Remote sensing of flying insects by dark-field detection with telescopes and opto-electronics: The Lund University Mobile Biosphere Observatory

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Abstract

We present a method for automatically detecting flying insects and remotely acquire several of their parameters with the use of remote sensing and stand-off methods. We employ telescopes with a spectrometer, a high-speed camera and Si and InGaAs quadrant photodetetors, we demonstrate the measurement of the reflection spectrum, wingbeat frequency, size and movement direction of flying insects in a narrow volume. We employ a telescope battery towards a black cavity in order to minimize optical background. When insects fly through the field of view of the telescope, the sunlight scattered from the insect contains information that can be used to recognize and identify the insect and to obtain its behavioural characteristics. Such an equipment gives us the possibility to facilitate the better understanding of insect behaviour, and to evaluate different insect traps, for example. The Lund University Mobile Biosphere Observatory (LUMBO) was recently built and its first campaign was conducted in the summer of 2013, when one of the objectives was to study the selectivity of a liquid filled polarization tabanid trap developed in the Environmental Optics Laboratory of the Eotvos University. Here we present an overview of the telescope-based novel stand-off methods and some aspects of data evaluation of remotely optically sensed insects.

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Introduction

We present a method for automatically detecting flying insects and remotely acquire several of their parameters with the use of remote sensing and stand-off methods. We employ telescopes with a spectrometer, a high-speed camera and Si and InGaAs quadrant photodetetors, we demonstrate the measurement of the reflection spectrum, wingbeat frequency, size and movement direction of flying insects in a narrow volume. The Lund University Mobile Biosphere Observatory (LUMBO) was recently built and its first two campaigns was conducted in the summer of 2013.

Figure 1: LUMBO during measurement at Stensoffa.

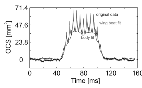
One of the several objectives of LUMBO was to study the selectivity of a polarization liquid tabanid trap which was recently invented and tested in Hungary [2]. Tabanids are vectors of various diseases and represent threat to ungulates, especially to cattle and horses. They are highly positively polarotactic insects, which means that they are attracted to strongly, horizontally polarized light. The measurement was performed at the Stensoffa Ecological Field Station in Sweden (Fig. 1). A large amount of data is created by the equipment on a single day representing a huge repository of information about the entomological aspects of the experiment site. Here we present an overview of the telescope-based novel stand-off methods and some aspects of data evaluation of remotely optically sensed insects.

Preliminary Evaluations

Each insect event in the quadrant data is similar to Fig 5A, the wing beat modulation is superimposed on the envelope of the body appearance. Subtracting the spectrum of a fitted Gaussian from the FFT of the event results in the spectrum caused by the wings. After estimating the fundamental frequency from the FFT spectrum, it can be refined precisely by fitting a sum of harmonics imposed on a body function:

$$OCS(t) = \beta(t) \sum_{h=0}^{h<f_s/2} \left[c_{1,h} \sin(2\pi f_0 ht) + c_{2,h} \cos(2\pi f_0 ht) \right]$$

Figure 6: Cross section time series of the body and wing beat component of the original signal.



Events were detected when OCS happened to be at least two times greater than noise level. Density of events per hour:
InGaAs (SWIR): 1049.9 $1/m^3h$
Si (NIR): 747.7 $1/m^3h$

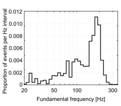


Figure 7: Histogram of the detected wing beat frequencies from the InGaAs quadrant (5461 of the 9449 fundamentals could be determined unambiguously).

According to trap data the tabanid/non-tabanid catch ratio of the 15 traps is:

$$\frac{N_{tabanid}}{N_{non-tabanid}} = \frac{127}{93} = 1.37$$

Question: What was this ratio in the FOV of LUMBO?

Methods

Experimental setup

We employ LUMBO's telescope battery towards a black cavity in order to minimize optical background. During dark-field measurements LUMBO must face north to ensure that the sun is located behind the equipment. When insects fly through the field of view of a telescope, the sunlight backscattered from the insect contains information that can be used to recognize and identify the insect and obtain its behavioural characteristics. Spectrometer give color information, the signals of the two quadrant photodiodes hold information e.g. about the wing beat frequency, the ratio of body and wing size, direction of flight, and finally the high-speed camera is useful when controlled insect releases are performed and the insect events need to be recognized in the data. Weather data was also collected during the measurements. 15 liquid filled polarization tabanid traps were placed just below the FOV and the data collection lasted 9 hours. One of our aims was to estimate the selectivity of the traps by comparing the diversity of the trapped and remotely detected insects.

