Remote Sensing of Vegetation

Many of remote sensing techniques are generic in nature and may be applied to a variety of vegetated landscapes, including

1. Agriculture
2. Forest
3. Rangeland
4. Wetland, and
5. Urban vegetation
6. …..

Photosynthesis Fundamentals

*Photosynthesis* is an energy-storing process that takes place in leaves and other green parts of plants in the presence of light. Photosynthesis process begins when sunlight strikes chloroplasts.

The light energy is stored in a simple sugar molecule (glucose) that is produced from carbon dioxide (CO₂) present in the air and water absorbed by the plant primarily through the root system.

Small bodies in the leaf that contain a green substance called chlorophyll.
Photosynthesis Fundamentals

Plants have adapted their internal and external structure to perform photosynthesis.

This structure and its interaction with electromagnetic energy have direct impact on how leaves and canopies appear spectrally when recorded using remote sensing instruments.

Spectral Characteristics of Vegetation

A healthy green leaf intercepts incident radiant flux ($\Phi_i$) directly from the Sun or from diffuse skylight scattered onto the leaf.

The amount of radiant flux reflected from the leaf ($\Phi_r$), absorbed by the leaf ($\Phi_a$), and transmitted through the leaf ($\Phi_t$) can be measured by energy balance equation.

$$\Phi_{i\lambda} = \Phi_{r\lambda} + \Phi_{a\lambda} + \Phi_{t\lambda}$$
which says the energy reflected from the plant leaf surface is equal to the incident energy minus the energy absorbed for photosynthetic or other purposes and the amount of energy transmitted through the leaf onto other leaves or the ground beneath the canopy.

EMR Interaction with Pigments in Leaf Cells

The process of food-making via photosynthesis determines how a leaf and the associated plant canopy actually appear radiometrically on remote sensed image.
Dominant factors controlling leaf reflectance

- Leaf pigments in the palisade mesophyll: chlorophyll $a$, $b$, $\beta$-carotene, etc.
- Scattering in the spongy mesophyll
- Leaf water content

Primary absorption bands

- Chlorophyll absorption bands
- Atmospheric water absorption bands

Reflectance (%) vs. Wavelength (µm)

Visible | Reflective infrared | Near-infrared | Middle-infrared

Leaf pigments graphs

- Green leaf
- Yellow
- Red/orange
- Brown

Reflectance (%) vs. Wavelength (µm) for different leaf colors

(0.45 - 0.52 µm)  (0.52 - 0.68 µm)  (0.63 - 0.69 µm)  (0.70 - 0.92 µm)
Near-IR Energy Interaction within Spongy Mesophyll Cells

In a typical green leaf, the near-IR reflectance increases dramatically in the region from 0.7-1.2 µm (about 76% in 0.9 µm). The spongy mesophyll layer in a green leaf controls the amount of near-IR energy that is reflected.
Leaf Additive Reflectance

The reasons that healthy plant canopies reflect so much near-IR energy are:

• The leaf already reflects 40-60% of incident near-IR energy from spongy mesophyll, and

• The remaining 45-50% of the energy penetrates (transmitted) through the leaf and can be reflected once again by leaves below it.
Distribution of Pixels in A Scene in Red and Near-IR Multispectral Feature Space

Reflectance Response of a Single Magnolia Leaf (*Magnolia grandiflora*) to Decreased Relative Water Content

Jensen, 2007
Airborne Visible Infrared Imaging Spectrometer (AVIRIS) Datacube of Sullivan’s Island Obtained on October 26, 1998

Near-infrared image on top of the datacube is just one of 224 bands at 10 nm nominal bandwidth

Imaging Spectrometer Data of Healthy Green Vegetation in the San Luis Valley of Colorado Obtained on Sept. 3, 1993 Using AVIRIS

AVIRIS Spectral Signatures of Various Crops
Temporal/Phenological Characteristics of Vegetation

Selecting the most appropriate season and date(s) for data collection requires an intimate knowledge of the plants' temporal and phenological cycles.

