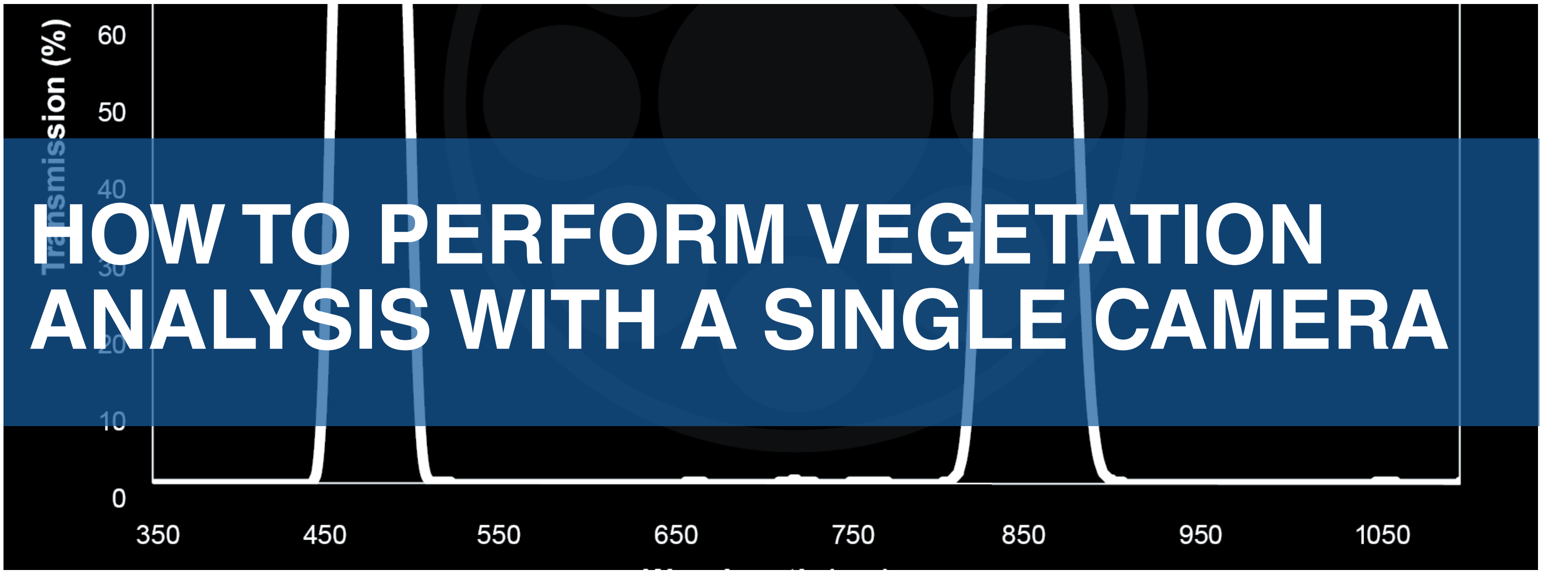
HOW TO PERFORM VEGETATION ANALYSIS WITH A SINGLE CAMERA



When light interacts with any object, certain wavelengths are absorbed, reflected, or refracted. This is especially true when it comes to plants because they draw a significant portion of their energy through photosynthesis by absorbing the sun's energy and converting it into glucose. Through years of studying vegetation, a number of methods have been developed to monitor plant health using their reflected spectral signature.

These methods have been broken down into over 150 vegetation indices (VIs), some of which include the Simple Ratio Index (SR), the Atmospherically Resistant Vegetation Index (ARVI), the Vogelmann Red Edge Indices (VOG1, VOG2, VOG3), and the Photochemical Reflectance Index (PRI). The Normalized Difference Vegetation Index (NDVI) is arguably the most common and well known vegetation index.

NDVI - EXPLAINED

NDVI is based on the known reflectance from both healthy and unhealthy vegetation. As described in the graphic below from the February 2012 edition of Applied Optics, the red data points show the reflectance of unhealthy vegetation and the green data points show healthy vegetation.

