AN UPDATE ON CROP CANOPY SENSORS FOR IN-SEASON N MANAGEMENT

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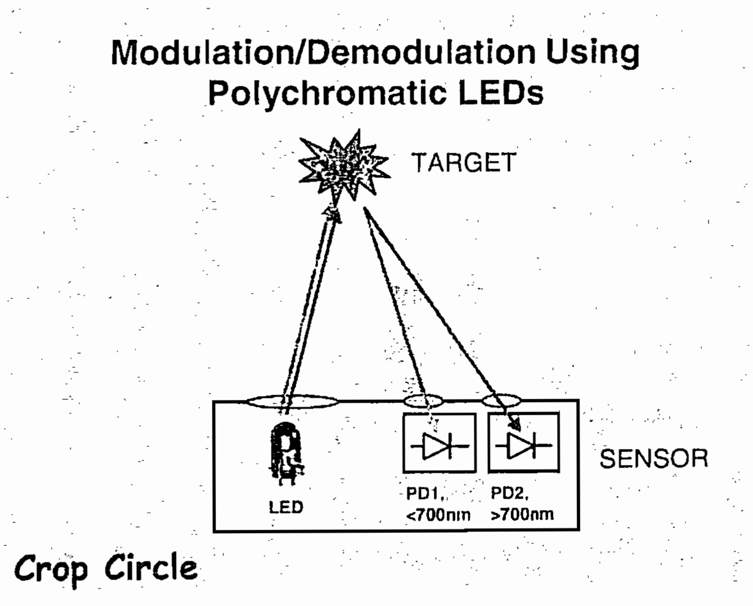
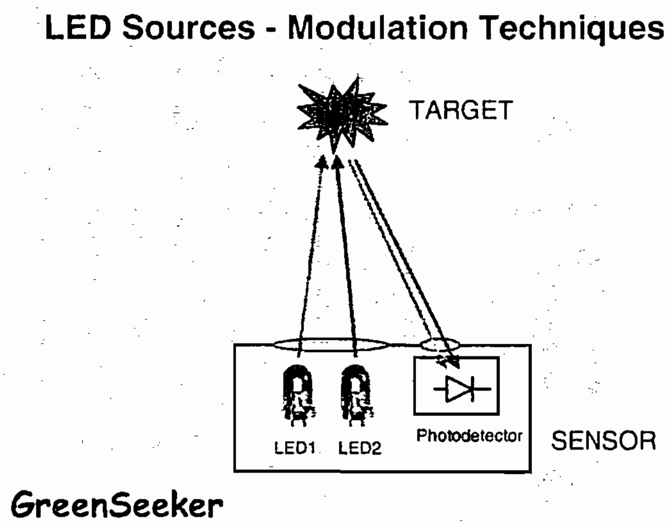
Remote sensing in agriculture has focused on the spectral and spatial properties of plants. Remote sensing provides the capability for rapid collection of vast quantities of spatial data that can be analyzed quickly for use in determining a course of action. This creates the potential for using remote sensing to assess and manage in-season production practices.

Past research has shown that a change in canopy reflectance may not be unique for a given stress. Also, other agents may have effects on canopy reflectance similar to those of the stress in question. The detection of stress mainly relies on being able to determine and detect deviations from normal function (Murtha, 1982). Some changes, such as those associated with developmental growth, are normal. Only after we understand what is normal for a crop at a given point in time can we look for and identify reflectance patterns that may indicate a stress. For the assessment of crop N status, field reference strips are one technique that can be used as an aide in determining what is or isn't normal (Francis et al., 1991).

Various approaches, including satellite and aircraft platforms and ground-based sensors have been developed and tested for measuring crop canopy reflectance. All have their distinct advantages and disadvantages. Mobile, ground-based sensors offer excellent spatial resolution and can be integrated with material delivery systems to facilitate real-time applications. The problem with most remote sensing tools is that they rely on natural radiation to generate the reflectance that is measured by a sensor. As, such, light intensity, viewing angle, time of day, shadows, atmospheric interferences, crop growth stage, and weather conditions are all factors that must be considered. To overcome some of these limitations, technologies that provided auxiliary lighting were introduced and later refined to employ modulated or pulsed light to differentiate between reflectance attributed to natural radiation and that coming from the auxiliary light source. Improvements in these technologies have led to development of active sensors such as NTech Industries' GreenSeeker (see www.Ntechindustries.com) and Holland Scientifics' Crop Circle



ACS-210 (see www.Hollandscientific.com). Design of the optics and electronics gives each a unique set of operational characteristics. For example, the polychromatic bank of light emitting diodes (LEDs) in the Crop Circle sensor emits light in two wavebands (visible and infrared) simultaneously, so the illumination provided by each LED covers the same area for each waveband. Because both wavebands are emitted simultaneously, two silicon photodiodes (spectral sensitivity range: ~300 nm to 1100nm) are required (one filtered for visible light sensitivity and another filtered for near infrared (NIR) light sensitivity). This requirement is actually good in that the sensitivity of a silicon photodiode decreases as the wavelength decreases, so the output of each photodetector (photodiode/preamplifier) can be optimized for each waveband. A double photodetector system eliminates any chance for cross-talk between visible and infrared reflectance signals in the sensor's signal conditioning circuitry and thereby greatly adds to the quality of the sensor readings. An additional advantage of this design is that a collimator lens can be used to uniformly concentrate the zones of illumination across the field-of-view.



Cautions to be considered when using an active sensor that employs individual LED banks to generate the two wavebands of light are that the illumination characteristics of the two diodes are almost certain to be different. As such, uniform illumination across the field-of-view is not possible, which makes positioning of the sensor over row crops like corn critical. Also, sensors utilizing multiple LED sources typically incorporate single-channel photodetection circuitry that can be especially prone to hysteresis (cross-talk) problems in that the electronics must alternately respond to high levels of NIR reflectance and low levels of visible light reflectance.

