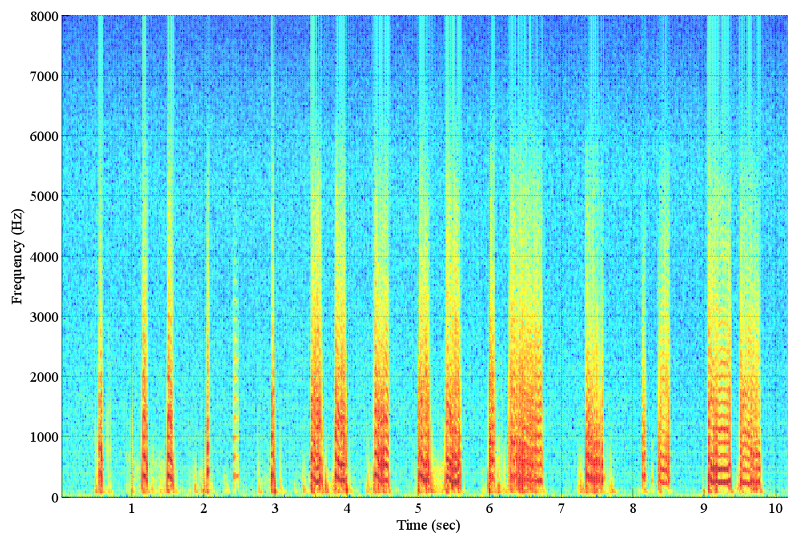
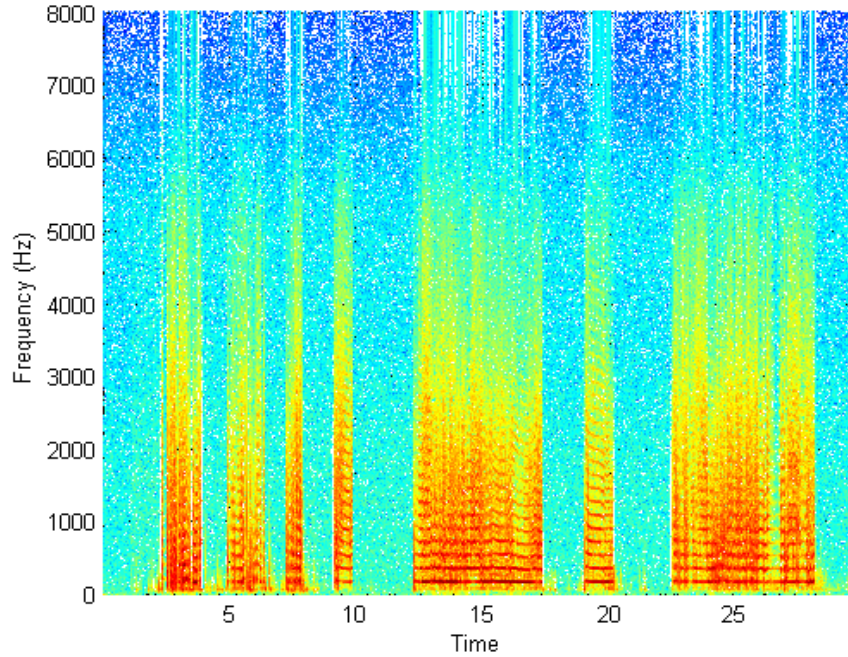


**Figure 5.** Traps used to capture alive *Bactrocera oleae* adults from olive trees. (a) A typical Olive-fly trap, (b) A custom-made trap with a second room attached.

