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Principal Investigator	Co-Principal Investigator	Co-Principal Investigator
Prof. Talat Ahmad ***Vice-Chancellor*** Jamia Millia Islamia Delhi	**Prof. Devesh K Sinha** Department of Geology University of Delhi Delhi	**Prof. P. P. Chakraborty** Department of Geology University of Delhi Delhi
Paper Coordinator	**Content Writer**	**Reviewer**
Dr. Atiqur Rahman Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia Delhi	**Dr. Atiqur Rahman** Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia Delhi	**Dr. A R Siddiqui** Department of Geography Allahabad University U.P

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1. Introduction

The term ‘hyperspectral’ is derived from two words; ‘hyper’ and ‘spectral’. ‘Hyper’ means ‘too many’ and ‘hyperspectral’ is used to refer to spectra consisting of large number of narrow, contiguously spaced spectral bands. The ‘hyperspectral remote sensing’ is developed in mid-80’s and considered to be the most significant recent break-through. Since then it has been widely used in the detection and identification of minerals, vegetation, artificial materials and soil background.

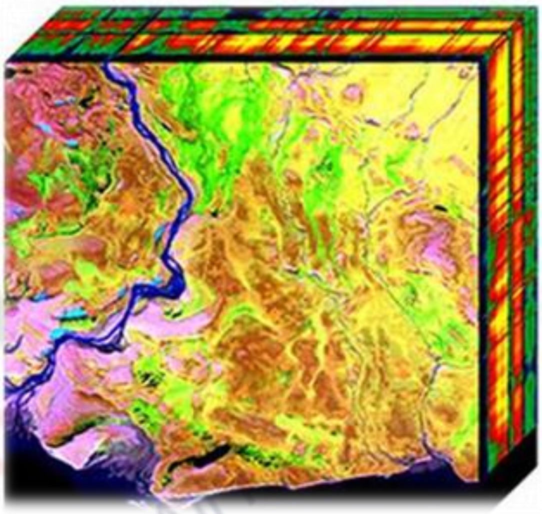

Two dimensional projection of a hyperspectral cube

FIG. 1

Hyperspectral remote sensing is technologically more developed than multispectral remote sensing and its sensors have the ability to acquire images in many narrow spectral bands that are found in the electromagnetic spectrum from visible, near infrared, medium infrared to thermal infrared.

Hyperspectral sensors capture energy in 200 bands or more which means that they continuously cover the reflecting spectrum for each pixel in the scene. Bands characteristic for these types of sensors are continuous and narrow (10-20 nm), allowing an in depth examination of features and details on Earth (Fig. 1).

Hyperspectral sensors are working in hundreds of bands, but not the number of bands defines the sensor as being hyperspectral. The criteria underlying the classification of sensors as hyperspectral are bandwidth and the continuous nature of the records. For example, a sensor that only works in 20 bands may be considered hyperspectral if all these bands are adjacent and with a 10 nm width (Fig.2).

Hyperspectral images provide ample spectral information to identify and distinguish spectrally unique materials through extracting the information upto sub-pixel scale. In this way hyperspectral, imagery provides the potential for more accurate and detailed information extraction than possible with any other type of remotely sensed data.

Hyperspectral records are based on spectroscopy in the range of 0.40.....2.50 µm where hyperspectral sensors are working. Field and laboratory spectrometers usually measure reflectance at many narrow, closely spaced wavelength bands, so that the resulting spectra appear to be continuous curves. When a spectrometer is used in an imaging sensor, the resulting images record a reflectance spectrum for each pixel in the image. The identification of a target material is determined by comparison of its spectral reflectance curve with 'library spectra' of known materials measured in the field or in the laboratory.

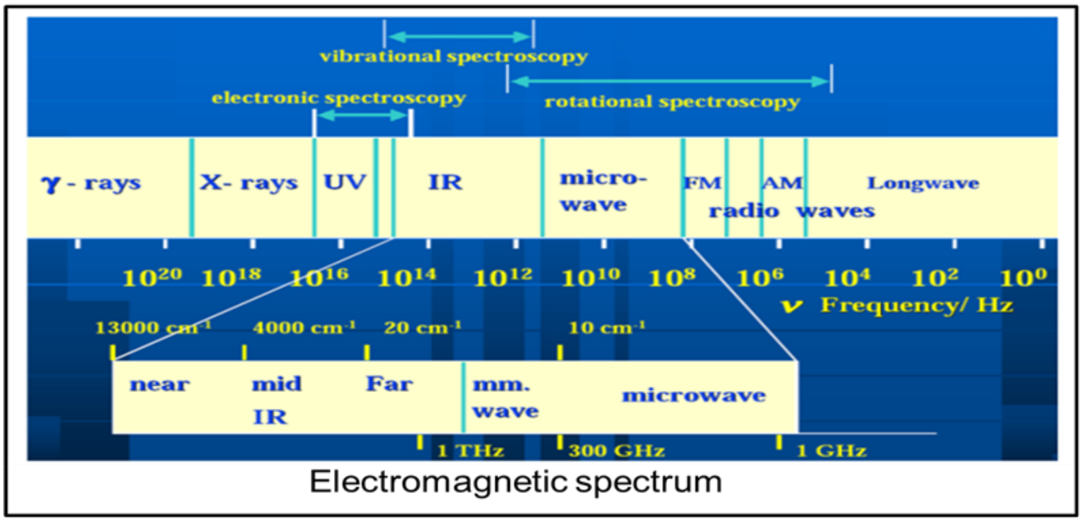
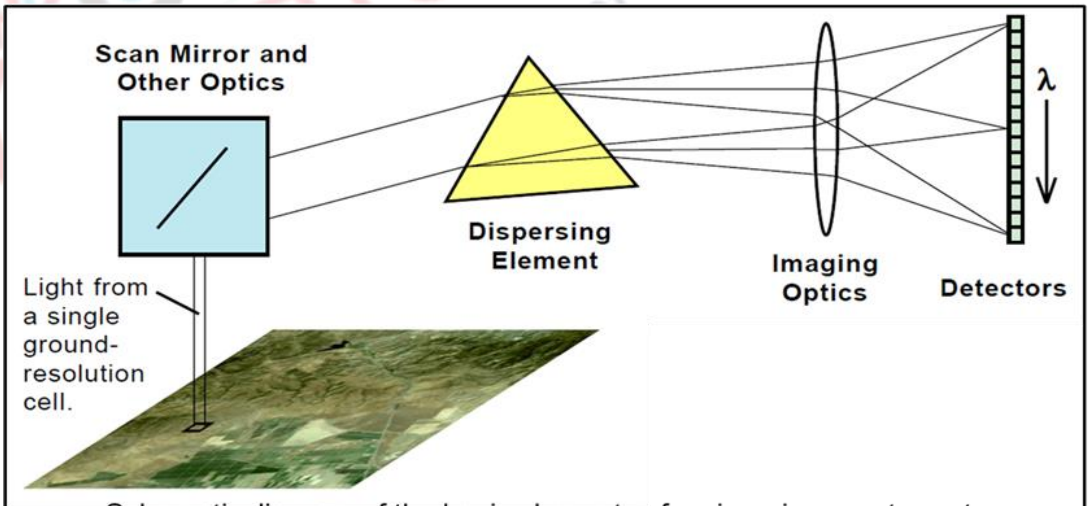