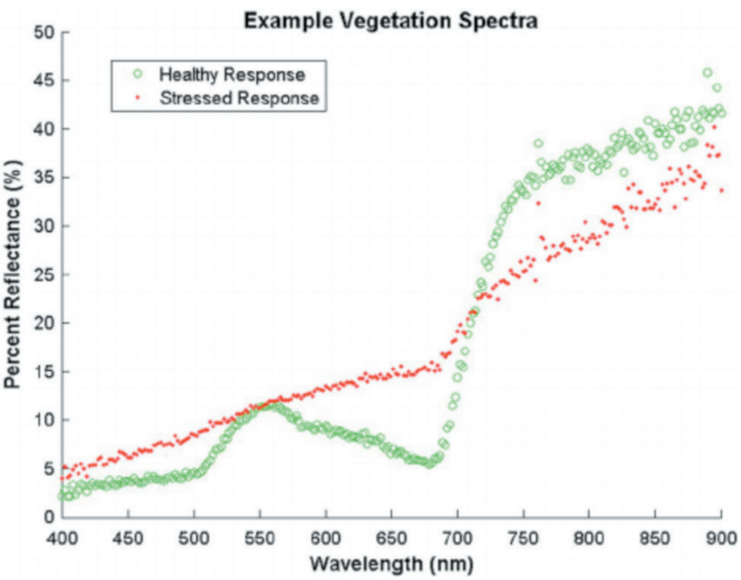


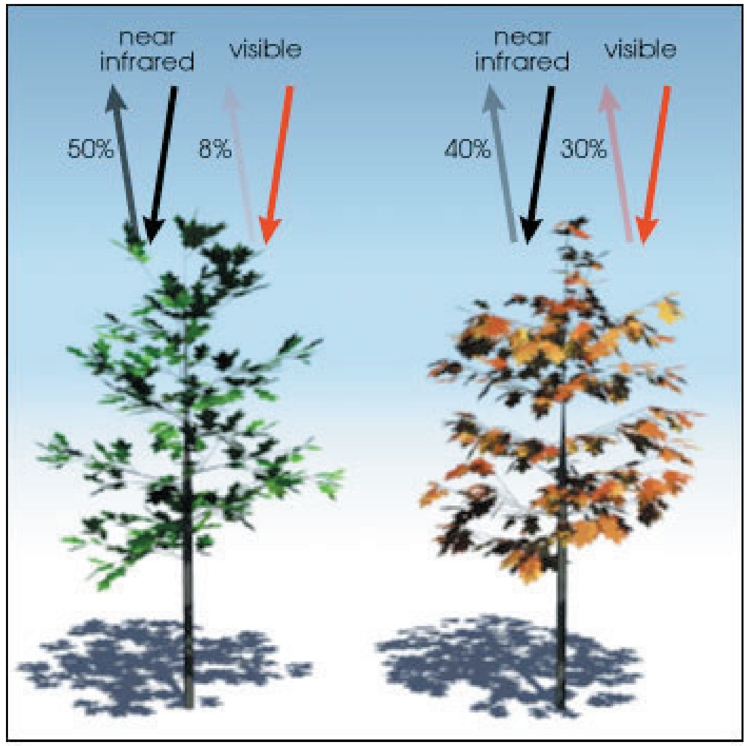
Figure 1. Reflectance of Healthy and Stressed Vegetation in Relation to Wavelength
Source:[1]

The spike at 550 nm in the healthy response curve translates to the green color associated with healthy plants. In other words, they reflect more green light than blue or red because these wavelengths are absorbed by the plant during photosynthesis. Healthy plants also reflect a high amount of infrared light to protect themselves from overheating.

The principle of NDVI is to compare the ratio between the red (~650 nm) and near infrared (~850 nm) light reflected by the vegetation. The ideal method to accomplish this is through the use of two monochrome cameras with filters allowing each of them to see only the specified wavelength. The images are then correlated and the following NDVI formula is applied:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Results from the equation will span from -1 to 1, where inorganic material will typically have negative values and healthy vegetation will be between 0.2 and 0.8.



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

Figure 2. Example of NDVI Calculation for Healthy and Stressed Vegetation
Source: Wikipedia

Since computers typically display images with 8-bits of color depth, a lookup table (LUT) is applied to the results of NDVI calculations to visualize the data. Therefore, it changes the scale of the images from between -1 and 1 to between 0 and 255. There are a large number of LUTs that exist for NDVI images, so it is important to ensure that the same one is applied when comparing images. Below is an image courtesy of Kansas State University showing an RGB and false-color NDVI image of a soybean plant where blue indicates a low NDVI value and red indicates larger NDVI values.