### 3. Results and Discussion

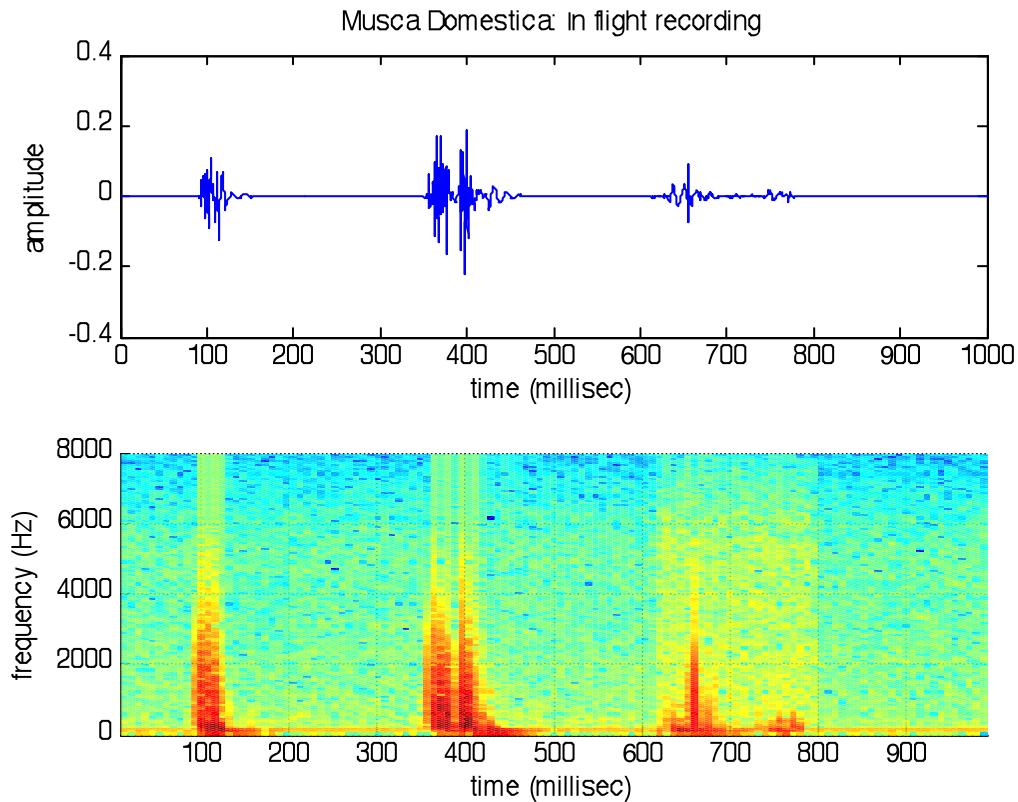
A spectrogram of a recording of the wing-flap of the insect *Bactrocera oleae* is shown in Figure 6 (top). The recording is sampled at 16 kHz, divided into 512 sample segments with 50% overlap and each segment is windowed with a Hamming window. The specimen is manually held in and out of the infrared beam while flapping its wings. A male adult is shown for the first 10 seconds and a female adult is shown afterwards. Notice how the fundamental frequency of 180 Hz and the overtones are

clearly resolved. Notice also the complete lack of any noise though no signal enhancement method is applied on the recording other than that of the electronic device. A small amount of energy in very low frequencies between 3 and 10 seconds are actually due to body-movements of the insect. We repeat our controlled experiment with other insects, the common housefly, *Musca domestica* and several mosquito species some of them seen in Figure 6 (bottom). The adults are again manually held in and out of the infrared beam while flapping their wings.





**Figure 6.** (top) Spectrogram of a recording of *Bactrocera oleae* from the opto-electronic sensor. (Bottom) Spectrogram of a recording of common housefly, *Musca domestica* from the opto-electronic sensor. All specimens were manually held in and out of the beam while flapping their wings.

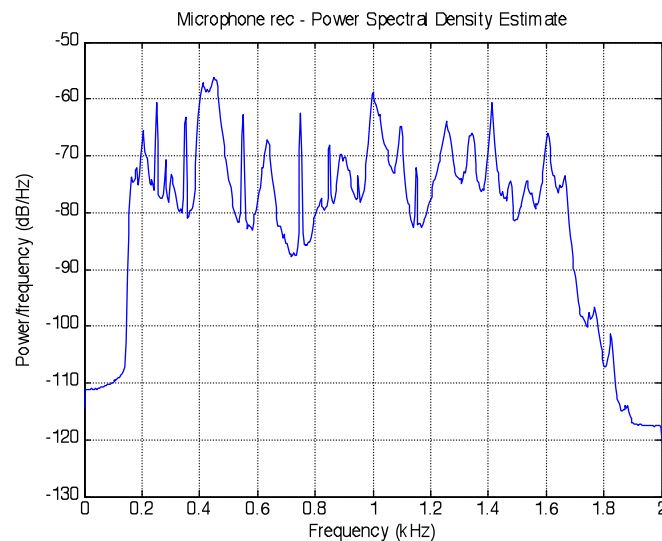
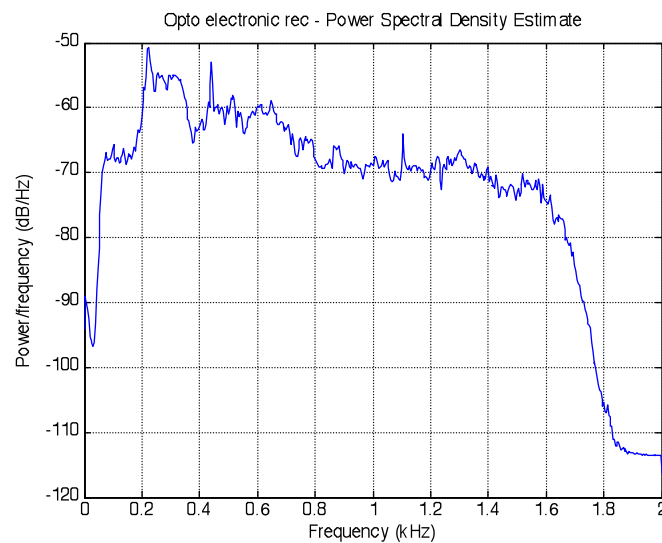


