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Original paper

Hyperspectral Remote Sensing and its application in Pest and Disease management in Agriculture

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Introduction

Agriculture faces multiple challenges in the 21st century, including the need to produce more food and fiber for a growing population with limited resources. Biotic factors like fungi, bacteria, viruses, nematodes, and insects can cause significant damage to crops, affecting productivity and yield. Traditional methods of assessment and management of these problems require significant manpower and expertise, making it time-consuming and inefficient. However, the use of modern tools and technologies such as remote sensing has proven to be a highly effective method of agricultural crop protection and management.Remote sensing technology can detect damage in agricultural crops quickly and accurately over a large area in a short period of time. Hyperspectral remote sensing is particularly useful in providing information about biophysical and biochemical characteristics of crops through the recording of narrow wave bands that reflect specific plant characteristics. While traditional broadband remote sensing only records broad wavelengths, which may cause a loss of critical information available in specific narrow bands, hyperspectral remote sensing can more accurately detect damage caused by stress, making it superior to conventional systems. Hyperspectral remote sensing has the capability to reflect narrow bands and provide accurate data of specific crop characteristics such as biochemical composition, physical structure, water content, and plant ecophysical status. By using remote sensing techniques, the incidence, severity, and expected load of inoculum of diseases can be forecasted, making it an important tool in plant disease management.The use of remote sensing technology can significantly improve the efficiency and sustainability of agricultural production. With the world population expected to grow by over a third between 2009 and 2050, it is necessary to manage the production of agricultural commodities more efficiently to feed the growing population with limited resources. The adoption of a multi-disciplinary approach involving plant pathology, engineering, and informatics is required to realize the full potential of these innovative technologies. A robust decision support system through transdisciplinary cooperation will improve the acceptance and full realization of these techniques.

What is remote sensing?

The term "**remote sensing**," was first used inthe United States in the 1950s by Ms.Evelyn Pruitt of the U.S. Office of NavalResearch. Remote means away from or at adistance and Sensing means detecting a propertyor characteristic. So "remote sensing" is defined as "theacquisition of informationabout an object, without being in physical contact with that object". It can also be defined as "the science and art of obtaininginformation about an object, area, or phenomenon through the analysis of data acquired by a device not in contact with the object, area, or phenomenon in question".The remotesensing technique may be ground, aerial or satellite based.Detection of electromagnetic energycan be achieved either in photographic or electronic form. The first is called a photograph, while the second is called an image. Most of the natural surfaces behave as diffuse reflectors, which associate remote sensing applications as a spectral behavior of living plant leaves.

The elements of the remote sensing process:

i) Energy Source or Illumination
ii) Radiation and the Atmosphere
iii) Interaction with the Target
iv) Recording of Energy by the Sensor

v) Transmission, Reception, and Processing
vi) Interpretation and Analysis
vii) Application

Active and passive remote sensing systems:

Sensors have been classified as active and passive systems with respect to energy source.
Active system: It represents the artificial energy that produces its own electromagnetic radiation such as microwaves, laser fluoro sensor, and radar
Passive system: It represents solar radiations, either absorbed, or reflected (visible wavelengths), or emitted (thermal infrared wavelengths) from the earth's materials.

Remote sensing techniques based on different sensors:

Based on sensors, the following two groups of remote sensing techniques are used in monitoring plant diseases:

1. Imaging approaches

a. RGB Camera
b. Multispectral imaging
c. Hyperspectral imaging
d. Thermal imaging
e. Fluorescence imaging

2. Non-imaging approaches

a. VIS and IR spectroscopy
b. Fluorescence spectroscopy

Remote sensing in pest & disease management in agriculture

Remote sensing technology has emerged as an efficient tool for managing pest attacks and crop stresses. One of the major benefits of using remote sensing is that it provides a detailed, accurate, and quick forecast of pest attacks and crop stresses, which can optimize pest control, reduce crop loss, and minimize the cost of cultivation. In addition to pest management, remote sensing can detect crop stresses such as nutrient or water deficiency, pest infestation, and disease development. Remote sensing techniques also provide an improvement in spatial and temporal resolution, making it an essential component of integrated pest management strategies.The application of remote sensing technology in agriculture has a long history, dating back to the early 1970s when the father of remote sensing in India, Prof. Pisharoty, used aerial photographs to detect coconut root-wilt disease in Kerala. Since then, many researchers have used remote sensing to detect and forecast plant diseases, including Fernandes *et al* (2011), who used a web-based approach for forecasting plant diseases. The application of knowledge representation, extraction, fusion, and reasoning has been used in the approach to improve its accuracy. To identify the pathogen infections at the asymptomatic stage, biophotonic sensors and remote sensing technologies were used. Late blight disease and early blight disease of the vegetation were detected using in-situ spectroscopy of potato by LGold *et al*. (2020) and tomato leaves by Xie *et al*. (2015) respectively.In addition to disease detection; remote sensing has also been integrated with other GPS and GIS technologies for detecting and mapping insect infestations. Robertson *et al*. (2008) used aerial videography integrated with GPS and GIS to develop regional mapping for insect infestations over a large agricultural and forest area. Remote sensing sensors are also used for pest scouting, monitoring migration swarms, detecting infestation levels, predicting outbreaks, and managing insect pests that invade different fruit orchards and crops, as demonstrated by Abdullah and Umer (2004), Oumar and Mutanga (2011), Yang and Everitt (2011), Yan *et al*. (2017), and Fernando *et al*(2018).Overall, remote sensing technology has become an essential tool for managing pest attacks and crop stresses, providing quick and accurate forecasts that can optimize pest control, reduce crop loss, and minimize the cost of cultivation. Its integration with other GPS and GIS technologies has further enhanced its capabilities, making it an important component of integrated pest management strategies in the 21st century.

