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Hyperspectral Remote Sensing Applications in Agriculture

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Abstract

Remote sensing satellites offer diverse data across the panchromatic, multispectral, and hyperspectral optical ranges, each with distinct capabilities. Hyperspectral sensors, in particular, capture over 100 contiguous spectral bands within a narrow 5–10 nm bandwidth, spanning wavelengths from 500 to 2500 nm. This high spectral resolution provides detailed information for accurate material identification, making hyperspectral imaging a powerful tool for mapping land resources. Unlike multispectral datasets, which cover fewer bands and have broader bandwidths, hyperspectral imaging can distinguish between similar spectral features, allowing for more precise analysis. This advanced imaging approach combines modern imaging systems with traditional spectroscopy, facilitating detailed assessments of soil, vegetation, and water quality. However, due to limited access beyond the scientific community and high costs, hyperspectral imaging has yet to see widespread adoption in fields like precision agriculture, where it could significantly enhance crop monitoring, disease detection, and resource management.

1. Introduction

The global agricultural sector faces numerous challenges posed by factors such as population growth, dwindling natural resources, environmental degradation, crop diseases, and the effects of climate change. To address these pressing issues, precision agriculture has emerged as an innovative approach, optimizing farming practices by precisely managing inputs like water, fertilizers, and pesticides. This targeted approach enables optimal crop growth and biomass production while reducing environmental impacts, making it a promising solution for sustainable food production and resource conservation. Remote sensing has become a key tool in precision agriculture, providing the ability to monitor and assess spatial variability within agricultural fields. By detecting changes in soil moisture, nutrient levels, and crop health, remote sensing technology allows for more accurate and timely decisions regarding site-specific management practices, such as variable rate applications of fertilizers or targeted irrigation. The data collected through remote sensing not only enhances crop management

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but also helps minimize resource wastage and mitigate environmental impacts (Liu et al., 2005). Remote sensing technology can be broadly classified into active and passive types, with passive optical remote sensing typically categorized into multispectral and hyperspectral imaging based on the spectral resolution of the sensors (Jensen, 2006). Multispectral imaging captures spectral signals across a few discrete bands, each covering a broad spectral range from tens to hundreds of nanometers. This technology has been widely used in agriculture for decades, enabling basic crop classification and health monitoring. However, multispectral data often lacks the fine spectral detail needed to differentiate between similar materials or identify subtle biochemical changes in crops. Hyperspectral imaging, on the other hand, captures spectral data across hundreds of narrow, contiguous bands, with each band usually less than 10 nanometers wide. This high spectral resolution enables hyperspectral sensors to detect fine-scale spectral features that may otherwise be lost in broader-band multispectral data. For instance, hyperspectral imaging can identify specific plant stress indicators, distinguish between crop species, and assess detailed biochemical properties like chlorophyll, water content, and nutrient deficiencies. The ability of hyperspectral imaging to capture subtle variations in spectral reflectance allows for a deeper understanding of plant health, stress conditions, and soil properties.

Despite its potential, hyperspectral imaging has not yet been widely adopted in precision agriculture due to challenges in accessibility, high costs, and the complexity of data analysis. The technology remains primarily within scientific research, though there is increasing interest in expanding its use to improve agricultural productivity and sustainability. As hyperspectral data becomes more accessible, it is expected to play a transformative role in precision agriculture, empowering farmers with accurate, real-time data to enhance crop management practices and address the global challenges facing agriculture today.

2. Hyperspectral Sensors and Image Processing

Hyperspectral sensors, often referred to as imaging spectrometers, represent a significant advancement in spectral imaging technology, surpassing the capabilities of multispectral imaging radiometers. Common spaceborne multispectral radiometers, such as LANDSAT, SPOT, IKONOS, and WorldView, capture data across a limited number of broad spectral bands. In contrast, hyperspectral sensors collect data across hundreds of narrow, contiguous spectral bands, providing an exceptionally detailed spectral profile for each observed location on Earth. This process, known as spectral imaging, involves capturing multiple images across different wavelengths, enabling precise and comprehensive data collection.

In hyperspectral imaging, each geographical location, or pixel, in an image contains a continuous spectrum of information across a wide range of wavelengths. The spectral reflectance for each pixel, defined as the amount of optical energy received by the sensor after being reflected from the Earth's surface, is a crucial component of this data. This reflectance value results from the interaction between sunlight and the surface materials, providing valuable insights into the Earth's spatial and spectral characteristics. As sunlight strikes various objects on the Earth's surface, it reflects in unique ways based on the material composition, structure, and other properties of those objects. The resulting reflected spectrum, or spectral signature, varies with wavelength and captures this detailed information.