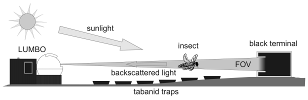


Figure 2: Experimental arrangement of LUMBO during data collection.

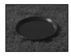


Figure 3: Photograph of the liquid filled tabanid trap.

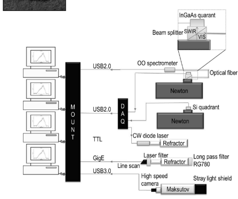


Figure 4: Experimental setup of LUMBO with the flow of information according to [1].

Telescopes	Skywatcher N 300/1200 Quattro
	Skywatcher AC 102/500 Startravel OTA
	Skywatcher Maksutov MC 102/1300 SkyMax OTA
Quadrant Photodiodes	InGaAs PIN photodiode 2.5 kHz (G6849) (SWIR: 900-1700 nm)
	Si PIN photodiode 2.9 kHz (S4349) (NIR: 190-1000 nm)
Cameras	Framos Lumenera LT225 CMOSIS Sensor (170 Hz)
	Spyder3 2k, GigE Line Scan DALSA Teledyne CCD
Laser	O-like diode laser 810 nm
Spectrometer	Ocean Optics spectrometer USB4000 (50 Hz)
Weather data	Digital Weather Station

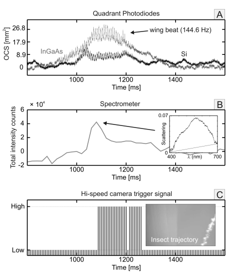


Figure 5: Calibration data of a *Hybomitra kaurii* tabanid fly.

Photo from: *www.boldsystems.org*

Calibrations

White polystyrene spheres (diameter = 12...25 mm) were dropped through the FOV so that the photodetector signals could be converted to optical cross sections (OCS) in mm^2: Since the black termination is never perfect, the photodetector signal must be corrected by subtracting the static signal, which can be estimated by a sliding median filter. Then the OCS can be calculated from the signal peaks corresponding to the polystyrene spheres.

Regarding spectrometer data, after background subtraction, division with the spectrum of the white spheres results in the pure spectral data of the scattering events (Inset of Fig 3B) [3].

Using a pendulum made of a white rod can be used to calibrate the orientation of the quadrants and the form factor of the telescopes.

Controlled releases

In order to obtain measurements of known insect species, controlled releases of various captured specimens were performed. An example for the OCS from the Si and InGaAs quadrants (Fig 5A), the total intensity measured by the spectrometer (Fig 5B) and the trigger events of the hi-speed camera (Fig 5C) as the function of the time is given in Figure 5 for a released tabanid fly (*Hybomitra kaurii*). As the released insect flies through the FOV, the intensity recorded by the photodetectors and the spectrometer increases and then decreases. Since the photodetectors were sampled at 20 kHz the wing beat modulation is clearly visible on the signal (Fig 5A). The sampling frequency of the spectrometer was 50 Hz. The high-speed camera was triggering only when motion was detected (Fig 5C).

Future Plans

Our goal is to discriminate between as many insect species as possible by improving the determination of the fundamental frequencies and combining the quadrant and spectrometer data.

We plan to create a library of data from known insect species released at LUMBO. We will further explore the possibility to study insect trap function and efficiency as well as insect biodiversity at night and daytime in different types of habitats.

Acknowledgements

Lund University Mobile Biosphere Observatory (LUMBO) is developed by scientists (M. Brydegaard et al.) Associated with two Linnaeus programs at Lund University, the Centre for Animal Movement Research (CAnMove) and Lund Laser Centre (LLC). LUMBO development costs was covered by a Linnaeus grant to CAnMove from the Swedish Research Council (349-2007.8690) and Lund University, an infrastructure grant from the Science faculty at Lund University, and project grants to S. Åkesson from Lund University and the Swedish Research Council (621-2010.5584). The field campaign was funded by grants to S. Åkesson from the Swedish Research Council (621-2010.5584) and Kungliga Fysiografiska Sällskapet in Lund. Our research was also supported by the grant OTKA K-105054 received from the Hungarian Science Foundation.

canmove.lu.se/research/tech/lumbo https://arago.elte.hu

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