Hyperspectral remote sensing:

Hyperspectral data collected over narrow spectral bands pose significant challenges in data handling and analysis due to the high dimensionality and inter-band correlation. Optimal band selection is crucial to capture most of the information of crop characteristics while avoiding redundancy. Hyperspectral spectra are generally noisier than laboratory conditions, and optimal bandwidth selection needs to be followed to preserve absorption features and keep local minima or maxima intact. A bandwidth of 5-10 nm is suggested for capturing optimal information on a particular feature, while a nominal bandwidth of 5-10 nm is recommended for all wavebands. The optimal bandwidths for crop stress studies are suggested to be 5-10 nm in red edge and early NIR regions and 25 nm in 500-700 and 800-900 nm regions. Multi and hyperspectral imaging are often captured by expensive and bulky sensors, whereas conventional cameras are ubiquitous. This has led to the development of systems based on the visible range for plant disease detection. More information on this topic can be found in Sankaran *et al.*'s 2010 study. Mica-Sense Red-Edge sensor includes five independent high precision sensors to capture the vegetation response at five spectral bands (SB): blue, green, red, red-edge and near-infrared are acquired in UAV images.

Application of Hyperspectral remote sensing against plant biotic stress:

Responses of plats to biotic and abiotic stresses are difficult to quantify visually, but can affect the reflectance spectrum of plants. Hyperspectral remote sensing has been found to identify different stresses objectively and non-destructively. Developing and differentiating spectral signatures due to common stresses can facilitate quick detection in satellite imagery, aiding in pest and disease management in important agricultural crops. Hyperspectral remote sensing has been used for pest and disease monitoring in various crops, including citrus, cotton, barley, wheat, etc.Plants respond to sunlight in three ways: reflection, absorption, or transmission, depending on the wavelength of the energy and the characteristics of the plant. Hyperspectral Remote sensing can detect the energy that is reflected, transmitted, or absorbed by plants, allowing for differences in leaf colors, textures, shapes, and attachment to be determined. Healthy plants generally exhibit higher reflection in the near-infrared region, while infected plants show at least one reduction in the visible region. Plant stress typically leads to an increase in visible reflectance due to a decrease in chlorophyll levels and reduced absorption of visible light. Infrared imaging is used by Colwell (1956)to detect the disease-related changes in the cereal crops. These mechanisms were subsequently used for a broad spectrum of different crop diseases such as potato blight (Brenchley 1968), bacterial blight of beans (Jackson and Wallen 1975), cotton root rot (Toler *et al*. 1981), and sheath blight on rice (Qin *et al*. 2003). Yellow rust disease detection and quantification in wheat crop was also evaluated using the hyperspectral technology (Kuska and Mahlein 2018). Hyperspectral camera is based on two measurement platforms:
(1) ground-based vehicle and (2) anunmanned aerial vehicle (UAV)
Spectral sensors measure the light reflected during a pathogen attack and disease developing on the crop leaf. These shifts of the signature from the crop canopy can be detected using spectral sensors, particularly in the electro-magnetic spectrum from 400–2500 nm.Several studies have demonstrated the potential of spectral reflectance and indices for detecting and assessing insect infestations in crops. Prabhakar *et al*. developed two novel indices for detecting leaf hopper severity in cotton, while Kumar *et al*. found significant differences in NIR reflectance between healthy and aphid-infested mustard crops and identified several spectral indices with significant correlations to aphid infestation. Prasanna kumar *et al*. identified four sensitive wavelengths related to brown plant hopper stress on rice plants and developed three new spectral indices to assess BPH damage. These findings could provide stakeholders with prompt forewarning of insect infestations and facilitate more effective crop management.

Conclusion

The advancement of remote sensing technology has provided numerous applications in agricultural approaches, particularly in pests and plant disease management. With the aid of information technology, interpretation, and data analysis, high-tech applications can support the growth of input knowledge and development of different research fields. High-resolution hyperspectral data from low altitude flights can be used to detect diseases in green vegetation. Multi-temporal remote sensing data have potential for crop disease mapping at regional scale. Spectra-based classification approach is an applicable method for crop disease identification, helping to spatialize diagnostic results, and reduce the use of pesticides. Remote sensing has become a promising technology for integrated pest management by investigating various environmental parameters and available natural resources as a complete system. However, there is a need for further development in designing and operating remote sensing systems to reduce costs and improve output imaging quality.

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