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REMOTE SENSING AND REFLECTANCE PROFILING IN ENTOMOLOGICAL STUDIES

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Introduction

Remote sensing describes the characterization of the status of objects and/or the classification of their identity based on a combination of spectral features extracted from reflectance or transmission profiles of radiometric energy. The art and science of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object under investigation. This topic unveils how remote sensing influences entomological research by enabling scientists to non-destructively monitor how individual insects respond to treatments and ambient conditions. Furthermore, novel remote sensing technologies are creating intriguing interdisciplinary bridges between entomology and disciplines such as informatics and electrical engineering.

Background concepts

Reflectance profiles represent the radiometric energy reflected by an object in a series of spectral bands. If an image is acquired, then each pixel is associated with a reflectance profile. An acquired reflectance profile is always relative and determined by the combination of following factors;

(*a*) The radiometric energy source used to elicit a reflectance profile

(*b*) The spectral and spatial sensitivity of the sensor used to acquire the reflectance data

(*c*) Calibration and processing steps involved in the photogrammetric process

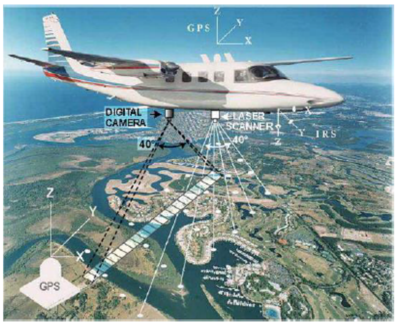
The fundamental objective in remote sensing is to differentiate objects on the basis of a combination of spectral features extracted from reflectance profiles, and this endeavour is based on two fundamental assumptions:

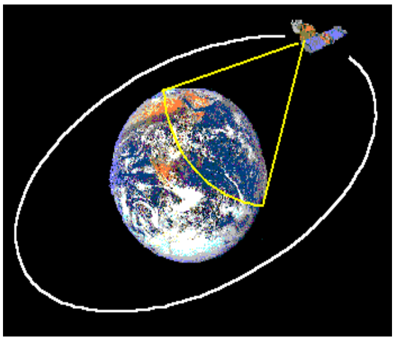
(*a*) It is possible to control for environmental heterogeneity (i.e., through calibration) so that spectrally repeatable reflectance profiles can be acquired from a given object over time and space

(*b*) A given object is associated with unique reflectance profile features, such that even very similar objects (such as insect specimens of the same species) can be distinguished from all other objects belonging to different categories (different species, or males and females, age classes, and difference in mating status) or individuals exposed to different experimental treatments.

Types of remote sensing

Field-based (ground based) Mounted on aircraft (airborne) Satellites (space borne)