The primary value of hyperspectral sensing lies in its ability to extract detailed information from these spectral signatures, which are essentially unique fingerprints for different materials. Each material on the Earth's surface, whether it's soil, vegetation, water, or man-made objects, has a distinct spectral signature that changes with wavelength. By analyzing these variations, hyperspectral imaging can identify specific materials and discern a wide array of physical and chemical properties, even among visually similar objects. For instance, hyperspectral imaging can distinguish between different plant species, detect crop health variations, assess soil composition, and even identify minerals based on their spectral characteristics.

Thus, hyperspectral sensors enable a deeper understanding of the Earth's surface by capturing high-resolution spectral data, which can be leveraged for numerous applications, including environmental monitoring, mineral exploration, agriculture, and urban planning. The ability to identify and analyze objects based on their unique spectral signatures makes hyperspectral imaging a powerful tool for scientific and practical applications in fields that require detailed material discrimination and analysis.

3. Multispectral Vs Hyperspectral

Table 1: Difference between Multispectral Vs Hyperspectral

Multispectral	Hyperspectral
Seperated spectral bands	No spectral gaps
Non-continuous coverage leaves gaps in spectral information between bands.	Contiguous bands, providing a continuous spectrum for each pixel
Broad band RS: Wider Band Width (100 nm)	Narrow band RS: Narrow Band Width (10-20 nm)
Coarser representation of spectral signatures	Complete representation of spectral signatures
Multispectral instruments can discriminate materials	Hyperspectral imaging is required to actually identify the material
Multispectral data are used to detect the existence of various materials but struggles to differentiate when materials are mixed or spectrally similar. For instance, multispectral data can indicate vegetation but may not distinguish between different plant species.	Hyperspectral data allows the identification of many materials even in mixed materials. Its continuous spectral data can separate overlapping spectral signatures, making it possible to identify materials within a mixed pixel, such as distinguishing different types of minerals or detecting disease in crops amidst healthy vegetation.

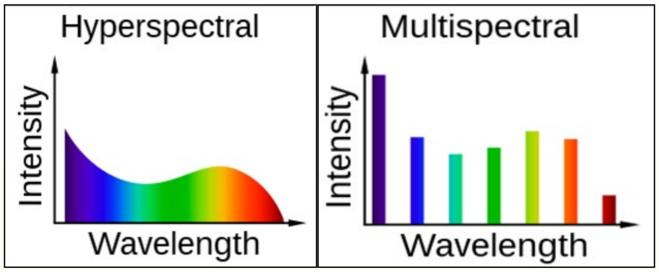

Figure 1: Multispectral Vs Hyperspectral

4. Hyperspectral Imaging Platforms and Sensors

Hyperspectral sensors can be installed on various platforms, including satellites, airplanes, UAVs, and close-range systems, to capture images with varying spatial and temporal resolutions.

4.1. Satellite based hypsespectral imaging

Satellite-based hyperspectral imaging is less common than multispectral imaging due to the limited number of hyperspectral sensors available compared to numerous multispectral options like Landsat, SPOT, WorldView, QuickBird, and Sentinel-2. While multispectral sensors capture data across a few discrete bands, hyperspectral sensors collect information across hundreds of contiguous spectral bands, providing more detailed spectral information. Examples of satellite-based hyperspectral sensors include the EO-1 Hyperion, which offers a broad spectral range, the PROBA-CHRIS, designed for high-resolution imaging, the Hyperspectral Imaging Sensor (HySI), PRISMA, and TianGong-1, each contributing to enhanced monitoring of Earth's surface and resources.

4.2. Airplane-based hyperspectral imaging

Airborne hyperspectral imaging has become a vital tool for collecting hyperspectral data for various monitoring applications, including agriculture, forestry, and environmental assessments. The first hyperspectral sensor, the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), paved the way for this technology by demonstrating its capabilities in capturing detailed spectral information. Besides AVIRIS, several other airborne hyperspectral sensors are widely used, such as the Compact Airborne Spectrographic Imager (CASI), known for its versatility and high spatial resolution, the Hyperspectral Mapper (HyMap), which is effective for geological and agricultural studies, and the AISA Eagle, which offers a wide spectral range for comprehensive data analysis in various applications. These sensors enable researchers and practitioners to monitor and analyze the Earth's surface with unprecedented detail and accuracy.