Phenological Cycle of Hard Red Winter Wheat in the Great Plains

<table>
<thead>
<tr>
<th>SEP</th>
<th>OCT</th>
<th>NOV</th>
<th>DEC</th>
<th>JAN</th>
<th>FEB</th>
<th>MAR</th>
<th>APR</th>
<th>MAY</th>
<th>JUN</th>
<th>JUL</th>
<th>AUG</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>14</td>
<td>26</td>
<td>50</td>
<td>108 days</td>
<td>28</td>
<td>24</td>
<td>14</td>
<td>14</td>
<td>13</td>
<td>29</td>
<td>25</td>
</tr>
</tbody>
</table>

Sow | Tilling | Emergence | Dormancy | Growth | Jointing | Boot | Soft dough | Hard dough | Harvest | Dead ripe | Maximum Coverage

Jensen, 2007
Phenological Cycles of Soybeans and Corn in South Carolina

Phenological Cycles of Winter Wheat, Cotton, and Tobacco in South Carolina
Phenological Cycle of Cattails and Waterlilies in Par Pond, SC.
Landsat Thematic Mapper Imagery of the Imperial Valley, California, Obtained on December 10, 1982

Band 1 (blue; 0.45 - 0.52 µm)
Band 2 (green; 0.52 - 0.60 µm)
Band 3 (red; 0.63 - 0.69 µm)
Band 4 (near-infrared; 0.76 - 0.89 µm)
Band 5 (mid-infrared; 1.55 - 1.75 µm)
Band 6 (thermal infrared; 10.4 - 12.5 µm)
Band 7 (mid-infrared; 2.08 - 2.35 µm)

Ground Reference

Sugarbeets
Alfalfa
Cotton
Fallow

Landsat Thematic Mapper Imagery of Imperial Valley, California, December 10, 1982

Landsat Thematic Mapper Color Composites and Classification Map of a Portion of the Imperial Valley, California

a. TM bands 2,3,4 (RGB)
b. TM bands 3,2,1 (RGB)
c. TM bands 3,5,2 (RGB)
d. TM bands 7,5,2 (RGB)

Classification Map of Imperial Valley, California on December 10, 1982. Using Landsat Thematic Mapper Bands 1, 2 and 7

- Sugarbeets
- Alfalfa
- Cotton
- Fallow
Vegetation Indices

Since 1960's, much of the remote sensing efforts in vegetation has gone into the development of vegetation indices.

Vegetation indices can be defined as dimensionless, radiometric measures that function as indicators of relative abundance and activity of green vegetation, often including leaf-area-index (LAI), percentage green cover, chlorophyll content, green biomass, and absorbed photosynthetically active radiation.

There are more than 20 vegetation indices in use.

Infrared/Red Ratio Vegetation Index

The near-infrared (NIR) to red simple ratio (SR) is the first true vegetation index:

\[ SR = \frac{\rho_{\text{red}}}{\rho_{\text{nir}}} \]

It takes advantage of the inverse relationship between chlorophyll absorption of red radiant energy and increased reflectance of near-infrared energy for healthy plant canopies (Cohen, 1991).
Normalized Difference Vegetation Index

The generic normalized difference vegetation index (NDVI):

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

has provided a method of estimating net primary production over varying biome types (e.g. Lenney et al., 1996), identifying ecoregions (Ramsey et al., 1995), monitoring phenological patterns of the earth’s vegetative surface, and of assessing the length of the growing season and dry-down periods (Huete and Liu, 1994).