FIG. 2

2. The Imaging Spectrometer

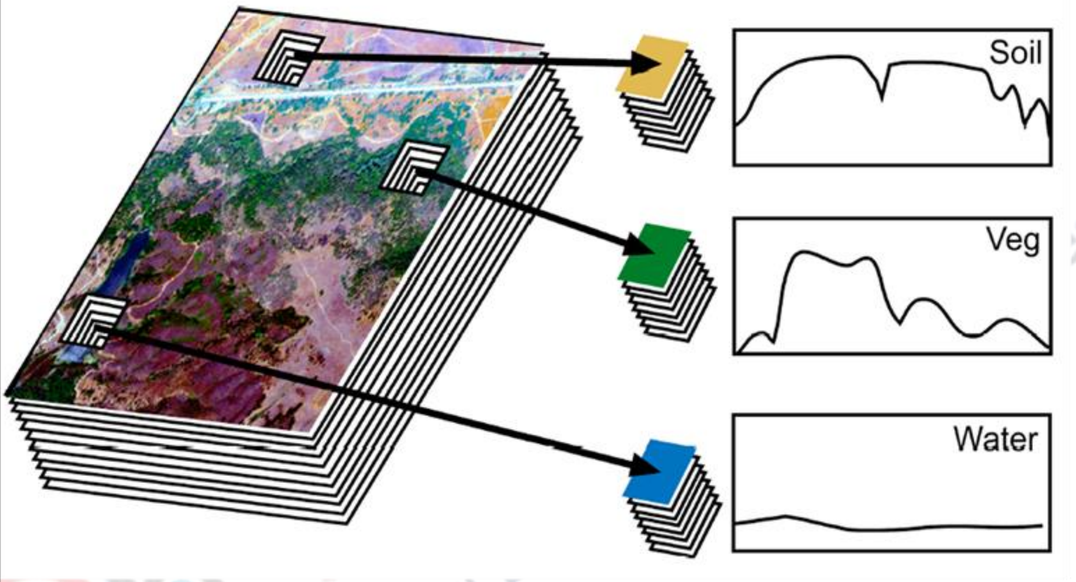
Hyperspectral images are produced by instruments called *imaging spectrometers*. The development of these complex sensors has involved the convergence of two related but distinct technologies: *spectroscopy* and the *remote imaging* of Earth and planetary surfaces. Spectroscopy is the study of light that is emitted by or reflected from materials and its variation in energy with wavelength. Spectroscopy deals with the spectrum of sunlight that is diffusely reflected (scattered) by materials at the Earth's surface. Instruments called spectrometers (or spectro radiometers) are used to make ground-based or laboratory measurements of the light reflected from a test material. An optical dispersing element such as a grating or prism in the spectrometer splits this light into many narrow, adjacent wavelength bands and the energy in each band is measured by a separate detector. By using hundreds or even thousands of detectors, spectrometers can make spectral measurements of bands as narrow as 0.01 micrometers over a wide wavelength range, typically at least 0.4 to 2.4 micrometers (visible through middle infrared wavelength ranges) (Fig. 3).



Schematic diagram of the basic elements of an imaging spectrometer.

FIG. 3

Remote imagers are designed to focus and measure the light reflected from many adjacent areas on the Earth's surface. In many digital images, sequential measurements of small areas are made in a consistent geometric pattern as the sensor platform moves and subsequent processing is required to assemble them into an image. Until recently, imagers were restricted to one or a few relatively broad wavelength bands by limitations of detector designs and the requirements of data storage, transmission, and processing. Recent advances in these areas have allowed the design of imagers that have spectral ranges and resolutions comparable to ground-based spectrometers.

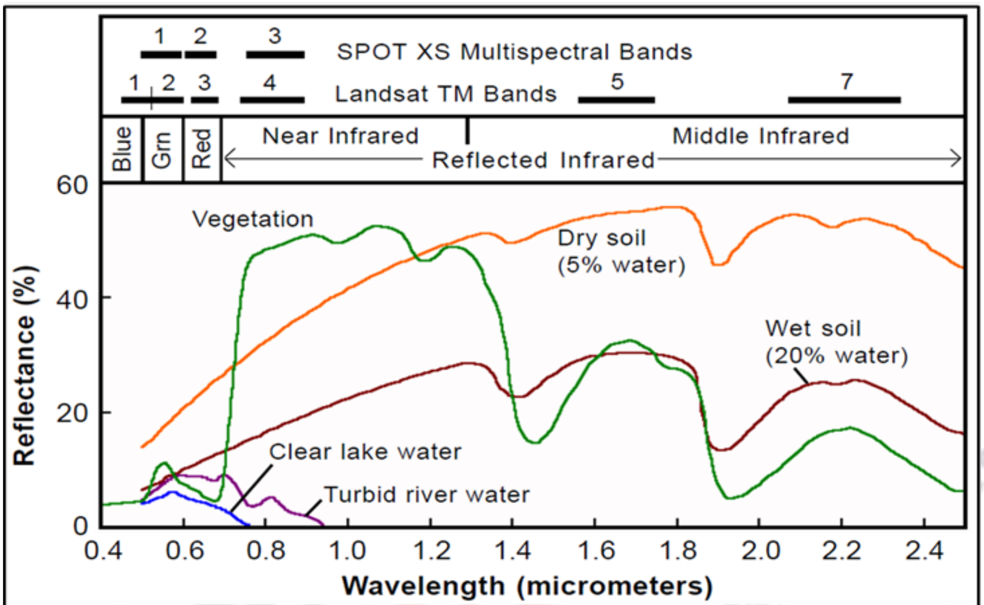


The concept of hyperspectral imagery

FIG. 4

2.1 Spectral Reflectance: In reflected-light spectroscopy, the fundamental property that we want to obtain is *spectral reflectance* that is the ratio of reflected energy to incident energy as a function of wavelength. Reflectance varies with wavelength for most materials because energy at certain wavelengths is scattered or absorbed to different degrees. A reflectance curve can be prepared by plotting of reflectance and wavelength on *x* and *y*-axis (Fig. 5).