[1]Justin A. Hogan, Joseph A. Shaw, Rick L. Lawrence, and Randal M. Larimer, "Low-cost multispectral vegetation imaging system for detecting leaking CO^2 gas," Appl. Opt. 51, A59-A66 (2012)"

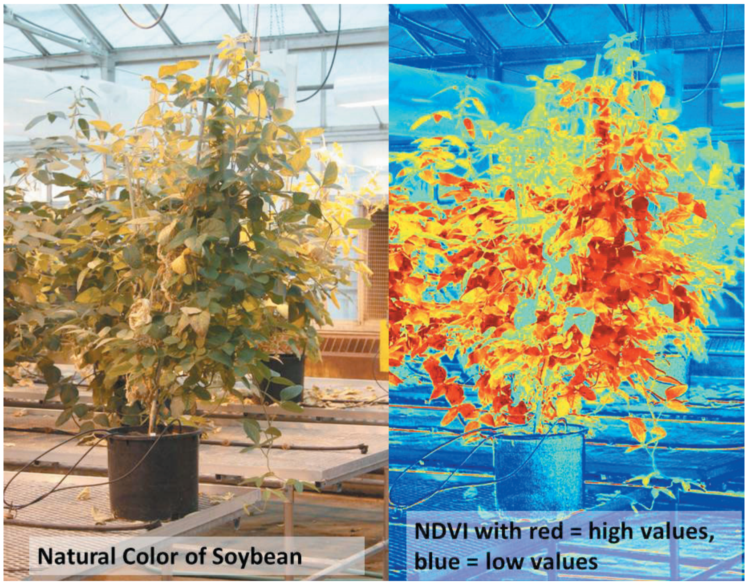


Figure 3. Soybean Plant in Natural and False-Color NDVI Representation
Source: K-State Flickr

APPROACH TO SINGLE-CAMERA NDVI

With advancements in UAV technology, NDVI is becoming more accessible to larger groups of people at lower costs. A major issue concerning UAVs is their payload requirements where size and weight need to be minimized as much as possible to prolong flight time. Knowing the typical spectral response of a color image sensor, seen in Figure 4, it is possible to use filters to target specific color channels and turn a single camera into a specialized NDVI camera yielding a close approximation to a two-camera system.

Typically, color cameras have an NIR-cut filter to negate the camera's responsivity past 700 nm. Removing this filter and adding a dual bandpass filter to observe the vegetation's reflectance at two specific wavelengths allows for an approximation of NDVI. For the purpose of this solution sheet, a dual bandpass filter with wavelengths of 475 and 850 nm, or blue and NIR, was used and its response can be seen in the Figue 5.

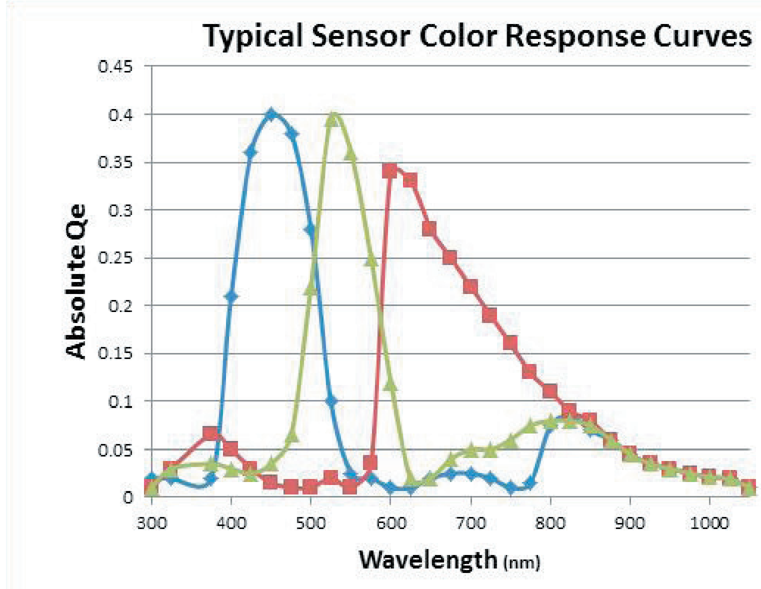


Figure 4. Typical Quantum Efficiency Curve for a Color Sensor

It is important to note that this is not the only solution for creating a single-camera NDVI system and that other filter setups exist.