Time Series of 1984 and 1988 NDVI Measurements Derived from AVHRR Global Area Coverage (GAC) Data for the Region around El Obeid, Sudan, in Sub-Saharan Africa
Infrared Index

Information about vegetation water content has widespread use in agriculture, forestry, and hydrology. Hardisty et al. (1983) and Gao (1996) found that the Normalized Difference Moisture or Water Index (NDMI or MDWI) based on Landsat TM near- and middle-infrared bands was highly correlated with canopy water content and more closely tracked changes in plant biomass than did the NDVI.

\[
NDMI = \frac{NIR_{TM4} - MidIR_{TM5}}{NIR_{TM4} + MidIR_{TM5}}
\]

Soil Adjusted Vegetation Index (SAVI)

Recent emphasis has been given to the development of improved vegetation indices that may take advantage of calibrated hyperspectral sensor systems such as the moderate resolution imaging spectrometer - MODIS (Running et al., 1994). The improved indices incorporate a soil adjustment factor and/or a blue band for atmospheric normalization. The soil adjusted vegetation index (SAVI) introduces a soil calibration factor, \(L\), to the NDVI equation to minimize soil background influences resulting from first order soil-plant spectral interactions (Huete et al., 1994):

\[
SAVI = \frac{(1 + L)(\rho_{nir} - \rho_{red})}{\rho_{nir} + \rho_{red} + L}
\]

An \(L\) value of 0.5 minimizes soil brightness variations and eliminates the need for additional calibration for different soils (Huete and Liu, 1994).
Atmospherically Resistant Vegetation Index (ARVI)

SAVI was made less sensitive to atmospheric effects by normalizing the radiance in the blue, red, and near-infrared bands. This became the *Atmospherically Resistant Vegetation Index* (ARVI):

\[
ARVI = \frac{\rho_{*,\text{nir}} - \rho_{*,\text{rb}}}{\rho_{*,\text{nir}} + \rho_{*,\text{rb}}}
\]

where

\[
\rho_{*,\text{rb}} = \rho_{*,\text{red}} - \gamma(\rho_{*,\text{blue}} - \rho_{*,\text{red}})
\]

The technique requires prior correction for molecular scattering and ozone absorption of the blue, red, and near-infrared remote sensor data, hence the term \(\rho_{*,}\).

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Aerosol Free Vegetation Index (AFRI)

Karnieli et al. (2001) found that under clear sky conditions the spectral bands centered on 1.6 and 2.1 \(\mu\) m are highly correlated with visible spectral bands centered on blue (0.469 \(\mu\) m), green (0.555 \(\mu\) m), and red (0.645 \(\mu\) m). Empirical linear relationships such as \(\rho_{0.469\mu m} = 0.25 \rho_{2.1\mu m}\); \(\rho_{0.555\mu m} = 0.33 \rho_{2.1\mu m}\) and \(\rho_{0.645\mu m} = 0.66 \rho_{1.6\mu m}\) were found to be statistically significant.

Therefore, based on these and other relationships, two *Aerosol Free Vegetation Indices* (AFRI) were developed:

\[
AFRI_{1.6,\mu m} = \frac{\rho_{*,\text{nir}} - 0.66\rho_{1.6,\mu m}}{\rho_{*,\text{nir}} + 0.66\rho_{1.6,\mu m}}
\]

\[
AFRI_{2.1,\mu m} = \frac{\rho_{*,\text{nir}} - 0.5\rho_{2.1,\mu m}}{\rho_{*,\text{nir}} + 0.5\rho_{2.1,\mu m}}
\]
Enhanced Vegetation Index (EVI)

The MODIS Land Discipline Group proposed the *Enhanced Vegetation Index* (EVI) for use with MODIS Data:

\[
EVI = G \frac{\rho_{\text{nir}}^{*} - \rho_{\text{red}}^{*}}{\rho_{\text{nir}}^{*} + C_1 \rho_{\text{red}}^{*} - C_2 \rho_{\text{blue}}^{*} + L}
\]

This algorithm has improved sensitivity to high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal and a reduction in atmospheric influences.
Table 10.3: Selected Remote-Sensing Vegetation Indicators