The overall shape of a spectral curve and the position and strength of absorption bands in many cases can be used to identify and discriminate different materials. For example, vegetation has higher reflectance in the near infrared range and lower reflectance of red light than soils.

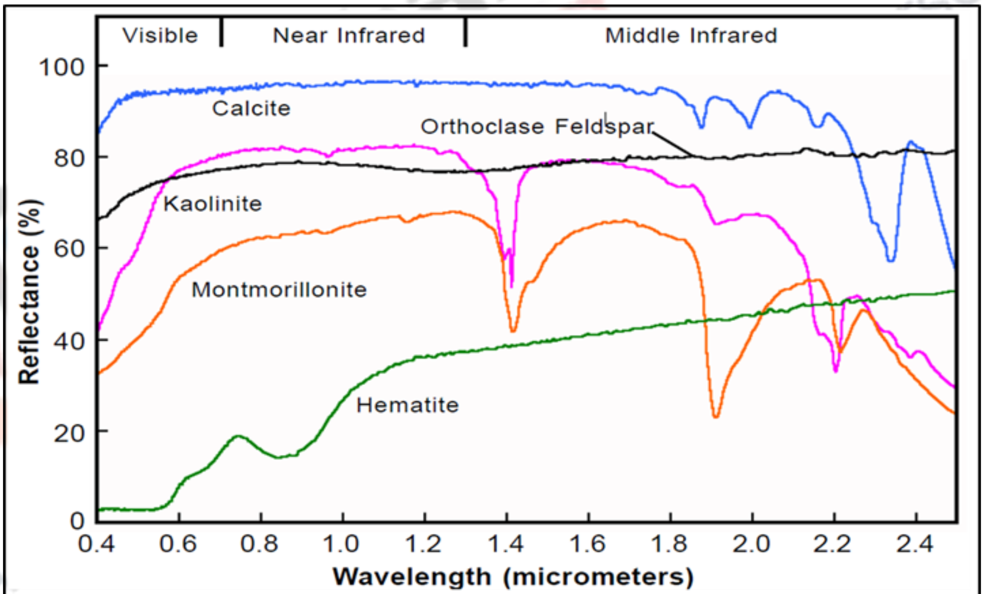


Representative spectral reflectance curves for several common Earth surface materials over the visible light to reflected infrared spectral range.

FIG. 5

2.2 Mineral Spectra: Every material is formed by chemical bonds, and has the potential for detection with spectroscopy. Spectroscopy can be used to detect individual absorption features due to specific chemical bonds in a solid, liquid, or gas. Solids can be either crystalline (*i.e.* minerals) or amorphous (like glasses). In inorganic materials such as minerals, chemical composition and crystalline structure control the shape of the spectral curve and the presence and positions of specific absorption bands. Wavelength-specific absorption may be caused by the presence of particular chemical elements or ions, the ionic charge of certain elements, and the geometry of chemical bonds between elements, which is governed in part by the crystal structure (Fig. 6).

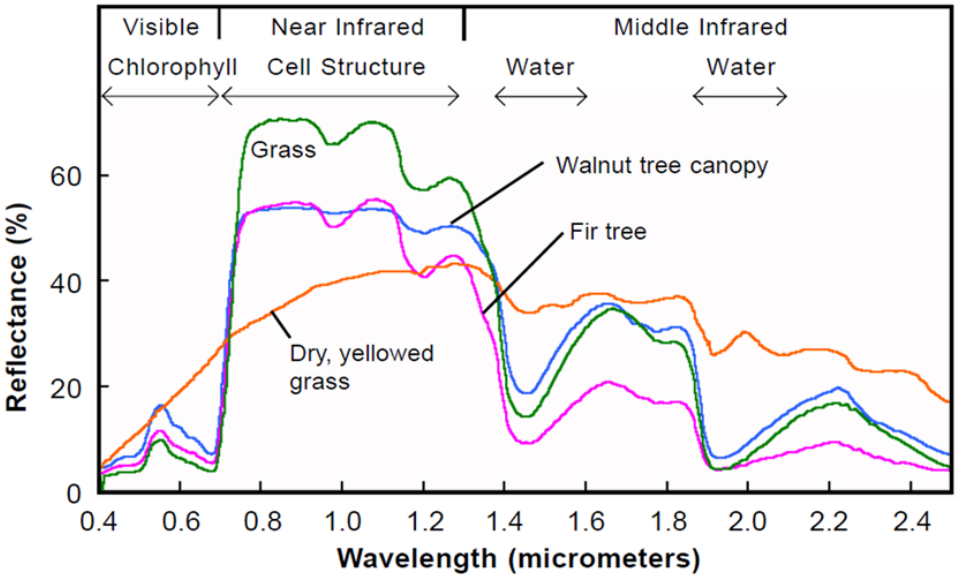
The illustration below shows spectra of some common minerals that provides examples of these effects. In the spectrum of hematite (an ironoxide mineral), the strong absorption in the visible light range is caused by ferric iron (Fe^{+3}). In calcite, the major component of limestone, the carbonate ion (CO_3^{-2}) is responsible for the series of absorption bands between 1.8 and 2.4 micrometers (µm). Kaolinite and montmorillonite are clay minerals that are common in soils. The strong absorption band near 1.4 µm in both spectra, along with the weak 1.9 µm band in kaolinite, are due to hydroxide ions (OH^{-1}), while the stronger 1.9 µm band in montmorillonite is caused by bound water molecules in this hydrous clay. In contrast to these examples, orthoclase feldspar, a dominant mineral in granite, shows almost no significant absorption features in the visible to middle infrared spectral range.