4.3. UAV-based hyperspectral imaging

UAVs (Unmanned Aerial Vehicles) have gained significant popularity as platforms for remote sensing data acquisition, particularly for multispectral imaging using digital cameras and sensors. With the advent of lightweight hyperspectral sensors, researchers have begun to mount these devices on UAVs to capture high-spatial-resolution hyperspectral imagery (Sun et al., 2017). Various types of UAVs, including multi-rotors, helicopters, and fixed-wing models, have been utilized in studies to enhance data collection flexibility. Compared to manned airplanes and helicopters, UAVs offer the advantage of capturing high-resolution images at significantly lower costs and with greater scheduling flexibility, making them an attractive option for agricultural monitoring, environmental assessments, and resource management.

4.4. Close-range hyperspectral imaging

Close-range hyperspectral imaging, conducted either on the ground or in laboratory settings, has emerged as a cutting-edge technology that allows for capturing hyperspectral imagery with exceptional spatial resolution. This technique achieves levels of detail down to centimeters or even sub-centimeter scales (Malmir et al., 2019). The high-resolution capabilities of close-range hyperspectral imaging make it particularly valuable for applications such as precision agriculture, where monitoring plant health and detecting diseases at a fine scale is crucial. It is also used in materials science, art conservation, and forensic investigations, providing detailed spectral information that enhances the analysis of various materials and surfaces.

5. List of Some Hyperspectral Sensors

Sensor	Platform	Spectral range (nm)	No. of spectral bands	Spectral resolution (nm)	Spatial resolution (m)	Country/Agency
AVIRIS	Aircraft	400-2500	224	10	20	NASA (USA)
Hyperion	EO-1 Satellite	357-2576	220	10	30	NASA (USA)
HyMap	Aircraft	400-2500	128	15	3-10	Integrated Spectronics (Australia)
PRISMA	Satellite	400-2500	239	12	30	ASI (Italy)
HysIS	Satellite	400-2500	256	10	30	ISRO (India)
PROBA-CHRIS	Satellite	415-1050	220	10	30	ESA, UK

6. Hyperspectral Applicationsremote Sensing Applications in Agriculture

1. Estimation of crop biochemical and Biophysical Properties

2. Evaluating Crop Nutrient Status

3. Classifying Imagery to Identify Crop Types, Growing Stages, Weeds/Invasive Species, and Stress/Disease

4. Retrieving Soil Moisture, Fertility, and Other Physical or Chemical Properties

7. Limitations of Hyper Spectral Data

1. Very sensitive to noise

Source of noise: i) Sensor calibration, ii) Sensor drift which results in change of sensor activity over time, iii) Irradiance variation, iv) Atmospheric attenuation

2. Difficult to interpret the spectral signatures of an impure pixel necessitates specialized training

3. The need for calibaration

4. Limited Spatial Resolution depending on the platform used

5. Sensitivity to Soil and Background Variability

6. Need for Ground Truthing

7. Acquisition and operational costs of hyperspectral sensors

8. Requires significant data storage

8. Conclusion

Hyperspectral imaging shows great potential for precision agriculture by providing detailed spectral data on plant and soil properties. Various platforms - satellites, airplanes, UAVs, and close-range systems - are available for collecting hyperspectral images with different spatial, temporal, and spectral resolutions. Each platform has unique advantages and limitations in terms of coverage, flexibility, complexity, and cost. Choosing the right platform depends on specific research needs. Advancements are needed to tackle issues like UAV battery life and high cost of hyperspectral sensors.

9. References

Jensen, J.R., 2006. Remote sensing of the environment: an earth resource perspective; Prentice Hall: Upper Saddle River, NJ, US.

Liu, J., Miller, J.R., Haboudane, D., Pattey, E., Nolin, M.C., 2005. Variability of seasonal CASI image data products and potential application for management zone delineation for precision agriculture. Canadian Journal of Remote Sensing 31(5), 400–411.

Sun, J., Yang, J., Shi, S., Chen, B., Du, L., Gong, W., Song, S., 2017. Estimating rice leaf nitrogen concentration: influence of regression algorithms based on passive and active leaf reflectance. Remote Sensing 9(9), 951.

Malmir, M., Tahmasbian, I., Xu, Z., Farrar, M.B., Bai, S.H., 2019. Prediction of soil macro-and micro-elements in sieved and ground air-dried soils using laboratory-based hyperspectral imaging technique. Geoderma 34, 70–80.