<table>
<thead>
<tr>
<th>Vegetation Index</th>
<th>Equation</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Ratio (SR)</td>
<td>$SR = \frac{NE}{NO}$</td>
<td>Berk and McRae, 1968</td>
</tr>
<tr>
<td>Normalized Difference Vegetation Index (NDVI)</td>
<td>$NDVI = \frac{NE - red}{NE + red}$</td>
<td>Hess et al., 1979; Dietz et al., 1979</td>
</tr>
<tr>
<td>Kauth-Thomas Transformation</td>
<td>$T = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Kauth and Thomas, 1978; Kauth et al., 1979</td>
</tr>
<tr>
<td>Leaf Area Index (LAI)</td>
<td>$LAI = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>Leaf Area Index (LAI)</td>
<td>$LAI = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>Image Index (IMI)</td>
<td>$IMI = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>NDTI (Near Infrared Temperature Index)</td>
<td>$NDTI = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>NDVI (Normalized Difference Vegetation Index)</td>
<td>$NDVI = \frac{NE - red}{NE + red}$</td>
<td>Hess et al., 1979; Dietz et al., 1979</td>
</tr>
<tr>
<td>Vegetation Absence Ratio (VAR)</td>
<td>$VAR = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>Moisture Stress Index (MSI)</td>
<td>$MSI = \frac{NDVI}{0.052}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>Leaf Relative Water Content Index (LRWC)</td>
<td>$LRWC = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>MIR Index</td>
<td>$MIR = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>Soil Adjusted Vegetation Index (SAVI)</td>
<td>$SAVI = \frac{1 + 0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>Atmospherically Resistant Vegetation Index (ARVI)</td>
<td>$ARVI = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>Soil and Atmospherically Resistant Vegetation Index (SARVI)</td>
<td>$SARVI = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
<tr>
<td>Enhanced Vegetation Index (EVI)</td>
<td>$EVI = \frac{0.052}{0.3 + \frac{0.0007}{0.0003}}$</td>
<td>Chou, 1983</td>
</tr>
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</table>
Distribution of Pixels in A Scene in Red and Near-IR Multispectral Feature Space

**Tasseled Cap or Kauth-Thomas Transformation**

This transformation produces from original MSS data space to a new four-dimensional feature space, called:

The soil brightness index (B),
Greenness vegetation index (G),
Yellow stuff index (Y), and
Non-such (N)

The name suggests the characteristics the indices were intended to measure.
**Tasseled Cap or Kauth-Thomas Transformation**

The transformation consists of linear combinations of the four MSS bands to produce a set of four new variables.

\[
\begin{align*}
TC1 &= +0.433 \text{MSS} 4 + 0.632 \text{MSS} 5 + 0.586 \text{MSS} 6 + 0.264 \text{MSS} 7 \\
TC2 &= -0.290 \text{MSS} 4 - 0.562 \text{MSS} 5 + 0.600 \text{MSS} 6 + 0.491 \text{MSS} 7 \\
TC3 &= -0.829 \text{MSS} 4 + 0.522 \text{MSS} 5 - 0.039 \text{MSS} 6 + 0.194 \text{MSS} 7 \\
TC4 &= +0.223 \text{MSS} 4 + 0.012 \text{MSS} 5 - 0.543 \text{MSS} 6 + 0.810 \text{MSS} 7
\end{align*}
\]

1985: The Transformation was extended using Landsat TM data:

- Brightness: \(0.0243_{\text{TM}1} + 0.416_{\text{TM}2} + 0.552_{\text{TM}3} + \ldots\)
- Greenness: \(-0.160_{\text{TM}1} - 0.282_{\text{TM}2} - 0.494_{\text{TM}3} + \ldots\)
- Wetness: \(0.032_{\text{TM}1} + 0.202_{\text{TM}2} + 0.31_{\text{TM}3} + \ldots\)

The Tasseled Cap transformation is a global vegetation index. Theoretically, it may be used anywhere in the world to disaggregate the amount of soil brightness, vegetation, and moisture content in individual pixels in Landsat MSS or TM images.