**Figure 7.** A series of in-flight recordings for *Musca domestica*. The flight time to cross the beam is estimated between 50-100 msec.

Figure 7 demonstrates the results of an almost real-field condition experiment we carried out in order to take in-flight recordings by placing a container with pests under the electronic McPhail.

One further experiment we carried out was to compare the recordings of the opto-electronic sensor with that of a common high-quality microphone. Therefore we enclosed in an insectary 20 house-flies and recorded their wing-beat with a typical microphone (Telinga twin-capsule Mono microphone and an Edirol Roland recorder set at sampling frequency of 44.1 kHz). The power spectral density of the recording was derived and compared with the power spectral density of the opto-electronic sensor to cross-check that the readings of the opto-electronic sensor find reasonable accordance with the microphone recordings. Although we took specific care to minimize acoustic interference from other sources we could not avoid that the microphone picked other sounds as well. Moreover, we noticed

reverberation due to acoustic reflections in the insectary. This experiment shown as the practical limits of using microphones in the real-field for such delicate applications. The important characteristic that we see in both subfigures of Fig. 8 are the frequencies at 220 and 440 Hz (the fundamental and first overtone) being clearly visible in both figures. The microphone seems to be able to capture better a larger number of overtones. Notice however that some energy leakage in certain frequencies are due to acoustic interferences and reverberation. In conclusion, we find that the two recordings are quite similar up to 1 kHz as visually inspection of the spectrogram and hearing of the audio provided both by the optoelectronic device and the microphone.



**Fig. 8.** Power spectral densities of recordings of house-flies. (Top) Recording from opto-electronic sensor. (Bottom): Recording taken with a high quality microphone placed inside an insectary hosting 20 house-flies.

Real-time pest monitoring can be fulfilled because the fundamental frequency and overtones of the wing beat are clearly resolved. Note that most insects beat their wings with frequencies between 100Hz up to <1 kHz (see [15] for a large collection of wing-beat frequencies). The highest wing beat ever reported for insect is for the asynchronous muscle system of *Forcipomyia* (*Diptera: Ceratopogonidae*) [16] attaining a wing beat frequency of 1046 Hz. Wing beats of this order are atypical for most insects that have a beat frequency lower than 300 Hz. The homo-structured phototransistors (i.e. ones using the same material throughout the device) can typically track frequencies up to 250 kHz but certain hetero-junction devices can reach 1 GHz. Clearly, the operating frequency of phototransistors is far higher than any biological organism can reach with its wings. Therefore, we conclude that optoelectronic devices cannot fail to respond in tracking the wing-beat of any insect.

#### 4. Conclusions

Detection and localization using optoelectronic sensors for agricultural tasks are becoming popular [17] and a valuable component of what is referred as precision agriculture. We constructed a prototype electronic insect trap that can count and record the wing-beat of the Olive fly. The optoelectronic sensor is capable of accurate sensing wing-beat characteristics of several insects as well. The following step is to embed a classification algorithm as in [18] in its electronics and a transmitting antenna using the Global system for Mobile communications (GSM) network. We will continue to evolve our prototype, as we did not waterproof it or optimize its power consumption, which is currently 43 mA. We believe that once optimized the electronic trap has the potential to revolutionize the way insect monitoring is carried out as it returns recordings of very high quality and it cost under 6 Euros (a price that is expected to significantly drop in case of wholesale orders). Once the insect recordings will be transmitted from the field to the pest manager using the GSM network the cost of maintaining a large number of dispersed traps will be reduced dramatically. The same sensor can be embedded in traps aiming at different insects such as mosquitoes (e.g. alerting for species that are possible carriers of the west Nile virus), bees and fruit flies. In the near future we will report on embedding the classification software on an electronic circuit and transmitting counts and recognition.

