Image Spectra and Colour Theory

Data Conversion/Entry (GIS, Databases)
November 6 – 10, 2006
Freetown, Sierra Leone
Lecture Overview

• Absorption, Transmission and Reflectance
• Specular versus Diffuse Reflection
• Visible and Infrared Interaction with Vegetation
• Ground Spectral Measurements of Common Crops and Earth Materials
• Detecting Stress in Plants
• Leaf Area Index
• Visible and Infrared Interaction with Water
• Ground Spectral Signatures
• Spectral Libraries
• Colour Theory
• Colour Mixing
• Red/Green/Blue Colour Cube
• Intensity/Hue/Saturation Colour Cone/Hexacone
• Computer Colour Control
• Normalized Difference Vegetation Index (NDVI)
There are three forms of interaction that can take place when energy strikes, or is *Incident* (I) upon the surface. These are: Absorption (A); Transmission (T); and Reflection (R).
We refer to two types of reflection, which represent the two extreme ends of the way in which energy is reflected from a target: specular reflection and diffuse reflection.

When a surface is smooth we get a mirror-like reflection where all (or almost all) of the energy is directed away from the surface in a single direction. Reflection occurs when the surface is rough and the energy is reflected almost uniformly in all directions. Most earth surface features lie somewhere between perfectly specular or perfectly diffuse reflectors.
Leaves: A chemical compound in leaves called chlorophyll strongly absorbs radiation in the red and blue wavelengths but reflects green wavelengths. Leaves appear "greenest" to us in the summer, when chlorophyll content is at its maximum. In autumn, there is less chlorophyll in the leaves, so there is less absorption and proportionately more reflection of the red wavelengths, making the leaves appear red or yellow. The internal structure of healthy leaves act as excellent diffuse reflectors of near-infrared wavelengths. If our eyes were sensitive to near-infrared, trees would appear extremely bright to us at these wavelengths.
Absorption centered at about 0.65 µm (visible red) by chlorophyll pigment in green-leaf chloroplasts that reside in the outer or Palisade leaf, and to a similar extent in the blue, removes these colors from white light, leaving the predominant but diminished reflectance for visible wavelengths concentrated in the green. Thus, most vegetation has a green-leafy color. There is also strong reflectance between 0.7 and 1.0 µm (near IR) in the spongy mesophyll cells located in the interior or back of a leaf, within which light reflects mainly at cell wall/air space interfaces, much of which emerges as strong reflection rays.

http://rst.gsfc.nasa.gov/Sect3/Sect3_1.html
Many factors combine to cause small to large differences in spectral signatures for the varieties of crops cultivated. Generally, we must determine the signature for each crop in a region from representative samples at specific times. However, some crop types have quite similar spectral responses at equivalent growth stages.
THE SEVEN BANDS OF LANDSAT THEMATIC MAPPER

Note the Near Infrared Response in the Forested Areas.

BAND1
blue
0.45 - 52 μm

BAND2
green
0.52 - 0.60 μm

BAND3
red
0.63 - 0.69 μm

BAND4
near infrared
0.76 - 0.90 μm

BAND 5
short-wave infrared
1.55 - 1.76 μm

BAND6
thermal infrared
10.5 - 11.5 μm

BAND7
short-wave infrared
2.08 - 2.35 μm
At some wavelengths, sand reflects more energy than green vegetation but at other wavelengths it absorbs more (reflects less) than does the vegetation. In principle, we can recognize various kinds of surface materials and distinguish them from each other by these differences in reflectance.
Under suitable circumstances, it is feasible to detect crop stress generally from moisture deficiency or disease and pests, and sometimes suggest treatment before the farmers become aware of problems. Stress is indicated by progressive decrease in Near-IR reflectance, as evidenced in this set of field spectral measurements of leaves taken from soybean plants as these underwent increasing stress that causes loss of water and breakdown of cell walls.