Active sensors work by using LEDs to generate modulated light (i.e. light pulsed at thousands of Hertz) in specific wavebands that are sensitive to plant properties of interest (e.g., chlorophyll, biomass, etc.). Natural light is not modulated, so with adequately sophisticated electronics, the detection circuitry of the sensors is able to differentiate between the radiance (reflectance) generated by the natural and modulated light. One of the primary limitations of active sensors is the low-energy irradiance generated by the LEDs, and as such, the sensors are only effective in the near proximity of the target (0.3 to 2.5 m). Along with this limitation comes the rapid decrease of light intensity with distance (intensity decreases with the square of the distance). Therefore, active sensors operating close to the target are very sensitive to changes in distance. This situation can probably be both good and bad, depending on how well the sensor distance above the soil surface is controlled.

Canopies like turf are typically well manicured and thus the distance between the sensor and canopy surface are generally well characterized. As such, differences in sensor readings are primarily indicative of spatial variability in biomass. A similar situation exists when sensors are used to map soil color, provided that sensor height above the soil surface is consistent. Irregular canopies like corn present a unique challenge because the large arcing leaves at various levels in the canopy result in a wide range of distances between the reflective surface and sensor. This variability in distance exists between rows and between plants so positioning of the sensor above the crop relative to the field of view is important. Other canopies like wheat present an intermediate situation in that the leaves are smaller and more numerous than corn and the distance between plants is less.

The responsiveness of active sensors to distance from the target can be caused by at least three different factors. First, an increase in NIR reflectance with constant distance and a uniform target signals an increase in living biomass. However, taller plants could cause the same increase in NIR reflectance, even though the sensor height remained the same. Finally, if sensor height is not controlled or accurately measured, there is no way to relate sensor output to anything meaningful. Considering these possibilities, it is important to know about other sensor limitations such as uniformity of the modulated radiation within the field-of-view, size and shape of the field-of-view, and electronic noise.

In applying precision agriculture to wheat production, Oklahoma State University developed a system that integrated data acquired by the GreenSeeker sensor with a decision aid and variable-rate technology. This system has shown that it can optimize farm profits while minimizing environmental impact by reducing N fertilizer inputs and applying those inputs only to N responsive sites (Raun et al., 2002).

Various vegetation indices, based on passive solar reflectance, have been developed to diagnose and evaluate plant health. These indices involve reflectance data from several wavebands and are generally preferred over single wavelengths because they compensated for short- and long-term changes in solar irradiance and atmospheric conditions (Patience and Klemas, 1993). The most common vegetation index is the Normalized Difference Vegetation Index (NDVI):

$$NDVI = (NIR-R)/(NIR+R)$$

Where, NIR represents reflectance from the near infrared portion of the electromagnetic spectrum (760-900 nm) and is most sensitive to living plant tissue. Reflectance from the red (R) portion of the spectrum (630-690 nm), like much of the visual portion of the electromagnetic spectrum, is sensitive to chlorophyll. Both GreenSeeker and Crop Circle software provide NDVI output. Active sensors essentially eliminate the need to deal with temporal changes in solar irradiance and atmospheric conditions. Therefore, the use of multi-waveband vegetation indices like NDVI may be sacrificing some of the differentiating power of single wavebands.

Active sensors are not strictly calibrated in the same manner as passive sensors. Radiance values collected by passive sensors are typically converted to percent reflectance by using a white standard (such as barium sulfate or a Spectralon panel) whose radiance value is set as 100% reflectance. The white standard is used with each sample or an up-dwelling sensor can be used to correct for any changes in solar irradiance after first calibrating to the white standard. Active sensors have the benefit of having a close, stable light source, so frequent calibration is not required. However, the trade-off is that great care must go into knowing the distance relationship between the sensor and target with active sensors.

Active sensors have only been available to researchers for 3 to 4 years. Recent studies indicate that the lessons learned from passive sensors and aerial photography need to be re-evaluated when using active sensors. Both commercially available active sensors provide NDVI and visible/NIR values as output. Both of these indices were developed from years of passive sensor research. When the Crop Circle sensor entered the scene, NIR and visible reflectance values became available to researchers. These data revealed that the relationships between visible and NIR reflectance established for passive techniques do not always apply to active sensors. In particular, the typical inverse relationship between NIR and red reflectance for passive sensors turns out to be a direct relationship with active sensors, at least for crops like wheat and corn. This is because the distance between the sensor and the canopy is not strictly controlled as it is with turf. It is understandable why a direct relationship between NIR and visible reflectance results in questionable NDVI values when using active sensors on corn and wheat. The reason for this relationship became known while working with turf where visible reflectance remained constantly low with the active sensor (i.e., turf absorbed all of the red light) while NIR reflectance increased. The take-home-lesson is that the distance relationship between active sensors and the target is critical. In contrast to vegetative targets, bare soil reflectance characteristics are the same for active and passive sensors.

Approximately a dozen different groups used either or both GreenSeeker and Crop Circle active crop canopy sensors on corn during the 2004-growing season. The overall goal of this association is to develop a ground-based sensing system for diagnosing a corn crop's N status and applying N treatments to the crop in real-time. This group meet in August of this year to: 1) discuss some of the preliminary findings, 2) address mutual problems and concerns, 3) set standard protocol for 2005 research. Information for this meeting can be found at http://nue.okstate.edu/Nitrogen_Conference2004.htm. The plan for 2005 is for the various locations to test two algorithms (the Oklahoma State and Missouri approaches) for N management in corn production.

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