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### 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.

### References and Notes

1. [http://ec.europa.eu/agriculture/publi/fact/oliveoil/2003\\_en.pdf](http://ec.europa.eu/agriculture/publi/fact/oliveoil/2003_en.pdf) (d.l.v 20/8/2014)
2. Michelakis S. (1990). The olive fruit fly, *Dacus oleae* (Gmel.) in Crete, Greece. *Acta Horticulturae* 286:371-374
3. Economopoulos A. P. (2002). The olive fruit fly, *Bactrocera* (*Dacus*) *oleae* (Gmelin) (Diptera: Tephritidae): Its importance and control; previous SIT research and pilot testing. Report to International Atomic Energy Agency (IAEA), Vienna, Austria
4. Eliopoulos, P.A. (2007). Evaluation of commercial traps of various designs for capturing the olive fruit fly *Bactrocera oleae* (Diptera: Tephritidae). *International Journal of Pest Management*, 53(3): 245-252.
5. Richards I. (1955). Photoelectric cell observations of insects in flight. *Nature* 175:128-129.
6. B. Hedwig, A highly sensitive opto-electronic system for the measurement of movements (2000), *Journal of Neuroscience Methods*, Volume 100, Issues 1–2, 31, pp. 165-171, ISSN 0165-0270, [http://dx.doi.org/10.1016/S0165-0270\(00\)00255-7](http://dx.doi.org/10.1016/S0165-0270(00)00255-7)
7. Engel, Jeff E.; Wytttenbach, Robert A. (2001). An optoelectronic sensor for monitoring small movements in insects. *Florida Entomologist*. September; 843: 336-343.
8. Karl Gotz (1987). Course-control, metabolism and wing interference during ultralong tethered flight in *Drosophila Melanogaster*, *Journal of experimental Biology* 128, 35-46.

9. Moore, Aubrey, Ross H. Miller, (2002). Automated identification of optically sensed aphid (Homoptera: Aphidae) wingbeat waveforms. *Annals of the Entomological Society of America* 95(1): 1-8.
10. Mankin R., Machan R., and Jones R. (2006). Field Testing of a Prototype Acoustic Device for Detection of Mediterranean Fruit Flies Flying into a Trap, *Proceedings of the 7th International Symposium on Fruit Flies of Economic Importance, Salvador, Brazil*, pp. 165-169.
11. Gustavo Batista, Eamonn Keogh, Agenor Mafra Neto, Edgar Rowton (2011). SIGKDD Demo: Sensors and Software to Allow Computational Entomology, an Emerging Application of Data Mining, *The 17th ACM SIGKDD Conference on Knowledge Discovery and data mining, San Diego, August 21-24*.
12. Aubrey Moore, James R. Miller, Bruce E. Tabashnik, Stuart H. Gage (1986). Automated Identification of Flying Insects by Analysis of Wing-beat Frequencies, *Journal of Economic Entomology*, pp. 1703-1706.
13. Li, Zhenyu, Zhou, Zuji, Shen, Zuorui, Yao, Qing, (2005). Automated Identification of Mosquito (Diptera: Culicidae) Wingbeat Waveform by Artificial Neural Network, Springer US, pp. 483-489.
14. Passaro, V.M.N.; Tullio, C.D.; Troia, B.; Notte, M.L.; Giannoccaro, G.; Leonardis, F.D. Recent Advances in Integrated Photonic Sensors. *Sensors* 2012, 12, 15558-15598.
15. David N. Byrne (1988). Relationship between wing loading, wingbeat frequency and body mass in Homopterous insects. *Journal of experimental Biology*. 135, 9-23. The Company of Biologists Limited 1988
16. Scherer C.W. (1995). Chapter 9 Fastest Wing Beat. *University of Florida Book of Insect Records, Department of Entomology & Nematology, University of Florida, Gainesville, Florida* 32611-0620.
17. Garrido, M.; Perez-Ruiz, M.; Valero, C.; Gliever, C.J.; Hanson, B.D.; Slaughter, D.C. Active Optical Sensors for Tree Stem Detection and Classification in Nurseries. *Sensors* 2014, 14, 10783-10803.
18. Potamitis I. (2014). Classifying insects on the fly, *Ecological Informatics*, Volume 21, May, Pages 40-49, ISSN 1574-9541, <http://dx.doi.org/10.1016/j.ecoinf.2013.11.005>.