Of the plants presented here, which plant will appear most yellow?
LEAF AREA INDEX (LAI)

Leaf Area Index (LAI), defined as the ratio of one-half the total area of leaves in vegetation to the total surface area containing that vegetation. If all the leaves were removed from a tree canopy and laid on the ground, their combined areas relative to the ground area projected beneath the canopy would be some number greater than 1 but usually less than 10. As a tree, for example, fully leaves, it will produce some LAI value that is dependent on leaf size and shape, the number of limbs, and other factors. The LAI is related to the the total biomass (amount of vegetative matter [live and dead] per unit area, usually measured in units of tons or kilograms per hectare) in the plant and to various measures of Vegetation Index.

Longer wavelength visible and near infrared radiation is absorbed more by water than shorter visible wavelengths. Thus water typically looks blue or blue-green due to stronger reflectance at these shorter wavelengths, and darker if viewed at red or near infrared wavelengths. If there is suspended sediment present in the upper layers of the water body, then this will allow better reflectivity and a brighter appearance of the water.
Over the spectral range covered by the Landsat TM bands, the types and ages of rocks show distinct variations at specific wavelengths. This is evident in the following spectral plots showing laboratory-determined curves obtained by a reflectance spectrometer for a group of diverse sedimentary rocks from Wyoming.
LABORATORY SPECTRAL REFLECTANCE OF A PARTICULAR SOIL AT VARIOUS SOIL MOISTURE CONDITIONS
What is the textural relationship here? In reference to this figure and the previous figure, how in imagery could you with certainty identify the effects of soil moisture versus material type?
SPECTRAL RESPONSES FROM NONVEGETATED LAND AREAS

http://rst.gsfc.nasa.gov/Intro/Part2_6.html
EXAMPLE FROM THE ASTER SPECTRAL LIBRARY

Name: Labradorite (Feldspar)  
(\text{NaSi,CaAl})\text{AlSi\textsubscript{2}O\textsubscript{8}}  
Type: Mineral  
Class: Silicates  
Subclass: Tectosilicates  
Particle Size: 125-500um  
Origin: Mexico, Sonora, Pinacate  
Collected by Burminco  
Description:  
Measurement: Hemispherical reflectance

http://speclib.jpl.nasa.gov/Search.htm
SPECTRA OF ALUNITE AS RECORDED BY LANDSAT TM, MODIS AND GROUND MEASUREMENTS

Note the differences in spectral resolution.

GROUND SPECTRAL SIGNATURES FOR THE KAOLINITE MINERALS

http://rst.gsfc.nasa.gov
SUBTLE SPECTRAL DIFFERENCES BETWEEN DOLOMITE AND CALCITE

The common minerals, Calcite (CaCO₃) and Dolomite (Ca,MgCO₃) have a prominent absorption band near 2.3 µm, which reaches about the same depth in spectra of each species. The continuum-removal diagram for both shows that Dolomite reaches its trough point at a slightly lower wavelength.

This approach to absorption band analysis has proved to be a powerful tool for enhancement and separation of small but often significant differences that allow us to properly identify materials (those belonging to related groups and those unrelated but with absorption bands that tend to coincide).

WHAT DEVICE COULD HAVE GENERATED THIS ENERGY PULSE?
Colour Theory

SENSITIVITY OF THE HUMAN EYE TO RED, GREEN, AND BLUE LIGHT

Tri-stimulus theory of colour vision. Colour is thought to be associated with cone vision. There are three types of cones in our eyes, each kind being responsive to one of the three primary colours of light (red, green, blue).
RED - GREEN - BLUE COLOUR CUBE
<table>
<thead>
<tr>
<th>COLOUR MIXING PROCESS</th>
</tr>
</thead>
</table>

**COLOUR ADDITIVE PROCESS**

eg. In a dark room, if you shine intersecting Red, Green, and Blue lights this is the pattern you will get.

Note: All computer display systems use the colour additive process.

**COLOUR SUBTRACTIVE PROCESS**

eg. If you took paints of Yellow, Magenta and Cyan, this is the pattern you would expect.

Note: Most plotters and computer output devices use the colour subtractive process.
COLOUR MIXING PROCESSES

COLOUR SUBTRACTIVE PROCESS

COLOUR ADDITIVE PROCESS
Human Colour Vision

Colour Blindness

- Most Common Red-Green.

- Red and Green Cones are shifted too close together.