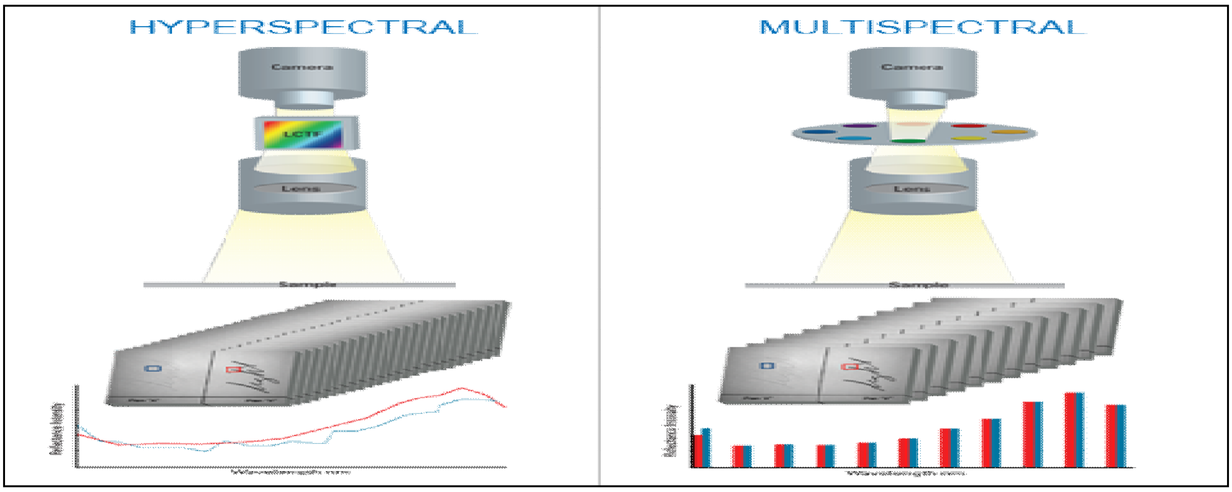


Spatial resolution of reflectance data

An important aspect of remote sensing is the size of the area from which reflectance profiles are acquired. This area is the same as the pixel size in an image, and it determines the spatial resolution. Spatial resolution of pixels markedly influences the ability of researchers to accurately classify both airborne and benchtop remote sensing.

Spectral resolution of reflectance data

Intuitively, spectral resolution (defined as the number spectral bands in the reflectance profile) is positively associated with the ability to differentiate objects, so that classifications based on hyperspectral imagery (hundreds of spectral bands) generally outperform those derived from multispectral imagery (3–12 spectral bands). However, there are comparative studies in which both multispectral and hyperspectral systems enabled investigators to accurately classify and detect biotic stressors in crops (Yang *et. al*., 2010).



Field-based remote sensing

An interesting body of research exists on the use of vertically projected radar systems under field conditions. In these applications of remote sensing, the radar beam's plane of polarization is rotated and three embedded signals are used to identify and quantify insect species (Chapman *et. al*., 2003): (*a*) maximum and minimum radar reflectivity, (*b*) estimates of body mass, and (*c*) wingbeat frequency. These applications of radar-based remote sensing have provided fascinating quantitative insight into the diurnal rhythms and long-term dynamics of migrating and dispersing insects across a wide range of orders. However, most field-based applications of remote sensing technologies concern detection and quantification of plant responses to arthropod herbivore or quantification of potential host plant distributions. In other words, features in reflectance data acquired from plants are used to indicate on the basis of plant species composition where insects may already be feeding (causing stress to plants) or where they may become established. The spatial mapping of emerging insect-induced stress can be used to predict when and where economic loss of crops (including forest trees) may take place.

In host plant responses to arthropods

A large body of research exists on the use of handheld spectrometers and ground-based multispectral and hyperspectral imaging technologies to detect and quantify arthropod induced stress in crops. Airborne platforms include satellites, manned aircraft, and unmanned aerial vehicles (UAVs) (also called unmanned aerial systems, UAS). Three remote sensing technologies mounted on airborne devices have received considerable attention. These are

(*a*) lidar (light detection and ranging)

(*b*) satellite imagery

(*c*) multispectral and hyperspectral systems.

Lidar measures the distance between the sensor and a surface target, and it has been used to characterize and estimate the three dimensional structure and biomass of crop plant canopies, respectively. It has been used to characterize defoliation by some insects like saw flies (*Neodiprion sertifer*) of Scots pine (*Pinus sylvestris*), but lidar data correlated only weakly with multispectral MODIS (moderate resolution imaging spectroradiometer) data (Eklundh *et. al.*, 2009). Satellite imagery is well suited to automated mapping over large geographic areas, such as monitoring insect defoliation in forests over multiple years and expansive areas.

Benchtop remote sensing

High spatial and spectral resolution remote sensing data acquired under controlled conditions (lighting, abiotics, projection angle, distance between objects and lens) are becoming increasingly important within a wide range of entomological research disciplines, such as systematics, toxicology, physiology, and behavior, but also new research disciplines such as photonics and phenomics. Photonics unveil the way to research and technology involving emission, control, and detection of light photons, so it relates to the hardware aspects of benchtop remote sensing. Phenomics refers to biological research into phenotypic responses by organisms and involves both detailed analyses of genetic and molecular data as well as in-depth characterization of physical traits and responses to environmental conditions. Benchtop remote sensing is highly relevant to detailed and quantitative characterizations of physical traits in organismal responses to environmental conditions.

