Basics of Remote Sensing for Agricultural Applications

Introduction

When farmers or ranchers observe their fields or pastures to assess their condition without physically touching them, it is a form of remote sensing. Observing the colors of leaves or the overall appearances of plants can determine the plant’s condition. Remotely sensed images taken from satellites and aircraft provide a means to assess field conditions without physically touching them from a point of view high above the field. Most remote sensors see the same visible wavelengths of light that are seen by the human eye, although in most cases remote sensors can also detect energy from wavelengths that are undetectable to the human eye. The remote view of the sensor and the ability to store, analyze, and display the sensed data on field maps are what make remote sensing a potentially important tool for agricultural producers. Agricultural remote sensing is not new and dates back to the 1950s, but recent technological advances have made the benefits of remote sensing accessible to most agricultural producers.

The Electromagnetic Spectrum

The basic principles of remote sensing with satellites, Unmanned Aircraft Vehicles (UAV), and other platforms are similar to visual observations. Energy in the form of light waves travels from the sun to Earth. Light waves travel similarly to waves traveling across a lake. The distance from the peak of one wave to the peak of the next wave is the wavelength. Energy from sunlight is called the electromagnetic energy, and it is part of the electromagnetic spectrum. The wavelengths used in most agricultural remote sensing applications cover only a small region of the electromagnetic spectrum.

Wavelengths are measured in micrometers (μm) or nanometers (nm). One μm is about .00003937 inch and 1 μm equals 1,000 nm. The visible region of the electromagnetic spectrum is from about 400 nm to about 700 nm. The green color associated with plant vigor has a wavelength that centers near 550 nm.
(Figure 1). Similarly, blue centers near 470 nm and red centers near 650 nm. Wavelength from 690 nm to 740 nm is called Red Edge because it is located between visible red and near infrared radiation. Wavelengths longer than in the visible region are in the infrared region (IR) (1). The infrared region nearest to that of the visible region - 700 to 2500 nm - is the near-infrared (NIR) region. When dealing with crops, the NIR range is subdivided into sections. The lower part of this range has low absorbance which results in extremely high reflectance (700 to 1300 nm). On the other hand, the upper part of this range has a high absorbance by water so, low reflectance. Both the visible and infrared regions are used in agricultural remote sensing.

When electromagnetic energy from the sun strikes plants, three things can happen. Depending upon the wavelength of the energy and characteristics of individual plants, the energy will be reflected, absorbed, or transmitted. Photons that hit an object and rebound and change direction become reflected radiation. Reflected energy bounces off leaves and is readily identified by human eyes as the green color of plants. Photons that are absorbed by the plants provide energy for heat or photosynthesis. Most of visible radiation that hits healthy plants is absorbed for photosynthesis.

The amount of reflectance is not uniform in all parts of the visible spectrum. The reflectance of green light is more than blue or red light because they are more suitable for photosynthesis. The higher reflectance of green light causes the green color of healthy plants. A plant looks green because the chlorophyll in the leaves absorbs much of the energy in the visible wavelengths and the green color is reflected. The photons that are neither reflected nor absorbed become transmitted radiation, and become energy is transmitted through the leaves to the ground.

**Spectral Signatures**

Interactions between reflected, absorbed, and transmitted energy can be detected by remote sensing. The differences in leaf colors, textures, shapes or even how the leaves are attached to plants, determine how much energy will be reflected, absorbed or transmitted. The relationship between reflected, absorbed and transmitted energy is used to determine spectral signatures of individual plants. Spectral signatures are unique to plant species. Remote sensing is used to identify stressed areas in fields by first establishing the spectral signatures of healthy plants.

The spectral signatures of stressed plants appear altered from those of healthy plants. Figure 3 compares the spectral signatures of healthy and stressed sugarbeets. Stressed sugarbeets have a higher reflectance value in the visible region of the spectrum from 400-700 nm. This pattern is reversed for stressed sugarbeets in the nonvisible range from about 750-1200 nm. The visible pattern is repeated in the higher reflectance range from about 1300-2400 nm. Interpreting the reflectance values at various wavelengths of energy can be used to assess crop health.

**Vegetative Indexes**

The comparison of the reflectance values at different wavelengths, called a vegetative index, is commonly used to determine plant vigor. The most common vegetative index is the normalized difference vegetative index (NDVI). NDVI compares the reflectance values of the red and NIR regions of the electromagnetic spectrum. The NDVI value of each area on an image helps identify areas of varying levels of plant vigor within fields.
**How Does Remote Sensing Work?**

There are several types of remote sensing systems used in agriculture but the most common is a passive system that senses the electromagnetic energy reflected from plants. The sun is the most common source of energy for passive systems. Passive system sensors can be mounted on satellites, manned or unmanned aircraft, or directly on farm equipment. There are several factors to consider when choosing a remote sensing system for a particular application, including spatial resolution, spectral resolution, radiometric resolution, and temporal resolution.

**Spatial Resolution**

Spatial resolution refers to the size of the smallest object that can be detected in an image. The basic unit in an image is called a pixel. One-meter spatial resolution means each pixel image represents an area of one square meter. The smaller an area represented by one pixel, the higher the resolution of the image. Spectral resolution refers to the number of bands and the wavelength width of each band.