Reflectance spectra of some representative minerals

FIG. 6

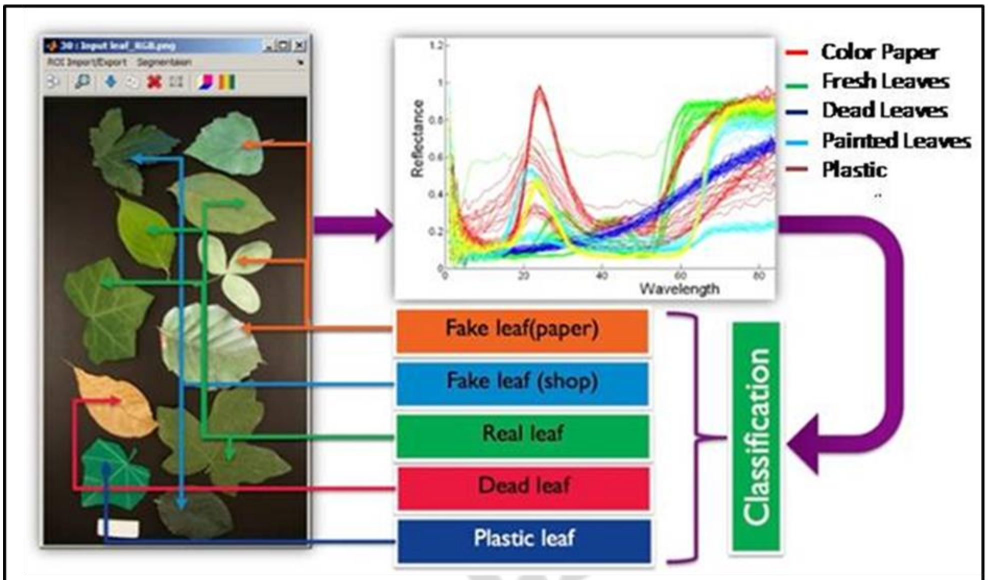
2.3 Plant Spectra: Reflectance spectra of green vegetation differ if compared to a spectral curve for dry or yellowed leaves. Different portions of the spectral curves for vegetation are shaped by different plant components. The spectral reflectance curves of healthy green plants have a characteristic shape that is dictated by various plant attributes. In the visible portion of the spectrum, the curve shape is governed by absorption effects from chlorophyll and other leaf pigments. Chlorophyll absorbs visible light very effectively but absorbs blue and red wavelengths more strongly than green, producing a characteristic small reflectance peak within the green wavelength range. As a consequence, healthy plants appear to us as green in color. Reflectance rises sharply across the boundary between red and near infrared wavelengths to values of around 40 to 50% for most plants (Fig. 7).



Reflectance spectra of different types of green vegetation compared to a spectral curve for senescent (dry, yellowed) leaves

FIG. 7

This high near-infrared reflectance is primarily due to interactions with the internal cellular structure of leaves. Most of the remaining energy is transmitted, and can interact with other leaves lower in the canopy. Leaf structure varies significantly between plant species, and can also change as a result of plant stress. Thus, species type, plant stress, and canopy state all can affect near infrared reflectance measurements. Beyond 1.3 µm, reflectance decreases with increasing wavelength, except for two pronounced water absorption bands near 1.4 and 1.9 µm. At the end of the growing season leaves, lose water and chlorophyll. Therefore, near infrared reflectance decreases and red reflectance increases, creating the familiar yellow, brown, and red leaf colors of autumn (Fig. 8).



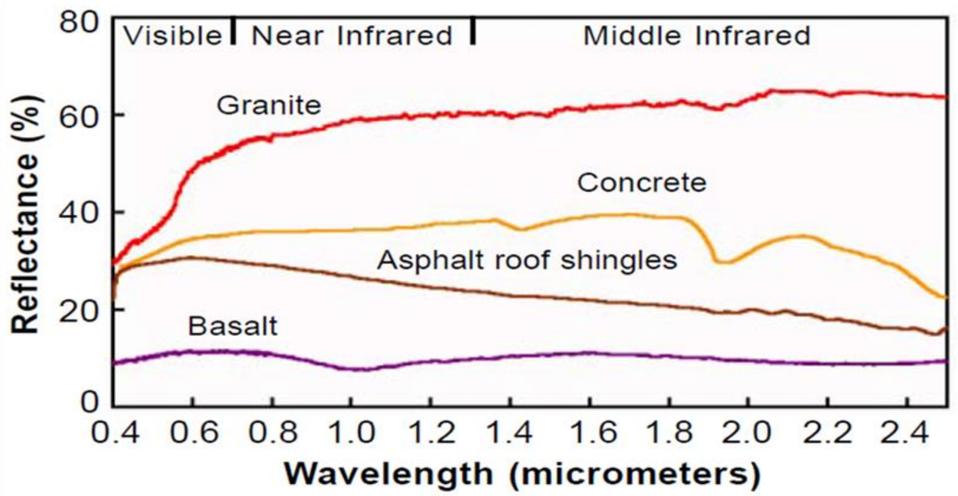
Spectral curve for natural and artificial leaves

FIG. 8

2.4 Spectral Libraries: Several libraries of reflectance spectra of natural and man-made materials are available for public use. These libraries provide a source of reference spectra that can aid the interpretation of hyperspectral images.

2.4.1. ASTER Spectral Library: This library has been made available by NASA as part of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imaging instrument program. It includes spectral compilations from NASA's Jet Propulsion Laboratory, Johns Hopkins University, and the United States Geological Survey (Reston). The ASTER spectral library currently contains nearly 2000 spectra, including minerals, rocks, soils, man-made materials, water, and snow. Many of the spectra cover the entire wavelength region from 0.4 to 14 µm.

The library is accessible interactively via http:// speclib.jpl.nasa.gov. Spectra can be searched by category, view a spectral plot for any of the retrieved spectra, and download the data for individual spectra as a text file. These spectra can be imported into a TNTmips spectral library. Order can also be made to acquire the ASTER spectral library on CD-ROM at there is no charge from the above web address (Fig. 9).