Arthropod systematics

Insect identification is part of these quarantine and inspection efforts, and benchtop remote sensing technologies to reduce processing time and automate some aspects of inspection for invasive insect species are being developed. Different reflectance-based spectroscopy methods have enabled researchers to classify a ideal range of insects, including species of stored-grain insects, two species of fruit flies (*Drosophila melanogaster* and *D. simulans*), tobacco budworm (*Heliothis virescens*), and corn earworm (*Helicoverpa zea*), and imaging spectroscopy is used to discriminate cryptic species of ants (*Tetramorium caespitum* and *T. impurum*). It is also demonstrated that three species of minute juvenile egg parasitoids

(*Trichogramma* spp.) developing inside moth host eggs could be accurately classified on the basis of the reflectance profiles acquired from the host eggs. Using two types of radiometric energy sources (UV and white light). Analysis is done on the reflectance of 21 spider species and their corresponding webs revealed that the reflectance features of the species-specific webbing structures (stabilimenta) are likely associated with predator defences. Study also carried out that how reflectance profiling has been used in taxonomic studies of fossil insects.

Cryptic Insect Infestations

This approach has been used to detect damage and internal infestation in food products, including field peas (*Pisum sativum*), wheat kernels (*Triticum aestivum*), soy beans (*Glycine max*), and jujubes (*Ziziphus jujuba*).

Insect Physiology and Phenomics

Benchtop remote sensing enables nondestructive characterization of insects and quantifications of how individual organisms perform based on their genetic code and in response to environmental conditions (i.e., phenomics). Because phenotypic responses by insect individuals are often complex, development of image-based systems to detect and quantify phenotypic responses are important aspects of phenomics projects (Burleigh *et. al.*, 2013). Results from synchrotron X-ray imaging studies may increase our current knowledge about the function of air sacs, hemolymph transport, pulsatile organs, pharyngeal pumps, digestive systems, leg joints, and feeding mechanisms of biting and fluid feeding insects (Westneat *et. al*., 2008).

Insect Behavior

In order to know the mating and predator avoidance behaviour of *Morpho* butterfly wing coloration and reflectance is examined across the visible light spectrum. In salticid spiders, also the reflectance profiling has been widely used to describe mating behaviour.

Conclusion

Now days, remote sensing technologies explored in entomological field to detect and quantify insect densities and their distributions. Remote sensing is highly suitable for integration into modern university teaching, as students with a strong inclination toward computer technologies may find it attractive and relevant to their future careers. Thus, remote sensing may not only directly affect and improve current crop management practices, but also be a platform to increase the interests of companies and research institutions to develop commercial and innovative solutions for the agricultural sector. Challenges associated with spatial resolution and spectral repeatability of airborne remote sensing data are creating opportunities for intriguing collaborative research among scientists in the biological and agricultural sciences and fellow researchers in informatics and electrical engineering. Benchtop remote sensing complements a wide range of more established entomological disciplines, and a rapidly increasing number of studies exist in which reflectance profiling of arthropods is used to quantify differences among closely related species. A range of imaging systems, such as synchrotron X-ray imaging, have provided detailed insights into important aspects of physiological studies and have proven to be valuable to phenomics studies of insects. This will likely play a growing role in basic insect taxonomy and in the development of diagnostic monitoring of invasive species. Finally, as imaging technologies continue to evolve in the medical and military fields, which have access to large research budgets, there will undoubtedly be many basic and applied remote sensing spin-offs with important implications and prospects for entomological research. Despite important challenges, airborne remote sensing technologies will undoubtedly be of major importance in optimized management of agricultural systems in the twenty-first century.

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