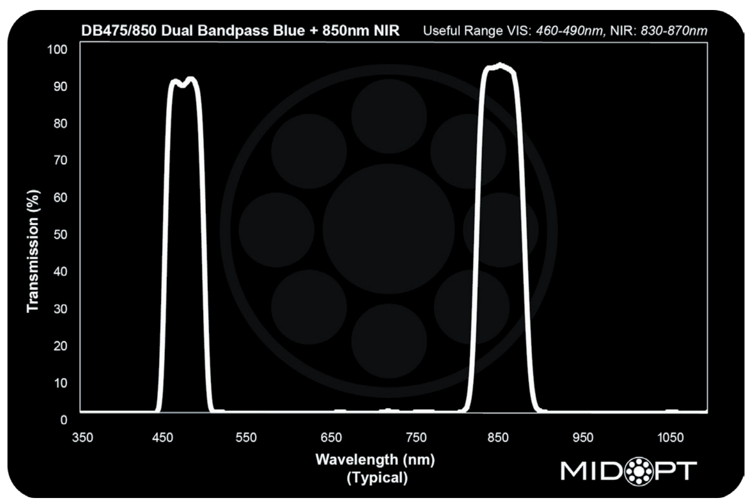


Figure 5. Spectral Response of the Dual Bandpass Filter Used in This Solution Sheet

Since this filter specifically targets blue and NIR wavelengths, modifications need to be applied to the standard NDVI formula. In the case of single-camera NDVI with this particular filter, the camera's blue channel measures the vegetation's absorption of light and its red channel is used to measure the reflected NIR light.

Keep in mind that the blue channel is also measuring some NIR light, so a correction for this is required. As the following graph shows, the NIR response of a typical image sensor is very similar in both the blue and red channels.

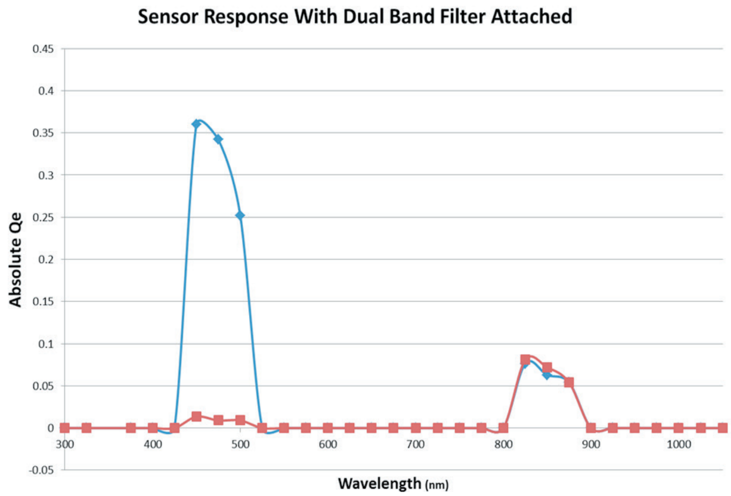


Figure 6. Sensor Response With Dual Band Filter Attached

Therefore, the data obtained in the red channel can be subtracted from the blue channel to compensate for the blue channel's sensitivity to NIR light. Knowing this, an approximation to the NDVI equation can be derived as seen below:

R' is the information registered by the camera's red channel;

And, B' is the information registered by the camera's blue channel.

Using the red channel (R') to measure the reflected NIR light and the blue channel (B') to measure the vegetation's absorption, the NDVI approximation equation becomes:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

$$NDVI_{Approx} = \frac{R' - (B' - R')}{R' + (B' - R')}$$

$$NDVI_{Approx} = \frac{2 \times R' - B'}{B'}$$

This equation could be further adjusted based on the sensor response by adding a gain factor to red. This could be calibrated using a two-camera solution and experimental results. A more general equation including the determined gain factor (k) would be:

$$NDVI_{Approx} = \frac{k \times Red - Blue}{Blue}$$

CREATING A SINGLE-CAMERA NDVI SYSTEM

Creating a single-camera NDVI system is relatively simple and possible with readily available "off the shelf" components. All Lumenera cameras are available without the IR cut filter which means that the entire portfolio of cameras is available for this solution. The camera will need to be paired with a dual bandpass filter allowing it to monitor at least one absorption band (blue or red) and the high reflectance band (NIR) of the vegetation. For this document, the Lumenera Lt965RC-WOIR was paired with MidOpt's dual bandpass DB475/850.

An image of the following scene containing (left to right, back to front) two plants, an orange, a glass of water, the filter calibration target, an apple, a water bottle, a banana, and some cashews was taken using the camera and filter mentioned above.

The captured image, seen below, was then imported to FIJI (ImageJ) – an open source photo editing software.