- People with colour blindness however are better at detecting gray scales.
TYPICAL IMAGE ANALYSIS DISPLAY SYSTEM
ARCHITECTURE

IMAGE 1

LUT 1

LUT 2

LUT 3

IMAGE 2

IMAGE 3

Graphic Planes

Vector Layers

IMAGES

LUTS

COLOUR

ENABLE

RED GUN

GREEN GUN

BLUE GUN

Modified from PCI - Image Analysis Manual
POSSIBLE NUMBER OF COLOURS USING 3 BANDS OF 8-BIT IMAGERY

GREEN $2^8$  X  BLUE $2^8$  X  RED $2^8 > 16$ Million

$2^8 = 256$

> 16 Million
GENERATING TRUE COLOUR COMPOSITES
LANDSAT BANDS 3, 2 AND 1

R: Band 3 (RED)
G: Band 2 (GREEN)
B: Band 1 (BLUE)

Stouffville Ontario - April 29, 1985 - Source F. Kenny, PRSO
Generating “False Colour” Composites using Landsat Satellite ETM Imagery for Sierra Leone
IHS COLOUR SYSTEM

**HUE:** In the IHS colour system, HUE represents the dominant wavelength of a colour.

**INTENSITY:** In the IHS colour system, INTENSITY (or brightness) ranges from black to white.

**SATURATION:** In the IHS colour system, SATURATION represents the purity of a colour.
RED - GREEN - BLUE COLOUR CUBE

- RED
- GREEN
- BLUE
- MAGNETA
- CYAN
- WHITE
- BLACK
- YELLOW

Intensity
Saturation
Hue
EQUATIONS RELATING THE RGB AND IHS COLOUR SPACES

RED = \frac{I}{\sqrt{3}} - \frac{S \cos(H)}{\sqrt{6}} - \frac{S \sin(H)}{\sqrt{2}}

GREEN = \frac{I}{\sqrt{3}} - \frac{S \cos(H)}{\sqrt{6}} + \frac{S \sin(H)}{\sqrt{2}}

BLUE = \frac{I}{\sqrt{3}} + \frac{2S \cos(H)}{\sqrt{6}}

Where: \ I = Intensity
\ S = Saturation
\ H = Hue
TRANSFORMING RGB COLOUR SPACE TO IHS COLOUR SPACE
Landsat bands 4, 3 and 2.
DEM Colour Enhancement Methodology Using the IHS Colour Model

H = Elevation  I = Shaded Relief

S = 127

Resultant RGB colour Composite
COLOUR CONTROL PANEL IN MICROSOFT PAINT

Note the simulations modifications in RGB and IHS
COLOUR CONTROL PANEL IN COREL DRAW 7

Note in addition to RGB, HIS there is also Yellow/Magenta/Cyan and L/a/b?
INTERACTIVE COLOUR CONTROL PANEL IN PCI
Generating R/G/B and I/H/S Composites in ILWIS

At the main ILWIS Menu select
Operations → Image Processing → Color

Separating Channels from Colour Composites In ILWIS
NDVI

• In addition to ratios of individual bands, more complex ratios may be computed.

• One widely used combination is the *Normalized Difference Vegetation Index* (NDVI) which can be effectively used to map and monitor healthy vegetation.

• NDVI can be expressed as:

\[
\text{NDVI} = \frac{\text{near infrared} - \text{red}}{\text{red} + \text{near infrared}}
\]

• NDVI can be calculated from a wide variety of airborne or satellite sensors.
• The equation for Landsat TM imagery is

\[
\text{NDVI} = \frac{(\text{Band4}-\text{Band3})}{(\text{Band4}+\text{Band3})}
\]
Normalized Difference Vegetation Index

September 21-30, 1999

Normalized Difference Vegetation Index (NDVI)

Derived Using MODIS Imagery
NDVI One Year Time Series over Canada
Derived from NOAA AVHRR Imagery

http://cct.rncan.gc.ca/optic/coarse/bio/images/ndvi_e.gif
Knowing that TM3 (Red) is centred at about 650 nm and that TM4 is centred at approximately 830 nm, calculate an NDVI for each of the 5 targets shown here. The equation for NDVI is

\[
NDVI = \frac{(\text{Band4} - \text{Band3})}{(\text{Band4} + \text{Band3})}
\]