A band is a narrow portion of the electromagnetic spectrum. Shorter wavelength widths can be distinguished in higher spectral resolution images. Multi-spectral imagery can measure several wavelength bands such as visible green or NIR. Landsat, Quickbird and Spot satellites use multi-spectral sensors. Hyperspectral imagery measures energy in narrower and more numerous bands than multi-spectral imagery. The narrow bands of hyperspectral imagery are more sensitive to variations in energy wavelengths and therefore have a greater potential to detect crop stress than multi-spectral imagery. Multi-spectral and hyperspectral imagery are used together to provide a more complete picture of crop conditions.

**Radiometric Resolution**

Radiometric resolution refers to the sensitivity of a remote sensor to variations in the reflectance levels. The higher the radiometric resolution of a remote sensor, the more sensitive it is to detecting small differences in reflectance values. Higher radiometric resolution allows a sensor to provide a more precise picture of a specific portion of the electromagnetic spectrum.

**Temporal Resolution**

Temporal resolution refers to how often a remote sensing platform can provide coverage of an area. Geo-stationary satellites can provide continuous sensing while normal orbiting satellites can only provide data each time they pass over an area. Remote sensing taken from cameras mounted on manned or unmanned airplanes is often used to provide data for applications requiring more frequent sensing. Cloud cover can interfere with the data from a scheduled remotely sensed data system. Remote sensors located in fields or attached to agricultural equipment can provide the most frequent temporal resolution.
Understanding Imagery

Different types of imaging such as color, thermal, multispectral and hyperspectral can provide unique applications in precision agriculture.

![RGB Multispectral Hyperspectral Thermal](image)

**Figure 2.** Different type of imaging

RGB Imagery

Color or RGB (red, green, blue) images are useful to recognize symptoms of diseases, nutrient deficiencies, damaged plants, specific weeds and plant species in crop fields. The appearance of an object in RGB images is the result of the light reflected from the object, its optical characteristics, and the human perception. RGB-based image analysis has been applied in agriculture for weed discrimination weed and crop mapping, variable physiological process across a leaf surface, and plant stand counting.

![RGB image](image)

**Figure 3.** RGB image (corn crop filed was captured by Phantom 4 UAV-NDSU Research center Carrington 2016)

![RGB image](image)

**Figure 4.** Classify weed species by maximum likelihood method (RGB image)
Thermal Imagery

Thermal imagery is based on the fact that objects emit infrared energy (heat) as a function of their temperature. In general, warmer objects emit more radiation than colder objects. Thermal cameras are essentially heat sensors which detect the differences in object temperatures. The infrared thermal camera senses radiation in the infrared range of the electromagnetic spectrum (800–1400 nm) and expresses as a false color image. Each pixel in a thermal has a unique temperature value.

Thermal imaging can be useful for monitoring plant temperatures across a field. Plant disease symptoms, water stressed plants and pest infestations can all cause increased canopy or plant leaf temperatures. Farmers can use thermal imagery to monitor infection patterns of diseases or pest’s infestation in crop fields.

Figure 5. (a) Orthorectified mosaic. (b) Segmented leaves. (c) Heat map of local leaf density.

Figure 6. RGB digital image, together with some corresponding thermal images of rice ‘macro array’ trial in the dry season of 2006 consisting of 300 plots combining 50 contrasting genotypes, two water treatments (well-watered and drought-stressed) and three replicates at the International Rice Research Institute.
Multispectral Imagery

Multispectral images consist of spectral information of objects in several spectrum wavebands. Multispectral sensors usually detect spectral information of red, green and blue electromagnetic spectrums, and also the red edge and near-infrared wave ranges. Developing vegetation indices such as normalized difference vegetation index (NDVI), and band ratio are two powerful method for multispectral image processing. These methods can be used to identify crop health, weed species, crop injury after herbicide spraying and diseases symptoms.

**Figure 7.** Spikelets showing symptoms of the disease Fusarium head blight can be visualized by a normalized difference vegetation index (NDVI).

**Figure 8.** UAV images collected by the two cameras a) RGB camera and b) multispectral camera
Hyperspectral Imagery

Hyperspectral cameras measure spectral reflectance of plants throughout the visible, near-infrared and mid-infrared (350-2500nm) portions of the electromagnetic spectrum in 5 to 10 nm bandwidths. Spectral reflectance of individual plant species at the canopy or single leaf scale is unique and referred to as a spectral signature. Spectral reflectance measurements are the first step to determine the potential of remote spectral data to classify weeds and crops, and to identify diseases symptoms. Absorption of light by plant pigments, plant structure and leaf chemistry produce unique spectral signatures which are helpful to monitor crop conditions. Satellites with hyperspectral sensors include Hyperion, Airborne Visible/ Infrared Imaging Spectrometer (AVIRIS), and Compact Airborne Spectrographic Imager (CASI).

Figure 9. Characteristics of spectral signature of barley leaves with net blotch, rust and powdery mildew, respectively.

References

2. Precision Ag Group ABEN Department, NDsu
3. Video and Image Processing Laboratory (VIPER) Purdue University West Lafayette, Indiana USA