Figure 7. RGB View of Example Scene

Figure 8. View of Example Scene Through DB475/850 Filter Using Lt965RC-WOIR

The image was then processed using an open source plugin for FIJI available on Public Lab called Photo Monitoring Plugin, written by Ned Horning.

The first processing step was to calculate the image calibration coefficients based on the calibration target and data provided by MidOpt. An ROI was drawn over each of the three reflectance targets and their associated reflectance data at both bandpass wavelengths was input to the plugin. At this step, the red channel was subtracted from the blue channel to account for the blue channel's sensitivity to NIR light.

The second processing step then calculated the image's approximate NDVI using the calibration coefficients. The camera's blue channel was selected for the visible band and the red channel for the NIR band. The below false-color NDVI approximation image was then generated from the plugin.

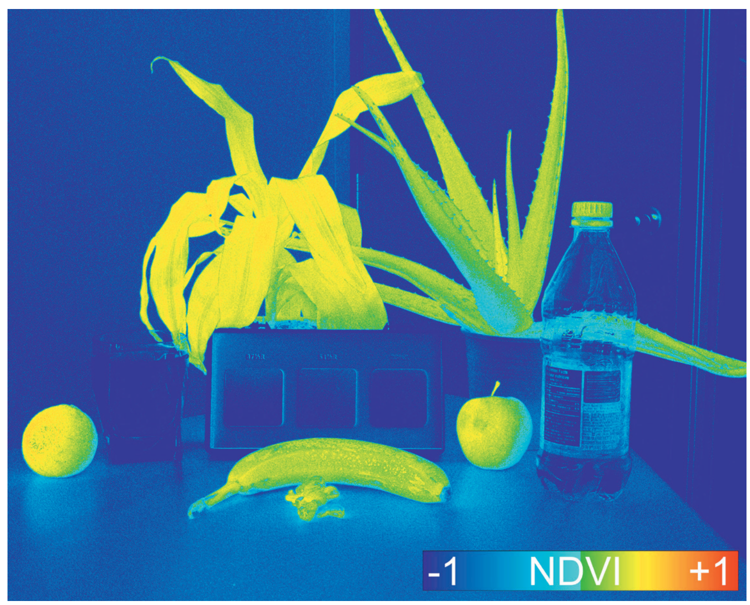


Figure 9. False-Color NDVI Approximation Generated by the Photo Monitoring Plugin Using the NDVIBlu2Red LUT

Through the approximation, all organic matter is highlighted by a yellowish-green color. It is important to note that the reason the underside of some of the leaves is blue (indicating a negative NDVI) is because only the upper side of the vegetation is meant to reflect infrared light.

Furthermore, the inorganic bottle cap has positive NDVI values due to the high level of infrared reflectance of the cap compared to its absorption of blue light.

CONCLUSION

NDVI is arguably the most popular vegetation index and is being more widely adopted due to advancements in UAV technology. Since UAVs have limited payload capacities, single-camera NDVI solutions are being explored and adopted as suitable approximations of the traditional dual-camera systems. Removing a color camera's IR cut filter and pairing it with a dual bandpass filter allows the system to strictly observe the absorption and reflectance bands associated with NDVI. Lumenera's entire portfolio of cameras is suitable to be designed into a single-camera NDVI system and can easily incorporate third party filters into the camera's design, such as those offered by Midwest Optical Systems and highlighted in this document.

If you have questions about camera specifications for your aerial imaging payload, reach out to our imaging experts at info@lumenera.com.

ABOUT LUMENERA

Lumenera Corporation, a division of Roper Technologies, headquartered in Ottawa, Canada, is a leading developer and manufacturer of high performance digital cameras and custom imaging solutions. Lumenera cameras are used worldwide in a diverse range of industrial, scientific and security applications.

As a global market leader Lumenera provides an extensive range of high quality digital cameras with unique combinations of speed, resolution, and sensitivity to satisfy the demands of today's imaging applications. Lumenera also offers custom design services to OEM partners requiring specialized hardware and software features.

Core competencies include digital bus technologies such as USB 3.0, USB 2.0, Ethernet, HDMI, and Gigabit Ethernet (GigE) as well as a complete command of digital imaging hardware and software built around CMOS and CCD based imagers. Our diversity provides our customers with the benefits of superior price-to-performance ratios and faster time-to-market.

Lumenera Corporation
7 Capella Court
Ottawa, ON
Canada, K2E 8A7

613-736-4077
info@lumenera.com
www.lumenera.com