Sample spectra from the ASTER Spectral Library

FIG. 9

2.4.2. USGS Spectral Library: The United States Geological Survey Spectroscopy Lab in Denver, Colorado has compiled a library of about 500 reflectance spectra of minerals and a few plants over the wavelength range from 0.2 to 3.0 µm. This library is accessible online at http://speclab.cr.usgs.gov/spectral.lib04/spectral-lib04.html.

Individual spectra or entire library can also be downloaded from website. The USGS Spectral library is also included as a standard reference library in the TNTmips Hyperspectral Analysis process. There is a need of extra precaution while using spectra provided by other spectral libraries. Scientists from USGS have evaluated many spectrometers and other spectral libraries and have found many to have significant wavelength shifts.

3. Hyperspectral Sensors

In hyperspectral remote sensing there are two types of sensors:

(i) Spectral Sensors on Satellites
(ii) Spectral Sensors on Aircraft

As a representative for the two types of systems, comparison between AVIRIS air sensor and the Hyperion satellite sensor is discussed below:

The Hyperion EO-1 sensor was launched in November 2000 by NASA with the purpose of taking hyperspectral images from space in order to create mineralogical mapping. It works in the spectral range 0.40…2.50 µm with 242 bands. It has spectral resolution of about 10 nm and spatial resolution of 30 meters. The data is taken from an altitude of 705 km. Hyperion is a push-broom instrument that takes pictures with a radiometric resolution of 8 bits with a band width of 7.5 km and being perpendicular on the movement of the satellite. The system used for taking images is formed of two spectrometers: (i) one working in the visible/near infrared (VNIR) (0.4…1.0 µm) and (ii) another one in shortwave infrared (SWIR) (0.9…2.5 µm).

Airborne Visible Sensor/Infrared Imaging Spectrometer (AVIRIS) developed by NASA/Jet Propulsion Laboratory (JPL) is a new in terms of hyperspectral systems attached to planes. AVIRIS was started in 1998 and its sensor is mounted on a Twin Otter aircraft flying at low altitude, taking pictures with a spatial resolution ranging between 2 and 4 meters. AVIRIS sensor can also take images from an altitude of 20 km with a spatial resolution of 20 meters, from a bandwidth of 10.5 kilometers. It is working in bands of 224, with spectral range from 0.40 to 2.50 µm. The sensor is a Whiskbroom system that uses a scanning system for acquiring data on the transverse direction of advancement.

Most hyperspectral sensors are mounted on aerial platforms and less on the satellite. However, sensors on satellites have the capacity to provide global coverage at regular intervals (Table 1).

Table 1: Characterization of Hyperspectral Sensors (Airborne and Satellite based)

Hyperspectral Sensors on Satellite			
Types of sensor	**Manufacturer**	**Number of Bands**	**Spectral Range (µm)**
FTHSI on MightySat II	Air Force Research Lab	256	0.35 to 1.05
Hyperion on EO-1	NASA Goddard Space Flight Center	220	0.4 to 2.5

Hyperspectral Sensors on Aircraft

AVIRIS (Airborne Visible Infrared Imaging Spectrometer)	NASA, USA	224	0.4 to 2.5
HYDICE (Hyperspectral Digital Imagery Collection Experiment)	Naval Research Lab	210	0.4 to 2.5
PROBE-1	Earth Search Sciences Inc., USA	128	0.4 to 2.5
CASI (Compact Airborne Spectrographic Imager)	ITRES Research Limited, Canada	up to 228	0.4 to 1.0
HyMap	Integrated Spectronics Pt. Ltd., Australia	100 to 200	Visible to thermal infrared
EPS-H (Environmental Protection System)	GER Corporation	VIS/NIR (76), SWIR1 (32), SWIR2 (32), TIR (12)	VIS/NIR (0.43-1.05), SWIR1 (1.5-1.8), SWIR2 (2.0-2.5), TIR (8-12.5)
AIS 7915 (Digital Airborne Imaging Spectrometer)	GER Corporation	VIS/NIR (32), SWIR1 (8), SWIR2 (32), MIR (1), TIR (6)	VIS/NIR (0.43-1.05), SWIR1 (1.5-1.8), SWIR2 (2.0-2.5), MIR (3.0-5.0),TIR (8.7-12.3)
DAIS 21115 (Digital Airborne Imaging Spectrometer)	GER Corp., USA	VIS/NIR (76), SWIR1 (64), SWIR2 (64), MIR (1), TIR (6)	VIS/NIR (0.40 to 1.0), SWIR1 (1.0 to 1.8), SWIR2 (2.0 to 2.5), MIR (3.0 to 5.0), and TIR (8.0 to 12.0)
AISA (Airborne Imaging Spectrometer)	Spectral Imaging Ltd., Finland	up to 288	0.43 to 1.0

4. Image Analysis

The hyperspectral images provide the fine spectral resolution needed to characterize the spectral properties of surface materials but the volume of data in a single scene is very vast. The difference in spectral information between two adjacent wavelength bands is typically very small and their grayscale images therefore appear nearly identical. Finding appropriate tools and approaches for visualizing and analyzing the essential information in a hyperspectral scene needs expertise and active research.

Followings are some of the techniques used for analyzing the spectral content of hyperspectral images:

4.1 Match Each Image Spectrum: One approach to analyzing a hyperspectral image is to match each image spectrum individually to the reference reflectance spectra in a spectral library. This approach requires an accurate conversion of image spectra to reflectance (Fig. 10).

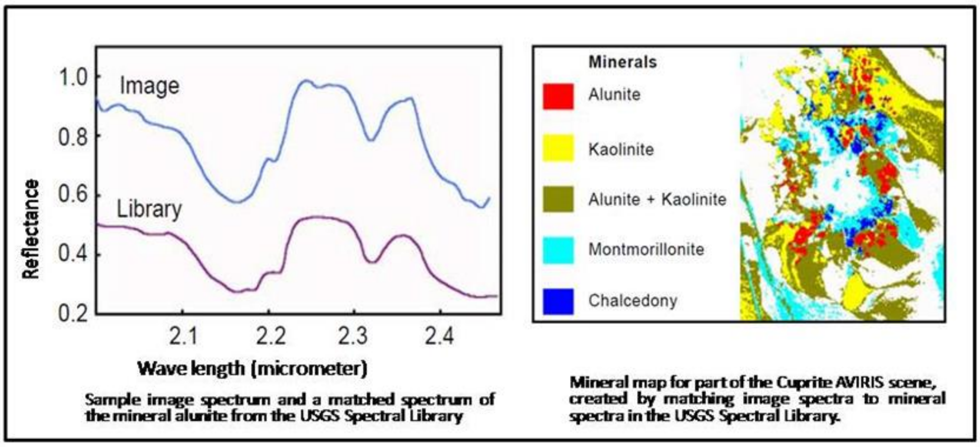
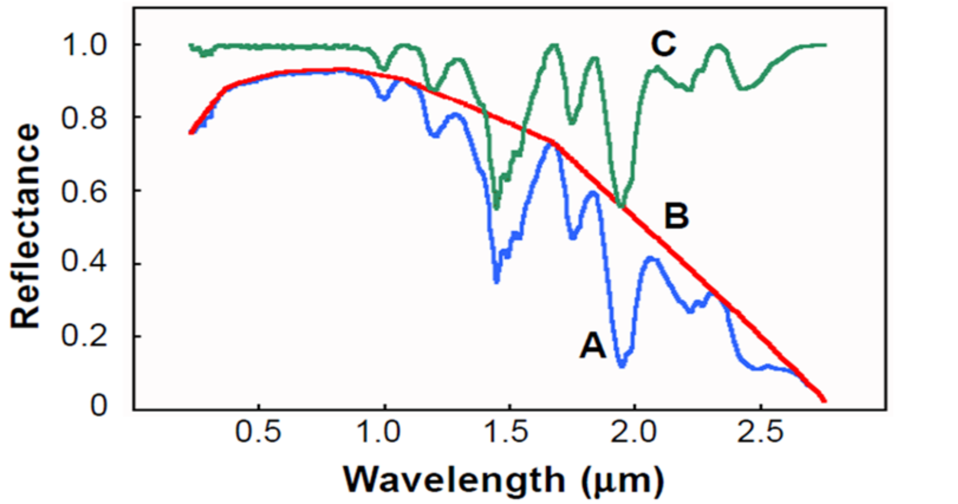


FIG. 10

4.2 Spectral Matching Methods: The shape of a reflectance spectrum can usually be broken down into two components: (i) broad, smoothly changing regions that define the general shape of the spectrum and (ii) narrow, trough-like absorption features. This distinction leads to two different approaches to matching image spectra with reference spectra.

One common matching strategy is to match only the absorption features in each candidate reference spectrum and ignores other parts of the spectrum. Many other materials, such as rocks and soils, may lack distinctive absorption features then these spectra are characterized by their overall shape.



Reference spectrum for minerals gypsum (A) with several absorption features. Curve B shows the continuum for the spectrum, and C the spectrum after removal of continuum

FIG. 11

4.3 Linear Unmixing: Linear unmixing is an alternative approach to simple spectral matching. The set of spectrally unique surface materials existing within a scene are referred to as the spectral *endmembers* for that scene. Linear Spectral Unmixing exploits the theory that the reflectance spectrum of any pixel is the result of linear combinations of the spectra of all endmembers inside that pixel. If the spectra of all endmembers in the scene are known, then their abundances within each pixel can be calculated from each pixel's spectrum (Fig. 12).

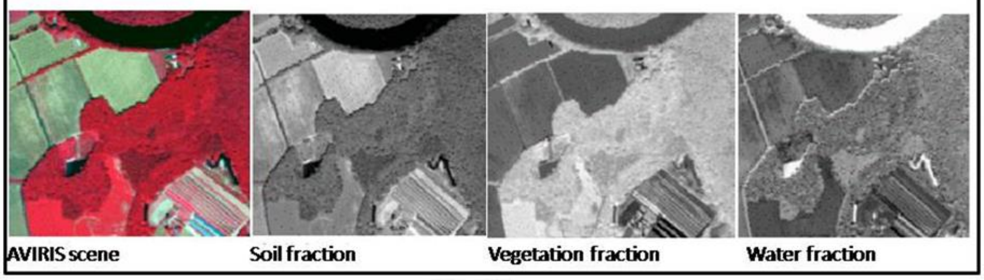


FIG. 12

The results of Linear Spectral Unmixing include one abundance image for each endmember. The pixel values in these images indicate the percentage of the pixel made up of that endmember. For example, if a pixel in an abundance image for the endmember quartz has a value of 0.90, then 90% of the area of the pixel contains quartz. An error image is also usually calculated to help evaluate the success of the unmixing analysis.

5. Application of Hyperspectral Remote Sensing

Hyperspectral images can be used in agriculture, forestry, geology, environmental monitoring etc. Hyperspectral data are used to determine chemical concentrations in leaves, vegetation stress, mapping the expansion of different species of plants, the surfaces contaminated by mining waste and other pollutants, watercolor mapping to determine and identify the presence of microorganisms and localization of the sources of pollution (Fig. 13).

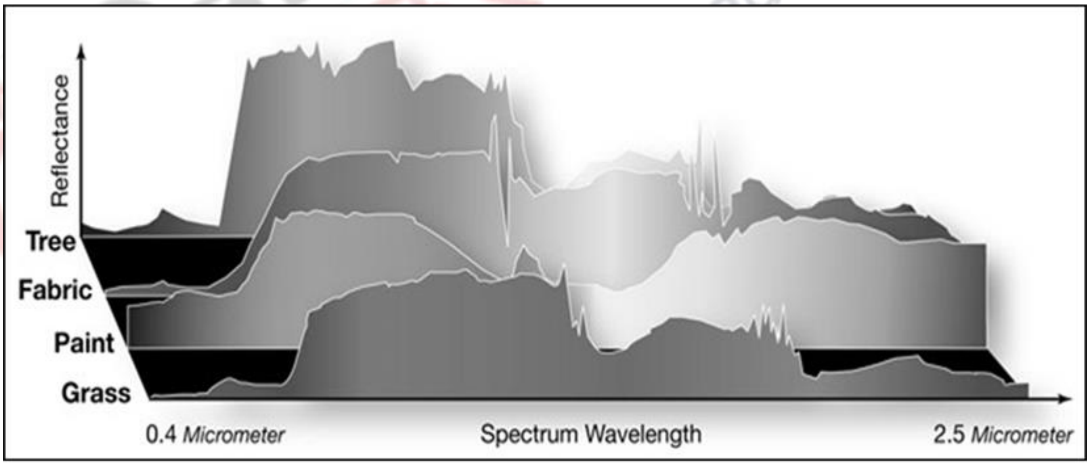
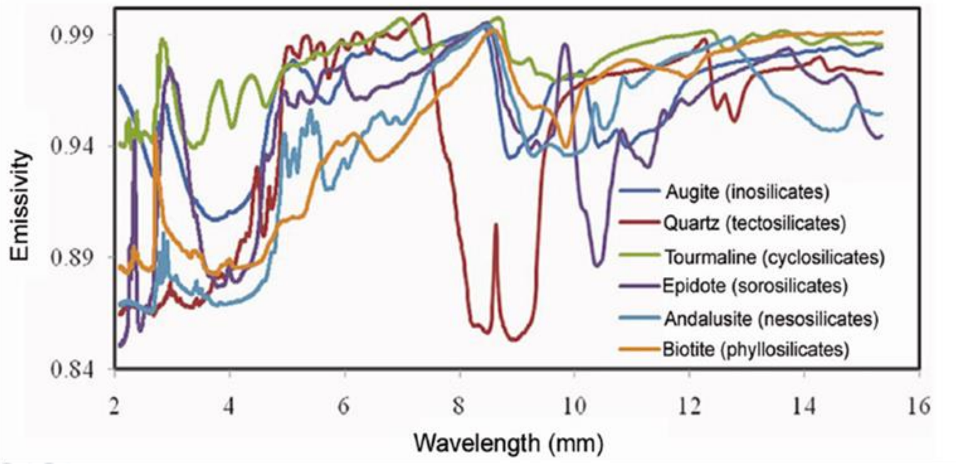


FIG. 13

Hyperspectral images are also used in detection and mapping of minerals and highlighting the properties of soil including moisture, organic content and salinity. In army, they are used to identify military cars that partially depend on the canopy trees and on the detection of certain targets.

5.1 Geological Applications: Over the last two decades, mineral mapping and lithological discrimination using airborne hyperspectral sensors like AVIRIS, HYDICE, DAIS, HyMAP have been extensively attempted. However, launch of NASA's EO-1 Hyperion sensor marked a new beginning in spaceborne mineral mapping and exploration of non-metals, precious minerals, hydrocarbon deposits and also in quality control and grade assessments.

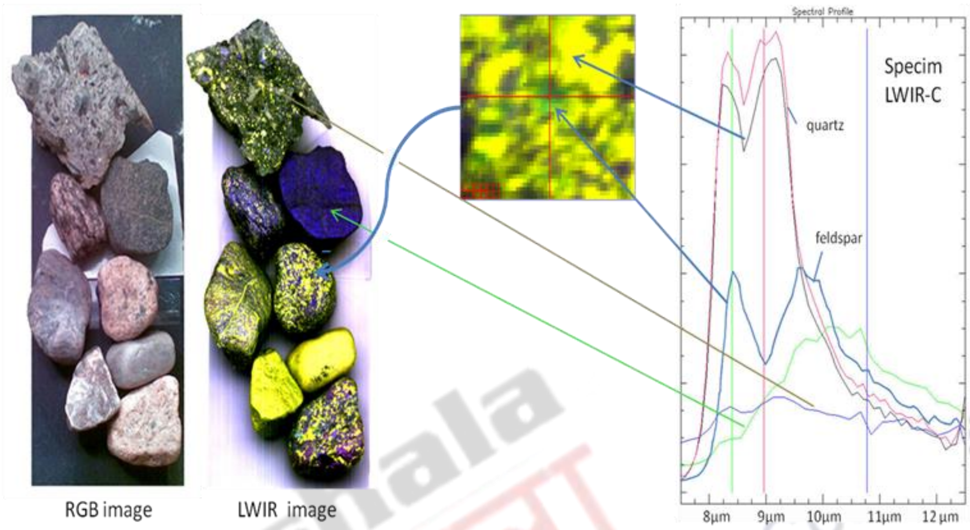
Hyperspectral remote sensing is also capable of identifying minerals and their distribution in forest area. Spectral reflectance of a specific metal is changed due to presence of vegetation, but, hyperspectral remote sensing is capable of identifying this changed spectral reflectance and after combining with lithology and soil chemistry, that particular mineral can be identified.



Spectra (2-16 µm) representing most important class of rock-forming minerals

FIG. 14

5.2 Detection of water quality: Detection of water quality is one of the major advantages of hyperspectral remote sensing. This includes classifying the trophic status of lakes and estuaries, characterizing algal blooms and assessment of ammonia dynamics for wetland treatments. Hyperspectral spectrometers have also proved useful in determining the total suspended matter, chlorophyll content and total phosphorus. Hyperspectral imagers allow for improved detection of chlorophyll and hence algae, due to the narrow spectral bands which are acquired between 450 nm and 600 nm.



A set of stones is scanned with a Specim LWIR-C imager in the thermal infrared range from 7.7 µm to 12.4 µm. The quartz and feldspar spectra are clearly recognizable

FIG. 15

5.3 **Flood detection and monitoring:** Until recently, near real-time flood detection was not possible, but with sensors such as Hyperion, this has been vastly improved. Most recent studies from NASA and the US Geological Survey are utilizing satellite observations of rainfall, rivers and surface topography into early warning systems. Specifically, scientists are now employing satellite microwave sensors to gauge discharge from rivers by measuring changes in river widths and satellite based estimates of rainfall to improve warning systems.

5.4 **Land-use and vegetation classification:** The availability of satellite and airborne hyperspectral data with its increased spatial and more critically fine spectral resolution offers an enhanced potential for the classification and mapping of land use and vegetation. Due to the large number of wavebands, image processing is able to capitalize on both the biochemical and structural properties of vegetation. The need for exploring these spectral properties is particularly important when we consider the limitations of using traditionally available wavebands, where most of the land cover is grouped and identification of individual species is difficult.

5.5 Agriculture: Hyperspectral remote sensing is used for monitoring the development and health of crops. Furthermore, work is underway to use hyperspectral data to detect the chemical composition of plants. Another application in agriculture is the detection of animal proteins in compound feeds to avoid mad-cow disease.

In the food processing industry, hyperspectral imaging, combined with intelligent software, enables digital sorters to identify and remove defects and foreign material (FM) that are invisible to traditional camera and laser sorters. The sorter's software compares the hyperspectral images collected to user-defined accept/reject thresholds, and the ejection system automatically removes defects and foreign material.

5.6 Surveillance: Hyperspectral imaging is useful in military surveillance because of countermeasures that military entities now take to avoid airborne surveillance. The SEALs from NSWDG who killed Osama bin Laden in May 2011 used this technology while conducting the raid.

5.7 Chemical imaging: Soldiers can be exposed to a wide variety of chemical hazards. These threats are mostly invisible but detectable by hyperspectral imaging technology. The Telops Hyper-Cam, introduced in 2005, has demonstrated this at distances up to 5 km and with concentrations as low as a few ppm.

5.8 Environment: Most countries require continuous monitoring of emissions produced by coal and oil-fired power plants, municipal and hazardous waste incinerators, cement plants, as well as many other types of industrial sources. This monitoring is usually performed using extractive sampling systems coupled with infrared spectroscopy techniques.

6. Summary

The name ‘hyperspectral’ is derived from two words; ‘hyper’ and ‘spectral’. ‘Hyper’ means ‘too many’ and the term ‘hyperspectral’ is used to refer to spectra consisting of large number of narrow, contiguously spaced spectral bands. Developed in mid-80’s, the concept of hyperspectral remote sensing is based on an instrument called *spectrometer*. This technology is considered to be the most significant recent break-through in the field of remote sensing and has been widely used in the detection of minerals, vegetation, artificial materials and soil background. Hyperspectral remote sensing is technologically more developed than multispectral remote sensing as its sensors have the ability to capture energy in 200 bands or more and in many narrow spectral bands (10-20 nm) that are found in the electromagnetic spectrum from visible, near infrared, medium infrared to thermal infrared.

Using this technology, several libraries of reflectance spectra of natural and man-made materials are prepared and available for public use. These libraries provide a source of reference spectra that can aid the interpretation of hyperspectral images. Hyperspectral images can be used in agriculture, forestry, geology, environmental monitoring etc. Hyperspectral data are used to determine chemical concentrations in leaves, vegetation stress, mapping the expansion of different species of plants, the surfaces contaminated by mining waste and other pollutants, watercolor mapping to determine and identify the presence of microorganisms and localization of the sources of pollution.

Frequently Asked Questions-

Q1. What is hyperspectral remote sensing?

Ans. The phrase 'hyperspectral' is derived from two words; 'hyper' and 'spectral'. 'Hyper' means 'too many' and the term 'hyperspectral' is referred to spectra consisting of large number of narrow (10-20 nm) and contiguously spaced spectral bands. Hyperspectral sensors capture energy in 200 bands or more which means that they continuously cover the reflecting spectrum for each pixel in the scene. Allowing an in depth examination of features and details on Earth.

Q2. Discuss the application of hyperspectral remote sensing in various fields?

Ans. Hyperspectral images are used in agriculture, forestry, geology, environmental monitoring etc. Hyperspectral data are used to determine chemical concentrations in leaves, vegetation stress, mapping the expansion of different species of plants, the surfaces contaminated by mining waste and other pollutants, watercolor mapping to determine and identify the presence of microorganisms and localization of the sources of pollution. It is also used in detection of minerals and highlighting the properties of soil. In army, they are used to identify military cars that partially depend on the canopy trees and on the detection of certain targets.

Q3. What are the different hyperspectral sensors boarded on aircraft? Write their characteristics also?

Ans. Hyperspectral sensors boarded on aircraft and their characteristics are listed below:

SN	Sensors boarded on aircraft	Manufacturer	Number of Bands	Spectral Range (μm)
1	FTHSI on MightySat II	Air Force Research Lab	256	0.35 to 1.05
2	Hyperion on EO-1	NASA Goddard Space Flight Center	220	0.4 to 2.5

Q4. What do you mean by "Linear Unmixing" technique used in hyperspectral image analysis?

Ans. "Linear unmixing" is an image analysis technique where spectral curve of a desired material is matched with spectral library. The set of spectrally unique surface materials existing within a scene are referred to as the spectral *endmembers* for that scene and if the spectra of all endmembers in the scene are known, then their abundances within each pixel can be calculated from each pixel's spectrum. For example, if a pixel in an abundance image for the endmember quartz has a value of 0.90, then 90% of the area of the pixel contains quartz.

Q5. Discuss about Airborne Visible Sensor/Infrared Imaging Spectrometer (AVIRIS)?

Ans. Airborne Visible Sensor/Infrared Imaging Spectrometer (AVIRIS) developed by NASA/Jet Propulsion Laboratory (JPL) was started in 1998 and its sensor is mounted on a Twin Otter aircraft flying at low altitude, taking pictures with a spatial resolution ranging between 2 and 4 meters. AVIRIS sensor can also take images from an altitude of 20 km with a spatial resolution of 20 meters, from a bandwidth of 10.5 kilometers. It is working in bands of 224, with spectral range from 0.40 to 2.50 µm. The sensor is a Whiskbroom system that uses a scanning system for acquiring data on the transverse direction of advancement.

Multiple Choice Questions-

1. Hyperspectral images are produced by instruments called

(a) Photometer
(b) Spectrometers
(c) Radiometer
(d) Altimeter

2. AVIRIS sensor is boarded on

(a) Satellite
(b) Aircraft
(c) Both of the above
(d) None

3. Spectral Range of 0.4 to 2.5 µm is property of the following sensors

(a) PROBE-1
(b) AVIRIS
(c) HYDICE
(d) All of the above

4. Decrease in near infrared reflectance and increase in red reflectance for leaf of vegetation is due to

(a) Change of green leaf into yellow colour during autumn
(b) Change of green leaf into brown colour during autumn
(c) Change of green leaf into red colour during autumn
(d) All of the above

5. The scanning system of Airborne Visible Sensor/Infrared Imaging Spectrometer (AVIRIS) works like

(a) Push-broom
(b) Whiskbroom
(c) Both of the above
(d) None

Suggested Readings:

1. Vorovencii, Iosif (2009). "The hyperspectral sensors used in satellite and aerial remote sensing." Bulletin of the Transilvania University of Braşov. Vol 2 (51): 51-56.
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